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Abstract Book

EURO 2022

Program

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Technical Program

Sunday, 17:30-19:00

■ SF-01

Sunday, 17:30-19:00 - A

Opening session

Stream: Opening and Closing
Plenary session

Monday, 8:30-10:00

■ MA-01

Monday, 8:30-10:00 - A

Burcu Balçık

Stream: Keynotes
Keynote session
Chair: *Özgen Karaer*

1 - Challenges and Opportunities for Operations Research to Improve Humanitarian Decision Making and Collaboration
Burcu Balcik

The complexity of the humanitarian systems and the high stakes for doing good with less have created a great deal of interest in the operations research community to address challenging problems faced by our societies and make a difference. In this talk, I will present some research problems and discuss how operations research can support humanitarian decision making at different levels. The focus will be on designing effective partnerships among humanitarian stakeholders for strengthening disaster preparedness and response capacity. As widely discussed in the literature, there exist several barriers and challenges for collaboration and coordination in humanitarian supply chains. However, given the current crises and future challenges, developing effective partnerships among key humanitarian stakeholders at international, national, and local levels is needed more than ever. I will introduce strategies and methods from insurance theory and supply chain management that can support designing implementable partnerships. I will discuss my experience in working with practitioners in these projects.

■ MA-02

Monday, 8:30-10:00 - B

EJCO, EJDP and EJTL

Stream: OR Journals
Invited session
Chair: *Immanuel Bomze*
Chair: *Jutta Geldermann*
Chair: *Dominique Feillet*

1 - EURO's open access journals - meet the Editors-in-Chief
Immanuel Bomze, Jutta Geldermann, Dominique Feillet

An opportunity to exchange with the Editors-in-Chief on relevant characteristics of the three Open-Access journals of EURO, namely

EURO Journal of Computational Optimization (EJCO),

EURO Journal of Decision Processes (EJDP), and

EURO Journal of Transportation and Logistics (EJTL).

We will briefly cover the advantages and benefits of publishing in these focussed outlets, and look forward to meet ambitious and engaged researchers in person.

2 - A Survey on Mixed-Integer Programming Techniques in Bilevel Optimization
Martin Schmidt, Thomas Kleinert, Martine Labbé, Ivana Ljubic

Bilevel optimization is a field of mathematical programming in which some variables are constrained to be the solution of another optimization problem. As a consequence, bilevel optimization is able to model hierarchical decision processes. This is appealing for modeling real-world problems, but it also makes the resulting optimization models hard to solve in theory and practice. The scientific interest in computational bilevel optimization increased a lot over the last decade and is still growing. Independent of whether the bilevel problem itself contains integer variables or not, many state-of-the-art solution approaches for bilevel optimization make use of techniques that originate from mixed-integer programming. These techniques include branch-and-bound methods, cutting planes and, thus, branch-and-cut approaches, or problem-specific decomposition methods. In this survey article, we review bilevel-tailored approaches that exploit these mixed-integer programming techniques to solve bilevel optimization problems. To this end, we first consider bilevel problems with convex or, in particular, linear lower-level problems. The discussed solution methods in this field stem from original works from the 1980's but, on the other hand, are still actively researched today. Second, we review modern algorithmic approaches to solve mixed-integer bilevel problems that contain integrality constraints in the lower level. Moreover, we also briefly discuss the area of mixed-integer nonlinear bilevel problems. Third, we devote some attention to more specific fields such as pricing or interdiction models that genuinely contain bilinear and thus nonconvex aspects. Finally, we sketch a list of open questions from the areas of algorithmic and computational bilevel optimization, which may lead to interesting future research that will further propel this fascinating and active field of research.

3 - Structured decision-making for sustainable water infrastructure planning and four future scenarios
Judit Lienert

Water supply and wastewater infrastructures are vital for human well-being and environmental protection; they adhere to the highest standards, are expensive and long-lived. Because they are also aging, substantial planning is required. Climate and socio-economic change create large planning uncertainties and simple projections of past developments are no longer adequate. This paper presents the initial phases of a structured decision-making (SDM) procedure which is designed to increase the sustainability of water infrastructure planning and includes various stakeholders in an exemplary Swiss case study. We evaluate the SDM approach critically based on stakeholder feedback, give general recommendations and provide ample material to make it applicable to other settings. We carried out 27 interviews and two stakeholder workshops. We identified important objectives for water infrastructure planning, including all three sustainability pillars and their respective attributes (indicators, benchmarks) to measure how well the objectives are achieved. We then created strategic decision alternatives, including "business-as-usual" upgrades of the central water supply and wastewater system as well as semi- to fully decentralized alternatives. To tackle future uncertainty, we developed four socio-demographic scenarios. We used these to test the robustness of decision alternatives in a later Multi-Attribute Utility Theory analysis. Additionally, we contribute to the topical discussion of combining scenario planning with multi-criteria decision analysis and demonstrate how various scenarios can stimulate creativity when generating decision alternatives. Their internal consistency is ensured by rigorously specifying them using a strategy generation table. Our SDM procedure can be adapted to inform decisions about sustainable water infrastructures in other contexts.

4 - Integrated optimization of sequential processes: General analysis and application to public transport
Anita Schöbel, Philine Schiewe

Planning in public transportation is traditionally done in a sequential process: After the network design process, the lines and their frequencies are planned. When these are fixed, a timetable is determined and based on the timetable, the vehicle and crew schedules are optimized. After each step, passenger routes are adapted to model the behavior of the passengers as realistically as possible. It has been mentioned in many publications that such a sequential process is sub-optimal, and integrated approaches, mainly heuristics, are under consideration. Sequential planning is not only common in public transportation planning but also in many other applied problems, among others in supply chain management, or in organizing hospitals efficiently.

The contribution of this paper hence is two-fold: on the one hand, we develop an integrated integer programming formulation for the three planning stages line planning, (periodic) timetabling, and vehicle scheduling which also includes the integrated optimization of the passenger routes. This gives us an exact formulation rewriting the sequential approach as an integrated problem. We discuss properties of the integrated formulation and apply it experimentally to data sets from the LinTim library. On small examples, we get an exact optimal objective function value for the integrated formulation which can be compared with the outcome of the sequential process.

On the other hand, we propose a mathematical formulation for general sequential processes which can be used to build integrated formulations. For comparing sequential processes with their integrated counterparts we analyze the price of sequentiality, i.e., the ratio between the solution obtained by the sequential process and an integrated solution. We also experiment with different possibilities for partial integration of a subset of the sequential problems and again illustrate our results using the case of public transportation. The obtained results may be useful for other sequential processes.

■ MA-03

Monday, 8:30-10:00 - C

Optimal Classification and Regression Trees

Stream: Machine Learning and Mathematical Optimization

Invited session

Chair: *Cristina Molero-Río*

1 - New optimization models for optimal classification trees

Valentine Huré, Zacharie Ales, Amélie Lambert

Interpretability is a growing concept in Machine Learning. Decision-making algorithms are more and more used in healthcare, finance or other high stakes contexts. Therefore, the need for algorithms whose decisions are understandable is of the utmost importance. Intrinsically interpretable classifiers such as decision trees are often seen as less accurate than black box models such as neural networks. For decision trees, state-of-the-art methods are recursive heuristics (e.g. CART) that may fail to find underlying characteristics in datasets. Recently, linear formulations were introduced to model the problem of the construction of the best decision tree for a given dataset. Notably, OCT, a MIO formulation, has shown better accuracy than CART. However this model does not scale up to datasets with more than 1000 data points. Our work focuses on improvements of MIOs that speed up their resolution in order to handle larger problems. We present a new quadratic formulation based on OCT and another that extends a flow-formulation (from binary dataset to real-value dataset). We prove that both our new formulations have stronger continuous relaxation than OCT. Finally, our experiments show that they have a significantly smaller resolution time than OCT.

2 - Randomized regression trees: a model variant with disaggregated predictions and a decomposition training algorithm

Antonio Consolo, Edoardo Amaldi, Andrea Manno

Decision trees are widely used for classification and regression tasks arising in a variety of application fields. Blanquero et al.(EJOR Vol.299, 2022) recently proposed a novel continuous nonlinear optimization formulation to train multivariate randomized regression trees (MRRTs) which may account for sparsity and fairness. For any given input vector, the prediction is a weighted combination of the leaf nodes outputs, where the weight is the probability that the vector falls in the corresponding leaf node. In this work, we investigate a variant of the MRRT model where, for every input vector and for every leaf node, the prediction is expressed as a linear regression of the input variables. The associated formulation is well-suited not only to decomposition but also to induce fairness measures. The decomposition training algorithm we present includes a specific initialization strategy and a heuristic for the reassignment of the input vectors along the branching nodes of the tree. Under mild assumptions, we also establish asymptotic convergence guarantees. The results obtained on 15 datasets from the UCI and KEEL repositories indicate that our model variant and decomposition algorithm yield promising results in terms of accuracy compared with the original formulation, and significant speed-up in training time and similar accuracy compared with the MILP-based approach described in Bertsimas and Dunn, "Machine Learning under a modern optimization lens", Dynamic Ideas, 2019.

3 - Learning Geospatial Decision Tree Splitters

Margot Geerts, Seppe vanden Broucke, Jochen De Weerdt

In several geospatial analytics applications, in particular house price prediction, there is a strong tendency to rely on simple traditional multivariate regression models. However, tree-based methods such as Random Forest and LightGBM consistently rank among the best performing models in this application. Yet, currently available decision tree learning algorithms are suboptimal for geospatial problems. First, conventional decision tree learners are restricted to univariate horizontal and vertical decision boundaries. For datasets including spatial data in the form of X-Y-coordinates, this leads to "unnatural" decision boundaries. Second, decision tree learners are insufficiently tailored to operate well on a combination of fine granular geospatial features (X-Y) and more coarse features (e.g., plot area or EPC). This creates a strong necessity for a tailored geospatial decision tree learning algorithm with more appropriate splits that can cope better with coordinates as input features. Two multivariate decision tree splitters are proposed: diagonal splits and Gaussian splits. With diagonal splits, the decision tree includes linear combinations of features in the set of candidate splits. Gaussian splits approximate the decision boundary by a Gaussian and splits around it. Incorporating these multivariate splitters will introduce intractability in finding the optimal split. Therefore, heuristic optimization is leveraged to achieve higher performance and scalability.

4 - On sparse optimal regression trees for multivariate functional data

Cristina Molero-Río, Rafael Blanquero, Emilio Carrizosa, Dolores Romero Morales

In this talk, we tailor optimal regression trees to deal with multivariate functional data. A compromise between prediction accuracy and sparsity, as a proxy for interpretability, is sought. In particular, whilst fitting the tree model, the detection of a reduced number of predictor variables and the proportion of the domain used by the model is performed. This is achieved through the inclusion of LASSO-type regularization terms. The resulting optimization problem can be formulated as a nonlinear continuous optimization model with linear constraints. We illustrate the performance of our approach on real-world and synthetic datasets.

■ MA-04

Monday, 8:30-10:00 - D

Machine Learning in Marketing and Behavioral Analytics (I)

Stream: Machine Learning and Mathematical Optimization

Invited session

Chair: *Vinicius Brei*

1 - Utilitarian and hedonic consumer behavior in a supermarket setting: an unsupervised machine learning approach
Burcin Bozkaya, Zeynep Kucuksari, Selim Balcisoy, Vinicius Brei

Understanding consumer behavior in terms of hedonic vs. utilitarian purchase decisions and the underlying factors that lead to such decisions have long been studied in the marketing and psychology literature. Almost all of this research, however, deals with purchases made across a large set of shopping categories, such as food (supermarket or restaurant), entertainment, healthcare, travel, etc. In this research, we focus on one specific category, which is supermarket shopping, and analyze shopping transaction data from a store chain in Brazil to understand and identify hedonic vs. utilitarian consumer behavior in the supermarket context. We propose measures and an approach to distinguish hedonic vs. utilitarian purchases along many dimensions including brand/no brand, value, quantity/amount, day and time, and location. As there is no ground truth or primary data (eg. surveys) that would indicate the type of each individual transaction or trip to the supermarket, we conduct an unsupervised approach to identify outlier transactions that could indicate hedonic or utilitarian designation. Our approach allows for calculation of a "hedonic score" at the consumer level as well as product level. The results with the supermarket transaction dataset indicate that our approach produces realistic outputs under a variety of scenarios. Our approach brings new theoretical perspectives to advance the hedonic and utilitarian literature in management and operations research.

2 - A City Two Tales: NYC Neighborhood Resilience and Fragility to the COVID-19 Pandemic from a Mobility Network Perspective
Selim Balcisoy, Mohsen Bahrami, Hasan Alp Boz, Aaron Nicholas, Nina Mazar, Burcin Bozkaya, Alex Pentland

What predicts a neighborhood's adaptability to essential public health policies and shelter-in-place regulations that prevent the harmful spread of COVID-19? In this paper, we present a novel application of human mobility patterns and human behavior in a network setting to answer this question. We analyze mobility data in New York City over two years, from January 2019 to December 2020, and create weekly mobility networks of visits from a census block group (CBG) to every other CBG and its various points of interest (POIs). Our results suggest that both the socio-demographic and geographic attributes of CBGs significantly predict neighborhood adaptability to policies such as shelter-in-place. That is, our findings reveal that in addition to factors such as race, education, and income, geographical attributes such as access to diverse amenities in a neighborhood that satisfy community needs were equally important factors for predicting neighborhood adaptability during the first period of the COVID-19 pandemic, before vaccinations became accessible. The results of our study provide insights that can enhance urban planning strategies that contribute to pandemic alleviation efforts, which in turn may help urban areas become more resilient to exogenous shocks such as the COVID-19 pandemic.

3 - Adversarial risk analysis for competitive business decisions in uncertain environments
Daniel Garcia Rasines, Simón Rodríguez Santana, Roi Naveiro, David Rios Insua

Real-world competitive scenarios are complex situations, where information may be incomplete and noisy. This can make the decision-making process a difficult task. In these cases, framing the problem using Adversarial Risk Analysis (ARA) can prove to be beneficial, removing the common-knowledge assumptions that hinder the usage of game theory to better reflect the nature of the problems. Through ARA's Bayesian formalism we can construct a supporting mechanism to aid with making decisions in sensitive issues, which can lead to improvements both for the aided entity and its clients.

After exploring some key ideas behind the ARA approach, we employ it to model different scenarios inside the retirement plan's market and in the loan's market. Through various examples, we are able to successfully assist in deciding which offer an entity should make to a potential client to optimize that entity's expected utility. We have explicitly shown this through numerical simulations, constructed based on real-world values for each case. In every scenario, we show the benefits of the final decision estimated to the decision-maker, for which the optimal expected utility is achieved. Finally, we discuss different alternative setups for these problems and further extensions for this work.

4 - Using satellite imagery and machine learning to forecast energy consumption
Vilmar Boff, Vinicius Brei, Alina Flores, Carla Netto, Ricardo Limongi

The traditional approach to predicting energy consumption uses time series forecasting models with historical data. However, the past might not be a good predictor of the future. Economic development, to look on the positive side, or energy theft, to look on the negative, can influence energy consumption. This paper studies the use of satellite imagery to help improve energy consumption prediction, using a data type that is exempt from ground-truth measurement problems, such as energy theft detection. We run the predictions using freely available data that has been increasingly applied to predict social and business phenomena: nighttime satellite imagery. We collected monthly nighttime satellite imagery covering the entire Brazilian extension between 2012 and 2019. After extracting the luminosity, we compared the performance of statistical and machine learning models with and without satellite luminosity. The best-performing model was a neural network that uses satellite luminosity information to help predict the energy consumption of different Brazilian states, reaching a MASE of 1.34 on average and a MAPE of 6.2 on average. Moreover, the best-performing model improves, on average, in .33% the performance of neural networks that do not use satellite data and, in 1.03%, the performance of the statistical model that uses the same data. Our contributions are robust and flexible in predicting energy demand at any desired geographical level.

■ MA-05

Monday, 8:30-10:00 - E

Optimization for Deep Learning

Stream: Deep Learning and Applications
Invited session
Chair: *Sureyya Ozogur-Akyuz*

1 - An Optimization based Framework for Sign Prediction in Signed Social Networks
Mukul Gupta

The relationships between objects in many real-world networks have polarity. These networks are called signed networks due to the polarity of relationships. In signed networks, the relationships have positive/negative signs representing the friendship/enmity between objects. The sign information of relationships would be useful for various mining tasks to get rich insights and to support the decision-making process. However, signed networks in the real world are scarcely labeled. To get the advantage of signed information, the signs of the unlabeled edges are to be predicted. In this work, the problem of sign prediction for unlabeled edges in undirected signed networks is considered and an optimization-based method is proposed. This method is domain-independent and uses only graph-structural information. Real-world signed networks are used for experiments to validate the effectiveness of the proposed method. The performance of the proposed method is compared to the baseline methods. The results of the experiments show the effectiveness of the proposed method.

2 - Alternating Optimization framework for Sparse Simultaneous Component Analysis Based on Data Integration
Rosember Guerra-Urzola, Juan Vera, Katrijn Van Deun, Klaas Sijtsma

Given multiple data blocks from different sources sharing the same observations (such as psychological questionnaires or genetic risk scores), Simultaneous Component Analysis (SCA) aims to find a few linear combinations of the variables that explain as much as possible the variability in the joined data set. However, rooting the analysis on all variables makes interpretability difficult, especially in high-dimensional settings. Therefore, looking for a sparse structure is natural; it identifies the common and distinctive source of variation across all data blocks. Solving the sparse SCA problem is intractable, given its combinatorial nature. Here, the nonconvex SCA problem is formulated as different convex maximization problems over the sphere, inducing sparsity via cardinality constraint and lasso penalties. To solve these models, optimization algorithms based on the alternating directions methods are proposed; these algorithms find high-quality feasible solutions for large dimensions. Extensive experiments, including a real-world data set, are used to assess the solution quality, computational time, and scalability of the methods

3 - Using Second-Order Conic Programming as an Embedded Feature Selection Algorithm
Sureyya Ozogur-Akyuz, Muhammad Ammar Ali, Buse Cisil Guldogus

Feature selection algorithms are essential to correctly classify datasets with high dimensions. They identify the most important aspects of a dataset and improve classification accuracy. From a different perspective, feature selection can be reframed as a pruning problem. In this study, we use second-order conic programming as an embedded feature selection technique with neural networks on multiple synthetic datasets. This study uses a technique previously used for ensemble pruning and repurposes it as a feature selection algorithm. This is done by training a neural network on multiple single features of the dataset and using their respective outputs to generate a probability class distribution along with a prediction. This methodology allows implementation of second-order conic programming to determine features that contribute most to accurate classification using neural networks as embedded classifiers.

4 - Modeling Ensemble of CNNs via Semi-infinite Programming
Melisa Caliskan-Demir, Sureyya Ozogur-Akyuz

Convolutional Neural Networks (CNNs) have been widely used in many fields recently which have proved a high success in image processing and classification problems. This study aims to develop an optimization model which prunes the ensemble of CNNs using Semi-infinite programming (SIP). An ensemble of 300 CNNs has been generated considering the accuracy and diversity of the architectures. The objective function is constructed by including the trade-off between accuracy and diversity using Shannon Entropy measures. While optimizing this trade-off, a weight for accuracy and diversity terms are assigned such that the weights are summed up to one to control this trade-off in the optimization process. As the solution of the problems in general highly depends on a given parameter, to avoid such dependency, we transformed the problem into SIP such that the parameter became an index of the infinite index set of the infinite constraint set. Here, the solution of SIP refers to the index of CNNs in the ensemble so that the voting among the new winning candidates through the SIP solution will become the final prediction of the classification problem. We tested our new model on CIFAR 10 data set which is a popular data set in image processing studies to validate new approaches. The performance of the new proposed approach achieves better performance values in terms of accuracy and F-statistics than existing methods in the literature.

■ MA-06

Monday, 8:30-10:00 - U1

Discrete-continuous or stochastic optimization and control in transportation and design (space-time) I

Stream: Combinatorial Optimization
Invited session
Chair: Gerhard-Wilhelm Weber

1 - Merging a demand-responsive transportation system with a traditional feeder system to offer a tailored service for passengers
Fábio Sartori Vieira, Kenneth Sörensen, Pieter Vansteenwegen

One of the advantages of a flexible transportation system over a traditional bus system is the ability to adjust the service to meet demand expectations. However, operation costs are higher, especially in areas with low demand during off-peak hours. Currently, operators need to offer services in such areas with a minimum availability for the passengers. This research aims to merge the current operation of a feeder system in low-demand suburban areas, with elements of demand-responsive systems. Using a mathematical model to optimize the routes and timetable of the services, operators can offer a more attractive service to passengers at the same cost as the service they already offer in these locations. The objective is to minimize passengers' travel time from the moment they desire to start their trips to when they arrive at the transfer station, where high-frequency services to other areas in the network are available. Simulations compare the effectiveness of this system with the traditional system operating under the same characteristics of demand. As a result, it is possible to observe a reduction in passengers' average waiting time by up to 50%. For different instances with variations in the demand distribution, it is observed that more stops with temporarily no requests, allow to further reduce the passengers' travel time.

2 - Quantum annealing for railway conflict management
Mátyás Koniorczyk, Krzysztof Domino, Krzysztof Krawiec, Konrad Jałowiecki, Sebastian Deffner, Bartłomiej Gardas

We are in the Noisy Intermediate-Scale Quantum (NISQ) devices' era, in which quantum hardware has become available for application in real-world problems. However, demonstrating the usefulness of such NISQ devices are still rare. In this work, we consider a practical railway dispatching problem: delay and conflict management on single-track railway lines. We examine the issue of train dispatching consequences caused by the arrival of an already delayed train to the network segment being considered. This problem is computationally hard and needs to be solved almost in real-time. We introduce a quadratic unconstrained binary optimization (QUBO) model of this problem, compatible with the emerging quantum annealing technology. The model's instances can be executed on present-day quantum annealers. As a proof-of-concept, we solve selected real-life problems from the Polish railway network using D-Wave quantum annealers. As a reference, we also provide solutions calculated with classical methods. Our preliminary results illustrate the degree of difficulty of real-life railway instances for the current quantum annealing technology.

3 - A Clustering and Routing Strategy for the Mobility Allowance Shuttle Transit with Dynamic Checkpoint
Luca Quadrifoglio, Dahye Lee

This study explores a dynamic checkpoint strategy for the Mobility Allowance Shuttle Transit with Dynamic Checkpoint (MAST-DC). By introducing a dynamic checkpoint option in the booking process, we allow customers to walk less distance with a slight increment on the fare price, which is expected to improve the level of service and increase the service provider's profit. A sequential iterative two-phase heuristic model first clusters to minimize customers' walking distance and then routes to minimize vehicle distance traveled. The clustering is performed using memetic differential evolution (MDE)-based algorithm, and the routing solves a traveling salesman problem (TSP). The procedure is repeated iteratively to potentially add more clusters, should sufficient slack time still be available after the routing. An analytical model is also developed to provide a lower bound estimate for the dynamic number of checkpoints and an upper bound estimate for the customers' average walking distance. A parametric simulation experiment is conducted to explore the impact of system parameters on the number of dynamic checkpoints and customers' walking distance and validate the robustness of the analytical model. Results show that the proposed MAST-DC system performs best if the demand rate is approximately 4 customers per square miles and the slack time is between 150 percent and 200 percent of the direct travel time.

4 - A survey on macroeconomic data in the eurozone and a control dashboard model based on the kam and nekhoroshev theorems and the hÉnon attractor

Marco Desogus, Elisa Casu

Starting from the examination of the main macroeconomic parameters that have characterized the structure of the Eurozone in the last decade - and their systemization - our aim was to apply a model suitable for describing its dynamics. In particular, the Kolmogorov-Arnold-Moser theorem was adapted to the question, up to low level perturbations caused by negative economic conditions, the first symptoms of financial or exogenous crises, and other turbulence affecting the economy. We then applied Nekhoroshev's theorem to represent the phenomena characterized by the occurrence of stronger resonance as well as the reactions of the system to the control and recovery measures implemented by the ECB Governing Council. The goal of the paper is to propose the adoption of a systemic stability planning and control dashboard - also suitable for the support and stimulation of growth cycles - with attention to optimal performance, which can be identified in compliance with (or restoration of) the macroeconomic trajectories determined in the model by the Hénon Attractor. The proposed scheme may find useful application - both for evaluation and operational purposes - in the current period, characterized by the complex and compromised scenario brought about by the SARS-COVID2 pandemic emergency, which has obviously imposed structured measures to support the economy.

■ MA-07

Monday, 8:30-10:00 - U3

Planning problems in electric energy systems I

Stream: OR in Energy

Invited session

Chair: Luis Baringo

1 - Designing heat and electricity production system for rural areas from renewables with flexible operating units

István Heckl, András Éles, Heriberto Cabezas

Our aim is to design an energy system including heat and electricity production for a rural area. The scheme of flexible operating units, from the P-Graph framework is applied to gain improvements in a case study, where available raw material (renewable energy sources) and possible locations for fermenters and CHP plants are given and the total profit is to be maximized. The model of the original case study involving the supply of the municipality of Bad Zell, optimized with the P-Graph framework was reproduced as a Mixed-Integer Linear Programming (MILP) model. Data for the newly introduced flexible fermenter model was obtained by multiple linear regression. The last model was designed in accordance with the flexible operating unit scheme to compare solutions and model performance with the original approach. The final version of the model involving the flexible operating unit scheme was found to be superior in the case study than the original results reported. This includes a 30% increase in yearly profits because of better utilization of the resources. Almost all renewable sources were used up except for corn silage. The flexible operating unit scheme can significantly improve solution quality with respect to ordinary, fixed input units. This suggests that using flexible operating units in an optimization model and designing equipment based on the results can be more advantageous than designing several types of fixed input equipment and optimizing afterwards.

2 - How flexible sector integration can mitigate storage needs in renewable energy systems

Jens Weibezahn, Leonard Göke

The provision and need for flexibility will play a pivotal role in the transformation towards an energy system achieving the Paris Climate Agreement targets and is shaped by interactions and synergies of both, electricity supply and demand. Extending the existing literature, this paper transcends the focus on supply-side options investigating how synergies with decarbonization beyond the power sector can mitigate flexibility needs and reduce system costs. The paper applies a bottom-up planning model capturing operation and expansion of technologies in the heating, transport, and industry sector. The scope includes 22 distinct energy carriers that can be stored and converted into one another by 120 different technologies to satisfy final demand and transported by 4 different types of transmission infrastructure. It deploys a graph-based formulation specifically developed to model high shares of fluctuating renewables and sector integration. Spatially, the model covers the European continent subdivided into 96 regions. Reflecting how decarbonization of the energy system is not only a techno-economic but also a social challenge, the paper compares four different scenarios varying the role of two technologies that are often met with public opposition: wind energy and power transmission. Our findings show that an isolated analysis of decarbonization in the power-or any other-sector, will miss key interactions and is at high risk of not identifying the most cost-efficient strategy.

3 - Energy and ancillary services long term co-planning under stochastic scenarios

Erick Sierra

Power systems planners' work is to anticipate future expansions needed to operate its power system, facing the load balance issues and the uncertainty from increasingly cleaner but more variable energy sources. The discussion turns around on how this increase in renewable energy penetration may impact the needs of ancillary services, which are required to support the system operation. Moreover, the planning tools need to allocate and co-optimize these resources adequately. This work presents the software FESOP for stochastic power generation, transmission, and storage capacity expansion planning. This flexible model considers technical and economic constraints for energy supply and spinning reserve requirements to address sudden generation variation. Uncertainty is modeled using different scenarios, consisting of various renewable generation profiles, water inflows, load profiles, and fuel costs. The objective function for this multistage stochastic optimization framework is to minimize the total investment costs and the expected operating cost over a given time horizon. The software yields the optimal expansion plan, including the investment cost and the expected operation result of the power system. The software was tested and validated mainly using the National Electric System in Chile, with satisfactory results for the energy and ancillary services expansion co-planning for the 2021-2050 period.

4 - A Stochastic Bi-Level Model for Optimal Expansion Planning of a Price-Maker Virtual Power Plant

Santiago Maiz, Raquel García-Bertrand, Luis Baringo

Virtual Power Plants (VPPs) play a key role in facing with the variability and uncertainties inherent in renewable energy production. They allow renewable energy sources to participate in the electricity markets avoiding the possible penalties due to the production deviations by combining them with conventional power plants, storage units, and flexible demands. In this work, we address the expansion planning problem of a VPP that participates in the electricity markets with the possibility of building new conventional and renewable generating units and storage facilities. The problem is tackled with a two-stage stochastic bi-level model where the upper-level problem represents the expected profit scheduling the production and building new units, while the lower-level problem models the clearing of the energy and reserve markets allowing to play the role of price-maker. The variabilities in the production levels of renewable energy are modeled using representative days obtained from a modified K-medoids algorithm, while the uncertainties in the deployment of reserve request are represented with a set of scenarios. The bi-level problem is converted to a single-level problem replacing the lower-level problem by its Karush-Kuhn-Tucker optimality conditions and then further transforms it into a mixed-integer linear programming model. A realistic case study shows that considering that the VPP behaves strategically has an impact on the expansion decisions, increasing its profit.

■ MA-08

Monday, 8:30-10:00 - U4

Metaheuristics and Hybrid Methods

Stream: Combinatorial Optimization
Invited session
Chair: *Guillermo Cabrera-Guerrero*

1 - Metaheuristics vs. Exact Solvers: Finding Optimal Solutions to the Minimum Sum Coloring Problem

Yu Du, Fred Glover

The minimum sum coloring problem (MSCP), a well-known NP-hard problem, has been the subject of several papers in recent years. Due to the computational challenge that these problems pose, most solution methods employed are metaheuristics designed to find high-quality solutions with no guarantee of optimality. Exact methods(like Gurobi) and metaheuristic solvers have greatly improved in recent years enabling optimal solutions to be found to a growing set of MSCP problems. Moreover, alternative model forms can have a significant impact on the success of exact and heuristic methods in such settings.

We introduce several alternative models for MSCP and provide a computational study using a standard set of test problems from the literature that compares the general-purpose exact solver from Gurobi to the leading metaheuristic solver AlphaQUBO. Our results highlight the effectiveness of metaheuristic solvers on this test bed and show that a constrained version of binary quadratic model (QUBO-Plus) using AlphaQUBO provides the best performance for finding optimal solutions to these important problems.

2 - A comparative study of some explicit linearization models for the quadratic binary optimization problem

Navpreet Kaur, Abraham Punnen

The Quadratic Unconstrained Binary Optimization problem (QUBO) received considerable attention recently from researchers and practitioners, particularly due to the emerging technology of quantum inspired computers and its linkages with QUBO. In this study, we introduce several aggregation based explicit linearization techniques for QUBO and compare these models with well known linearization models from the literature. Theoretical as well as experimental comparisons are provided. Our experimental results disclose that aggregation based techniques are viable alternatives for computing lower bounds for QUBO as well for computing heuristic solutions for the problem.

3 - Hybrid branch-and-fix evolutionary approaches for the Hamiltonian cycle problem on directed graphs

Roberto Santana, Maialen Murua

There are few optimization methods that can be applied to the Hamiltonian cycle problem (HCP) on directed graphs. The Branch and Fix (BF) algorithm proposed by Ejov et al. (2009) can solve the HCP on this type of graphs. BF uses the idea that the HCP can be embedded in a discounted Markov decision problem and addresses this problem by solving a sequence of linear programs, phantoming branches proved not to contain any Hamiltonian cycle.

One characteristic of BF is that the time spent to find a solution is sensitive to the way the nodes are labeled. The time for finding a solution can significantly change depending on this order. Another characteristic of the algorithm is that, if solutions are not found on a given maximum computational time, the algorithm produces no output. Therefore, no useful information is obtained from this computational effort.

In this paper we introduce two variants of hybrid BF evolutionary approaches (EAs) for HCP. The first approach uses an EA with a permutation representation to find the labeling order of the nodes that maximizes the number of vertices fixed by BF during the search of the Hamiltonian cycle. The second approach exploits the partial solutions found by the BF algorithm to seed a population of HCP candidates that are then further explored throughout the EA search, by means of the application of the genetic operators. Our results show that these approaches can provide efficiency gains in parallel computation scenarios.

4 - A Hybrid Relaxed MIP model and rVNS algorithm for the Beam Angle Selection problem in IMRT

Guillermo Cabrera-Guerrero, Maicholl Gutierrez, Carolina Lagos

Intensity Modulated Radiation Therapy (IMRT) is a widely used radiotherapy technique to treat cancer. The main goal of IMRT is to obtain a treatment plan that kills cancer cells in the tumour while doing as little damage as possible to surrounding organs at risk (OAR). To this end, we must first search for the best possible set of beam angles, called beam angle configuration (BAC), to irradiate from. This work proposes a reduced variable neighbourhood search (rVNS) algorithm that generates a set of neighbours using a roulette wheel selection strategy. The weight of each beam in the roulette is obtained at the beginning of the algorithm through a relaxed Mixed Integer Programming (rMIP) model which solves the BAO problem considering all the available beam angles. The solution of the rMIP gives us the usage of each beam angle in the treatment plan. Those beam angles with higher values will have a larger portion of the roulette wheel, while those beam angles with smaller values are banned. We call this approach the MIP-based reduced variable neighbourhood search strategy. We tested our approach on a set of clinical prostate cases. The results show that the rVNS algorithm using the rMIP strategy leads to better treatment plans than the rVNS without the rMIP strategy.

■ MA-09

Monday, 8:30-10:00 - U5

MIP for scheduling and capacity management

Stream: Mixed Integer Linear Programming
Invited session
Chair: *Roel Leus*

1 - Sequencing unreliable jobs on parallel machines with job duplication

Ben Hermans, Alessandro Agnetis, Mario Benini, Paolo Detti, Marco Pranzo

We study the problem of scheduling a set of n unreliable jobs on m identical machines, where jobs can be duplicated in order to increase the probability of being successful on at least one machine. If the copy of a job fails on a machine, then the corresponding machine is blocked and cannot perform the subsequently scheduled job copies. Given a revenue for every job that is obtained if and only if at least one of its copies is successfully completed, the objective is to sequence the n job copies on each of the m machines so as to maximize the expected revenue.

In this talk, we propose a mathematical programming formulation for the special case of m = 2 machines. Next, for the general case, we propose an index-based heuristic with a worst-case performance guarantee that scales logarithmically in the number of machines. Finally, we describe a local search heuristic as well as a tabu search, and compare their performance based on extensive numerical experiments.

2 - A Partial Assignment Acceleration Technique for Logic-Based Benders Decomposition

Elina Rönnberg, Emil Karlsson

Logic-based Benders decomposition (LBBD) is suitable for designing exact methods that hybridise MIP and CP, and such methods have been especially successful for solving resource allocation and scheduling problems. In general, the efficiency of LBBD methods relies on acceleration techniques tailored to the problem structure. The most common ones are to strengthen the master problem, to handcraft improved cuts, and to perform cut strengthening.

Cut strengthening refers to reducing the set of variables included in a cut to obtain a stronger one. This can be done by a systematic search where subproblems are solved for different subsets of variables. Our contribution is to extend such search for feasibility cuts by including an additional step each time a subset of variables has been evaluated: (i) If the current subset is confirmed to yield a cut, we form a restriction of the original problem, constructed with respect to the variables not included in the current subset. If this restricted problem is feasible, its solution is feasible in the original problem. (ii) If the current subset does not yield a cut, a restriction is instead constructed with respect to the variables included in the subset. If a feasible solution to this restricted problem is found, it yields a feasible solution to the original problem.

The impact of using our acceleration technique is confirmed by an evaluation on 120 publicly available instances of a large-scale multiprocessor scheduling problem.

3 - A flow-based formulation for parallel machine scheduling using decision diagrams

Roel Leus, Daniel Kowalczyk, Christopher Hojny, Stefan Ropke

We present a new flow-based formulation for identical parallel machine scheduling with a regular objective function and no idle time. We use a decision diagram that contains all the possible sequences of jobs that follow specific ordering rules to construct the new formulation. These rules, taken from work by Baptiste and Sadykov, are based on a partition of the planning horizon into, generally non-uniform, intervals. The new formulation will have numerous variables and constraints, and hence we apply a Dantzig-Wolfe decomposition in order to compute the linear programming relaxation of the new flow-based formulation in a reasonable amount of time. Moreover, we will see that the lower bound will be stronger than the lower bound obtained by the classical time-indexed formulation. We develop a branch-and-price framework to solve the new formulation, which allows to solve several instances from the literature for the first time. We also compare with the arc-time indexed formulation; we find that the two formulations are not comparable (meaning that neither of the two is stronger than the other).

■ MA-11

Monday, 8:30-10:00 - U7

Robustness analysis in MCDA

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: Eleftherios Siskos

1 - Heuristics for the robust implementation of the Choquet integral as important index in multicriteria ranking problems

Eleftherios Siskos, Antoine Desbordes, Peter Burgherr

Decision problems are often characterized by complex criteria dependencies, which can hamper the development of an efficient and theoretically accurate multicriteria decision aid model. These dependencies, called criteria interactions have the form of either a redundancy or synergistic effect, requiring arduous and demanding preference statements for their quantification. In this paper, the behaviour of criteria interactions is analysed, in the context of an interactive robustness control procedure, until the concurrent acquisition of a stable decision model and satisfactory evaluation results. For this purpose, a preference elicitation framework is developed, based on the method of cards and heuristically selected pairwise questions. Robustness is assessed, with the aid of indicators, measuring the reduction of the model's feasible space, and rank acceptability indices. The latter stem from the implementation of the hit and run weighting sampling algorithm and a synergy of the SMAA algorithm with the Choquet integral, approached as an importance index. The elicitation questions are automatically sampled and selected, assuring a high information gain in the most unstable criteria, while averting the bias of favouring the predominant ranks, achieved in the previous elicitation rounds. The complete framework is applied to various instances of a small-scale ranking problem, attempting to minimize the number of required questions and the cognitive effort of the decision maker.

2 - Experimental comparative analysis of unambiguous model selection approaches to solve multi-criteria ranking and choice problems

Michał Wójcik, Miłosz Kadziński, Krzysztof Ciomek

The additive value function is one of the most popular models for solving multi-criteria ranking and choice problems. This approach allows the Decision Maker to express preferences using pairwise comparisons, which are then transformed into constraints in the linear programming problem. Due to the incompleteness of such a representation, there may be many coherent models giving different solutions to the problem. For a more intuitive form, it is necessary to select one of the functions that best reflects the DM's preferences. The multitude and variety of approaches to choosing an unambiguous model make it difficult to choose the best one. In addition to pairwise comparisons, some methods also use the results of Stochastic and Robust Ordinal Regression.

For this purpose, extensive computational experiments were performed to determine which approaches work best under certain conditions. For each method, the ability to reproduce a reference ranking and to represent a whole space of consistent solutions was investigated. For this purpose, seven quality measures have been defined. The methods were assessed according to the characteristics of the problem, such as the number of pairwise comparisons provided by the DM, the number of alternatives and criteria, and the shape of the marginal value function. The result of the analysis are guidelines to use the best approaches depending on the characteristics of the problem. These tips may be helpful, especially for MCDA experts.

3 - Parametric and non-parametric models to induce a probability distribution in the space of compatible value functions

Sally Giuseppe Arcidiacono, Salvatore Corrente, Salvatore Greco

Ordinal Regression (OR) is a popular methodology of multiple criteria decision aiding that induces a value function representing the preferences of a Decision Maker (DM). Based on the remark that, in general, there is an infinite plurality of value functions compatible with the preferences expressed by the DM, Robust Ordinal Regression (ROR) has been proposed extending OR. Conjugating ROR with a Stochastic Multicriteria Acceptability Analysis, a probability distribution has been considered in the space of the value functions compatible with the DM's preferences. In this context, we propose a methodology to induce a probability distribution in the space of the compatible value functions through parametric and nonparametric models. We also test the reliability of the obtained results in a set of experimental computations.

4 - Preference disaggregation: a probabilistic view
Mohammad Ghaderi

Preference disaggregation concerns the construction of value functions from the preference information supplied by a decision-maker, typically in the form of qualitative judgments and holistic pairwise comparisons of decision alternatives. From a methodological perspective, similar to discrete choice analysis and choice-based conjoint analysis, preference disaggregation combines the input information with assumptions to identify the relationships between a set of preferentially relevant variables, i.e., decision criteria, and observed choices, i.e., reflected preferences, via constructing interpretable value functions. Unlike the traditional econometric methods of discrete choice analysis, preference disaggregation analysis circumvents restrictive specification and distribution assumptions by formulating the problem of parameters estimation as a constrained optimization problem. Despite its nonparametric advantages, a drawback of this class of methods is the deterministic nature of the outputs that they produce and a lack of concrete theoretical basis to account for the imperfect knowledge of the problem from the analyst's point of view. I attempt to fill this gap by introducing a generalized preference disaggregation framework that adopts a probabilistic view for addressing the issue of inferential uncertainty from the analyst's perspective, or decision-makers perspective when a constructive view of preferences is at work .

■ MA-12
Monday, 8:30-10:00 - U9

Machine learning in energy-related problems

Stream: OR in Energy
Invited session
Chair: Salvador Pineda Morente

1 - Energy System Evolution Strategies for Mobile Microgrids using Deep Reinforcement Learning Flexibility Analysis
Cesare Caputo, Michel-Alexandre Cardin, Anna Korre, Antonio del Rio Chanona, Pudong Ge, Fei Teng

Mongolia presents a unique energy landscape, with a significant population following a nomadic lifestyle, and large seasonal fluctuations in both heating and electricity demand resulting from the local climate. This creates a number of challenges, and opportunities, in terms of energy systems capacity planning to balance delicate trade-offs between mobility, security, efficiency, sustainability and economic feasibility. Given the development of a novel Plug and Play control strategy which allows for the interconnection of nearby dwellings, the system evolution strategy of a representative mobile minigrid over 30-years is considered in this work. Uncertainty is explicitly modelled on herder migration patterns, demand evolution, energy generation and distribution capacity. Deep Reinforcement Learning Flexibility Analysis is then used to evaluate initial design and adaptation strategies under unknown future conditions for the multi-energy system. The results suggest the development of dynamic solutions, producing a spectrum of decision-making policies to improve performance under different scenarios, measured according to expectations of cost, equivalent emissions, and lifetime unmet load. Decision rules used to guide micro-grid capacity adaptation under uncertainty are retroactively evaluated, with important implications for policy makers looking at enabling energy access for nomadic communities worldwide, and unintuitive insights in terms of optimal operational strategies.

2 - Deep Reinforcement Learning for Optimized Operation of Renewable Energy Assets
Jan Martin Specht, Reinhard Madlener

Machine learning and, more specifically, reinforcement learning (RL) entered operations research literature just recently and are even less employed in practice. A domain that could profit massively from RL is the energy sector, which is facing the challenges of transitioning to sustainable energy solutions. This transition requires the coordination of a vast number of smart energy assets to optimize their utility in meeting multiple objectives, e.g. targeted charging of electric vehicles to max-imize self-consumption or to avoid load peaks in the electric grids. This study demonstrates the potential and current obstacles of RL and provides a guide for interested practitioners on how to tackle similar tasks without advanced skills in neuronal network programming. For the application in the energy domain it is demonstrated that state-of-the-art RL algorithms can be trained to control potentially millions of small-scale assets in private households. In detail, the applied RL algorithm outperforms today heuristic algorithms and only falls slightly short of the results provided by linear optimization, but at less than a thousandth of the simulation time. Thus, RL paves the way for aggregators of flexible energy assets to optimize profit over multiple use cases in a smart energy grid and thus also provide valuable grid services and a more sustainable operation of private energy assets.

3 - Electric vehicles and solar panels co-adoption via diffusion models
Sebastian Souyris, Subhonmesh Bose, Sridhar Seshadri, Diego Ybarra Arana

Electrification has been identified as a critical enabler of the decarbonization of transportation. Therefore, it is imperative to study the adoption growth in solar photovoltaics (PVs) and electric vehicles (EVs) to plan for this impending transformation. However, existing PV and EV adoption studies typically ignore the influence between them and other green technologies, such as the evolution of charging stations. We employ state-of-art techniques in structural economics—the dynamic discrete choice model—to study these technologies' diffusion. Our work projects the adoption of PV and EV trends into the future under plausible counterfactual scenarios.

4 - Is learning for the unit commitment problem a low-hanging fruit?
Salvador Pineda Morente, Juan Miguel Morales

The blast wave of machine learning and artificial intelligence has also reached the power systems community, and amid the frenzy of methods and black-box tools that have been left in its wake, it is sometimes difficult to perceive a glimmer of Occam's razor principle. In this letter, we use the unit commitment problem (UCP), an NP-hard mathematical program that is fundamental to power system operations, to show that simplicity must guide any strategy to solve it, in particular those that are based on learning from past UCP instances. To this end, we apply a naive algorithm to produce candidate solutions to the UCP and show, using a variety of realistically sized power systems, that we are able to find optimal or quasi-optimal solutions with remarkable speedups. To the best of our knowledge, this is the first work in the technical literature that quantifies how challenging learning the solution of the UCP actually is for real-size power systems. Our claim is thus that any sophistication of the learning method must be backed up with a statistically significant improvement of the results in this letter.

■ MA-13
Monday, 8:30-10:00 - U119

Trip planning and network desingn

Stream: Discrete Optimization and Algorithms (contributed)
Contributed session
Chair: Valentina Morandi

1 - Approximate dynamic programming for liner shipping network design
Sangmin Lee
The maritime industry revolves around liner shipping services, which deliver large volumes of commodities around the world via vessels operated on fixed routes and schedules. For this reason, the liner shipping network design problem (LSNDP) plays a crucial role in the profitability of shipping companies. The LSNDP has traditonally been solved using mathematical programming methods, including mixed-integer programming algorithms and heuristics. Such methods, however, suffer from poor scalability when the problem is subject to significant uncertainty in some parameters, such as demand, costs, and sailing and/or berthing time. In recent years, variations of Approximate Dynamic Programming (ADP), also known as Reinforcement Learning, have shown potential for large-scale stochastic optimization as they benefit from machine learning techniques. We, therefore, formulate the LSNDP as a Markov decision problem (MDP), which provides a basis for applying ADP. To validate the proposed MDP framework, our starting point is to solve a deterministic version of the LSNDP by value iteration and for smaller instances. The result shows that the value iteration algorithm produces the optimal solution. To handle large-scale instances and uncertainty, we suggest how to apply ADP to the proposed MDP.

2 - Multi-Agent Trip Planning with Activity Reservations in Crowded Destinations
Joris Slootweg, Rob van der Mei
In this paper we outline an algorithm for multi agent leisure trip planning with activity reservations in congested areas with heterogeneous visitor preferences. We propose an algorithm that starts with creating a tour for each user with just a small subset of activities assigned to each visitor. These trips are then expanded in an iterative fashion to improve the trips of all users. For creating the individual trips we suggest a greedy blocking heuristic that generates good individual trips and use a variant of Iterated Local Search on long trips or Full Enumeration on short trips in case we need to escape local optimums. When evaluating user satisfaction with his trip based on the activities he can visit. The algorithm outperforms first-come-first-served on large instances with regards to average user satisfaction. At the same time the distribution of the user satisfaction can also be seen as a lot fairer. On small instances we solve the instances to optimum using Integer Linear Programming as well. We show that for small congested instances the proposed algorithm stays relatively close to the optimal solution without increasing when the number of users increases. Finally, the algorithm scales well with regard to the number of users and the number of events. Since in our computational experiments we found that the trip length will limit the computational impact of the number on events. While the capacity will limit the computational impact of the number of user

3 - A centralized decision support system to determine optimal paths for visitors of crowded events
Valentina Morandi
In the last years, technology has been applied to crowded venues with a level of information that is much higher, compared to the one we had in the past. An example is the amount of available real-time information on shopping malls, theme parks, large fairs, and international events. Provided information could be multifaceted: the number of free parking slots, number of people currently visiting the location, entrance and location queue waiting time, etc. In most cases, the number of people simultaneously allowed in a specific area needs to be limited below a predefined threshold over time, mainly for safety reasons, or the physical capacity of the points of interest within the venue. Unfortunately, provided information could not help if people intend to visit the same highly-rated locations within the event since the scheduling of the visit is chosen autonomously and, hence, queues and delays occur. In such situations, a coordination mechanism able to provide directions to people regarding where and when to go, as well as tracking where people are over time, can help avoid overcrowding and create a better and safer environment. A MILP model has been designed and tested recommending paths, schedules and arriving time to individuals, in such a way overcrowded situations are avoided while maintaining a high standard of service for people entering the event.

4 - Online Algorithms for Multi-Agent Tourist Trip Planning Problems
Jesse Nagel
Tourist destinations can experience large amounts of congestion, causing long queues and unhappy travelers. Efficiently distributing tourists over a number of attractions can increase both user happiness and attraction profit. Finding such a distribution, which takes user preferences into account, is referred to as the Multi-Agent Tourist Trip Planning Problem. Current algorithms for this problem require the set of tourists to be known in advance. Such information is however not always available. Therefore, we introduce an online variant of this problem where tourists are revealed to the algorithm one-by-one. The algorithm must immediately and irrevocably decide which attractions the tourist can visit. Several algorithms to solve this problem are presented, where we vary the amount of advance knowledge the algorithm has on the problem set. We compare these algorithms to those available for the deterministic variant of the problem by applying them to some example cases. Finally, we show theoretical bounds on the competitive ratios of the algorithms.

■ MA-15
Monday, 8:30-10:00 - U262

Multi-Objective Decision Making

Stream: Decision support (contributed)
Contributed session
Chair: Giovanni Misitano

1 - A new framework to solve flexible jobshop scheduling problems in the context of Industry 5.0
Madani Bezoui, Alexandru Olteanu, Marc Sevaux, David Garcia
Human intervention is reduced in Industry 4.0 through automation of the manufacturing process. Today, Industry 5.0 puts human beings at the center of the industry, using their creativity and expertise in collaboration with powerful, intelligent and precise machines with two goals: to bring back a human touch in the industry and to have more personalized products. The aim of this work is to provide a framework that uses a decision maker preference elicitation algorithm in the form of an RMP model in the first step, and then incorporates it in resolving a multi-objective flexible job shop scheduling problem in the second step. Three objectives to be minimized are considered: the makespan, the total machining time, and the quadratic difference of the workload between all machines with the average load. A hybrid Tabu search method is proposed and tested on publicly available instances. The link between our approach and Industry 5.0 will then be established.

2 - Explainability and its potential in interactive multiobjective optimization
Giovanni Misitano, Bekir Afsar, Giomara Lárraga, Kaisa Miettinen
Multiobjective optimization methods support decision makers in finding the most preferred trade-offs among conflicting objective functions. By providing preference information, a decision maker can guide interactive multiobjective optimization methods towards desirable solutions. At the same time, the decision maker learns about the interdependencies among the objective functions. However, the current interactive methods do not really support building an understanding on how preferences affect the interactive process to find solutions, or how the preferences should be changed to achieve more desirable solutions. This is the motivation of our work. We argue that explainability provides insight in interactive multiobjective optimization. Explainability is a well-known concept in the field of artificial intelligence, but in multiobjective optimization, its potential is still untapped. We propose a new method, R-XIMO, that can augment any reference point based

interactive multiobjective optimization method with explainability. A reference point is a preference type consisting of desirable objective function values. We apply SHAP values in our method to explain reference point based multiobjective optimization methods. In particular, we explain to the decision maker both how preferences have affected computed solutions and how preferences can be changed to achieve more desirable solutions. Our results show that explanations have a lot of potential in multiobjective optimization.

3 - Assessing and comparing the performance of interactive multiobjective optimization methods
Bekir Afsar, Ana Belen Ruiz, Francisco Ruiz, Kaisa Miettinen

Many practical applications have shown the potential of interactive multiobjective optimization methods in which a decision maker (DM) engages in the solution process iteratively and directs the production of solutions with one's preferences. Interactive methods seek to reduce computation cost and cognitive load by examining a limited number of solutions at a time. They enable the DM to learn about the trade-offs among the conflicting objectives, the feasibility of their preferences, and to adjust their desires based on the gained insight. Because of these benefits, the number of interactive methods in the literature has increased significantly. However, most of them have not been assessed in real-world applications or compared to one another. Choosing the best-suited method for a problem to be solved is crucial and needs further attention. Some aspects of interactive methods can be assessed without involving humans, whereas others, such as usability, cognitive load can only be assessed with human subjects.

In this work, we present the journey starting from a systematic review to realistic means of assessing and comparing interactive methods. We first list the desirable properties of interactive methods which characterize their goodness. We then present some experimental setups and designs using both human DMs and so-called artificial DMs. Finally, we outline prospective research directions, such as quality indicators specifically designed for interactive methods.

■ MA-16
Monday, 8:30-10:00 - U264

Innovative Real Options Methodologies

Stream: Real Option Analysis
Invited session
Chair: *Yuri Lawryshyn*

1 - Electricity forward prices: Modelling and analysis with Nordic, Brazilian and German data
Stein-Erik Fleten, Marina Dietze, Leif Kristian Falch, Eivind Almeland Rolstad, Alexandre Street, Davi Valladão

We estimate electricity forward curves based on elementary forward prices. This novel semi-parametric structural model (i) explores the non-arbitrage relations between contracts with overlapping delivery periods, (ii) considers a parametric structure for price seasonality and exogenous variables, and (iii) uses non-parametric techniques to extract the remaining inter-temporal and cross-maturity information from data. We address the multi-objective estimation problem by hierarchical optimization. Based on historical data, we show that our model outperforms benchmarks in terms of estimation error for missing data. We also have access to time series of electricity spot price forecasts, allowing analyses of ex-ante risk premia and extrapolation of forward curves.

2 - Utilizing Boundary Fitting and Importance Sampling for Simulated Real Option Valuation
Yuri Lawryshyn

Real option analysis (ROA) is recognized as a superior method to quantify the value of real-world investment opportunities where managerial flexibility can influence their worth, as compared to standard discounted cash-flow methods typically used in industry. One stream of ROA research focuses on the development of models for practical / industry implementation. However, many of these approaches can only model relatively simple scenarios. Previously, we introduced a methodology based on exercise boundary fitting in an effort to develop a practical Monte Carlo simulation-based real options approach and showed that our methodology converges for simple options and can be expanded to model more complex real world scenarios. However, the methodology proved to have slow convergence. In this work we address the issue by incorporating importance sampling. Our new approach shows significantly better convergence and we apply the methodology to a build / abandon scenario.

3 - New variant of the possibilistic FPOM for real option valuation for practical purposes
Pasi Luukka, Jan Stoklasa, Mikael Collan

This research proposes additions to the possibilistic fuzzy pay-off method for real option valuation that allow the practical use of the method. The additions, pointed at practical consideration of the valued project downside-risk, are based on using a novel interpretation of the possibilistic mean as a proxy for the weight of the downside and respectively the upside of a possibility distribution in the context of project profitability.

The proposed new method-variant can be used in the comparison of projects with identical upside and non-identical downside and allow a more realistic consideration of the effect of changes in the real option value when the circumstances surrounding the downside risk of a project change. The proposed additions are the first variant of the possibilistic fuzzy pay-off method for real option valuation and considerably increase the usability of the method in practice.

■ MA-17
Monday, 8:30-10:00 - U356

Accounting 1

Stream: Operational research in financial and management accounting
Invited session
Chair: *Matthias Amen*

1 - A quantitative approach to define reporting segments
Matthias Amen

Segment reporting should give more detailed insights into diversified companies, but should also avoid information overload. Therefore, following the International Financial Reporting Standard (IFRS) 8, the operating segments of a company have to be aggregated to reporting segments. IFRS 8 gives a set of requirements for this aggregation.

For many companies it may be obvious how to form these reporting segments. But this may be a complex problem for companies with a large degree diversification. For those companies it is useful to model the special assignment problem and optimise it according to a given criterion.

This presentation shows how such an assignment problem can be solved with Operations Research methods. It will be demonstrated on a numerical problem instance.

2 - Verification of the recognition criteria for deferred tax assets on tax losses carried forward
Carolin Famulla

Regarding to the income taxes, nearly in all European countries there is the possibility to offset current tax losses with taxable income of prior or future periods. The time scale and the amount of offsettable losses is determined by each country itself. In some states, e. g. Germany and France, a tax loss carryback as well as a loss carryforward are possible, while in other states there exist only the possibility to offset current losses with future tax income. According to International Accounting Standard 12.34, a company has to recognize deferred tax assets on tax losses carried forward, if there will be a sufficient taxable income in future periods to offset the current tax losses, which are carried forward. In this context, I will present an approach to verify the recognition criteria for deferred tax assets on loss carryforwards. Therefore, it is necessary to specify a probability threshold. Taking the probability criteria, it can be decided, if the futural taxable income is sufficient to offset the loss carryforwards. Thereby, the tax planning calculation is used to forecast the taxable income of future periods. If, as a result, the recognition criteria is not fulfilled because of minor deviations from the probability threshold, possibly the forecasted taxable income can be increased through a plan revision and using tax planning opportunities.

3 - Dirichlet-multinomial bandits for systematically prioritizing risk management operations
Max Buckley

Our previous work introduced the framing of particular operations risk management workflows as Bayesian multi-armed bandit problems. We focused on risk management workflows in which an operations team is tasked with reviewing entities flagged by multiple lead sources — in order to remove entities violating company policy. The proposed approach viewed each lead source as an arm, and at review time chose between the entities presented based on a composite estimate of how likely that arm is to be actionable and the size (in dollars, clicks, etc.) of the entity. This 'prioritization based on optimistic impact' allows for a system that aligns the operations team's prioritization with the overall business KPIs, while also allowing for a balancing and control of the exploration/exploitation tradeoff.

This paper extends that work. By moving from a Beta-binomial to a Dirichlet-multinomial model we move from a simple binary classification (non violating, violating), to a one-of-n (non violating, violation type a, violation type b, etc.). This extension allows management to provide a vector of violation priority weights. These weights allow lead sources that flag high weight violations to be prioritized further. An example of this would be found in video reviews where violations like harsh language could be given a lower weight than adult content, which could in turn be given a lower weight than one that induces additional legal risk like a copyright violation.

4 - A multivariate Average-Value-at-Risk
Daniela Visetti, Andreas H. Hamel, Daniel Kostner

A definition of Value-at-Risk for multivariate random variables with respect to a general convex cone was introduced through a set-valued approach in a paper by Hamel and Kostner in 2018. Here the Average-Value-at-risk for multivariate random variables is defined. Its properties are studied and some examples are provided.

■ MA-18
Monday, 8:30-10:00 - U358

Stochastic Optimization in Energy

Stream: Stochastic and Robust Optimization
Invited session
Chair: *Alessio Trivella*

1 - Optimal Balancing of Wind Parks with Virtual Power Plants
Vadim Omelčenko, Valery Manokhin

In this paper, we explore the optimization of virtual power plants (VPP), consisting of a portfolio of biogas power plants and a battery whose goal is to balance a wind park while maximizing their revenues. We operate under price and wind production uncertainty and in order to handle it, methods of machine learning are employed. For price modeling, we take into account the latest trends in the field and the most up-to-date events affecting the day-ahead and intra-day prices. The performance of our price models is demonstrated by both statistical methods and improvements in the profits of the virtual power plant. Optimization methods will take price and imbalance forecasts as input and conduct parallelization, decomposition, and splitting methods in order to handle sufficiently large numbers of assets in a VPP. The main focus is on the speed of computing optimal solutions of large-scale mixed-integer linear programming problems, and the best speed-up is in two orders of magnitude enabled by our method which we called Gradual Increase. Apart from the paper, the extensions of Gradual Increase will be presented and the operations with other types of assets, e.g. hydro storage facilities.

2 - Value-oriented forecasting of net demand for electricity market clearing
Juan Miguel Morales, Miguel Angel Muñoz, Salvador Pineda Morente

We consider a day-ahead electricity market with uncertain supply (e.g., wind and solar power production), where power producers are dispatched following a merit order based on marginal production costs. Unlike the conventional practice of using the forecast value of the uncertain supply to clear the market, in this talk, we introduce a procedure to find the estimate of the uncertain supply (typically different from its conditional expected value) that leads to the most cost-efficient dispatch considering the subsequent real-time operation of the power system. This procedure utilizes the predicted value of the uncertain supply as explanatory variable and translates into a two-stage mixed-integer stochastic program. Numerical experiments on realistic case study based on the European power system show that our approach leads to substantial cost savings compared to the customary way of doing.

3 - Data Markets for Energy
Jalal Kazempour, Pierre Pinson, Liyang Han

Energy forecasting has attracted enormous attention over the last few decades, with novel proposals related to the use of heterogeneous data sources, probabilistic forecasting, online learning, etc. A key aspect that emerged is that learning and forecasting may highly benefit from distributed data, though not only in the geographical sense. That is, various agents collect and own data that may be useful to others. In contrast to recent proposals that look into distributed and privacy-preserving learning (incentive-free), we explore here a framework called regression markets. There, agents aiming to improve their forecasts post a regression task, for which other agents may contribute by sharing their data for their features and get monetarily rewarded for it. The market design is for regression models that are linear in their parameters, and possibly separable, with estimation performed based on either batch or online learning. Both in-sample and out-of-sample aspects are considered, with markets for fitting models in-sample, and then for improving genuine forecasts out-of-sample. Such regression markets rely on recent concepts within interpretability of machine learning approaches and cooperative game theory, with Shapley additive explanations. Besides introducing the market design and proving its desirable properties, application results are shown based on simulation studies (to highlight the salient features of the proposal) and with real-world case studies.

4 - Meeting Corporate Renewable Power Targets
Alessio Trivella, Danial Mohseni-Taheri, Selvaprabu Nadarajah

Several corporations have committed to procuring a percentage of their electricity demand from renewable sources by a future date. Long-term financial contracts with renewable generators based on a fixed strike price, known as virtual power purchase agreements (PPAs), are popular to meet such a target. We formulate the problem of meeting a renewable target using a portfolio of PPAs as a Markov decision process accounting for price and supply uncertainties. Since computing an optimal procurement policy is intractable, we consider forecast-based reoptimization heuristics that vary the sourcing of different PPA types and the timing of new agreements, and propose a novel information-relaxation based reoptimization heuristic. We perform a computational study involving realistic PPA instances and stochastic models of the uncertainty calibrated on data. Our findings support the effectiveness of PPAs for meeting a target, highlight the benefit of sourcing and timing flexibility in procurement decisions, and show that dynamic PPA portfolios from our information-relaxation based procurement heuristic are near optimal. Our insights may thus help companies tying the knot between climate goals and financial performance.

■ MA-19

Monday, 8:30-10:00 - Y228a

OR in Sports 2

Stream: OR in Sports
Invited session
Chair: Dries Goossens

1 - A network flow model to reduce peak-hours congestion in fitness centers with an account for users' preferences
Franklin Djeumou Fomeni, Matthieu Gruson, Janosch Ortmann

It is well known worldwide that physical activity is a good medium to keep a healthy body. People around the world are becoming more and more health conscious and are engaging in physical activities. Over the past few decades, there has been a noticeable boom in the number of fitness centers around the world as well as the number of fitness centers users. In addition to contributing to the health of the population, fitness centers contribute significantly to the economy. They make profit by recruiting new members or by making sure that existing members do renew their memberships. During peak hours at fitness centers, the number of people present in the facility is usually larger than the number of equipment available in the facility. Therefore, some customers have to idle while waiting for equipment to be free, or sometimes have to exercise with equipment that they did not plan to use, thus deviating from their workout plans. As a result, fitness companies lose a significant number of customers or fail to attract potential customers. In this talk, we will present a network flow optimization model that can be used to reduce peak-hours congestion in fitness centers, as well as to improve the experience of the customers in fitness centers. The model maximizes the utilization of the facility equipment, while ensuring that each customer can perform their workout plan with a minimal idling time.

2 - Analysing the schedule of the Finnish Hockey League
Jari Kyngäs, Kimmo Nurmi, Nico Kyngäs

The schedule of the Finnish Hockey League has been under discussion in the recent years. Experts and viewers have been considering when to play and against whom to play to get as much spectators as possible.

We used data from season 2014-2015 to season 2019-2020. The last round from season 2019-2020 was extracted from the data because covid-19 regulations forbade spectators. We also excluded all the special games, such as those played outdoors, because they all had much more spectators than the venues would hold and therefore these games would skew the analysis.

We analyzed the number of spectators per month and per weekday for each team separately. Usually, this kind of information is published for the entire league, but we believe it should be considered for each team separately. It turns out that there are quite clear differences between the teams. It is believed that Saturday is the most profitable game day, but it seems that this is not the case for every team.

We also analyzed each game, opponent by opponent, to find out which games were the most attractive, i.e., had the most spectators and possibly the highest revenue. For this, we had to consider the weekdays the games were played because there are usually more spectators on weekends than on working days (excluding Friday).

Finally, we also were able to extract the most attractive games, i.e., games that should be played in the weekends.

3 - Automatic Generation of Amateur Tennis Tournament
Arnaud Malapert

A knockout tournament is a type of tournament where, in each round, the losers are eliminated while the winners advance to the next round. Its design has been studied for balanced tournaments where players have played the same number of matches, plus or minus one, at any round, because they are frequent in professional sports. Another knockout tournament setting is very popular where players start at different rounds depending on their ranks. This is more relevant when there are many players with very different strengths, such as in amateur tournaments. In this work, we define a new data structure, the matches graph, that represents knockout tournaments and an integer program for designing it with great flexibility and expressiveness. This general approach is applied to the French Amateur Tennis Tournament Problem that is based on the national sports regulations. The experimental results show its efficiency, scalability, and flexibility. Real-life instances are solved within a few seconds and a use case highlights its practical interest.

■ MA-20

Monday, 8:30-10:00 - Y228b

OR Education

Stream: OR Education
Invited session
Chair: Marina Segura

1 - Applying DEMATEL to Explore the Dominant Relation among Sustainable Assessment Indicators in Taiwan Higher Education
Rouwen Wang, Ya-Ting Chuang, Hualing Chiang

Higher education institutions play essential roles in achieving sustainable development (SD). Although sustainability assessment indicators (SAIs) of higher education have been flourishingly developed, it is still a question to resolve inefficient implementation of SD depending on SAIs. The aim of this study is to map the interrelationship network of SAIs by using the Decision Making and Trial Evaluation Laboratory (DEMATEL) approach. It identifies the critical 16 factors of SAIs and distinguishes the most influential factor based on relation and prominence with 17 experts' ratings. Results show that "infrastructure buildings design" and "governance plan" of higher education are dominant factors to affect other SAIs factors which entail "energy use", "air purification", "water recycling", "waste disposal", and "ground management" etc. This study provides the priority of SAIs factors of the higher education institutions to achieve sustainability goals.

2 - Mathematical Programming with Julia - New open-source book
Thomas Stidsen, Richard Lusby

Mathematical Programming i.e. Linear Programming (LP) and Mixed Integer Programming (MIP) have been very succesfull tools for mathematical planning and have been applied in many different application areas. Here we will briefly introduce a book, which we have written based on 18 years of teaching mathematical programming modelling.

For decades specialized modelling languages like GAMS, AIMS, OplStudio etc. have been applied to make model building easier. Over the last decade standard programming languages have gotten better and better mathematical programming modelling support. Our book is based on the Julia programming language, utilizing the JuMP modelling package. Julia and JuMP is open-source software and supports open-source solvers like Clp, Cbc, HiGHS and GLPK and naturally commercial solvers like Gurobi, Cplex and FICO Xpress. Our book will not only be open-source but it will also contain working code examples for all exercises. We target entry level OR teaching for students with basic programming experience and a basic understanding of OR concepts. Our main motivation is to make OR solution methods more accessible in general.

3 - The use of 3D printing technology in mathematical educational procedures
Evgenia Fronimaki, Athanasia Kadrefi, Maria Koltsaki, Maria Mavri

The only essentials in 3D printing technology are the sketch of an object, a 3D printer and a filament to print. This kind of technology will re-write a huge part of people's daily routine even though their ability in learning. In order to understand this, imagine how easy is to design a model based on your interests and print it whenever you want only by having a 3D printer. Education has also been influenced by this innovative technology; it has impacted educational activities and pedagogical theories and approaches. The whole procedure that begins from teachers and leads to the students' ability around a topic will change. Starting from elementary schools, this technology can be the factor that gives students the ability to understand better science and mathematics. 3D printing technology will increase students' imagination and empower their skills of problem solving and creativity as long as increase their ability of thinking-designing-producing. The goal of this study is to examine how 3D printing technology influences the existing education procedures and make them more attractive for students. We explore the role of 3D printing technology in mathematical education and more specifically how students could benefit from this innovative technology to overpass mathematical difficulties, we identify the gap between the goals of educational system and the learning outcomes and we propose an educational scenario of teaching maths with the use of 3D printing technology.

4 - Gamification as a motivational tool to improve the performance and skills acquisition of social science students in quantitative subjects
Marina Segura, Jesús Barreal

Gamification has become an increasingly used tool in the field of university teaching. Its use has demonstrated its usefulness in motivational aspects and improving academic performance. In this regard, student motivation is one of the most difficult challenges university professors due to its relationship with the acquisition of knowledge and relevant skills to the degree they are studying and ultimately with the performance of some subjects. The negative predisposition towards quantitative subjects, such as operational research and statistics, of students in social sciences has been highlighted, and it is a challenge for the professor to change these attitudes. The objective of this work associated with a teaching innovation project is to improve the motivation and attitude of social science students towards quantitative subjects, as well as their active participation in the teaching-learning process, individually and in groups, with the ultimate aim of increasing their skills and performance.

■ MA-21
Monday, 8:30-10:00 - Y229a

AHP/ANP 1

Stream: AHP/ANP
Invited session
Chair: *Fang-Jie Shiu*

1 - A Decision Support Model for Sustainable Agriculture Supply Chain: an ISM and AHP Approach
Sandeep Singh

Agriculture employs a significant portion of the population worldwide. The growing concern of social and environmental sustainability has raised the debate on food production, distribution, technological modification, agriculture waste, changes in supply chain structure and many more. Therefore, this paper tries to develop a sustainability framework for assessing sustainability practices from primary growers' perspectives. This study attempts to bridge this gap in the sustainable agriculture supply chain literature by identifying each dimension of sustainability's enablers and providing a decision assessment model. We have adopted the multi-criteria decision-making approach in this paper. We have used interpretive structural modelling (ISM) to develop the precedence digraph of the variables which lead to all the three dimensions of sustainability. Analytic Hierarchy Process (AHP) is used to develop a three-level Hierarchy of goal, criteria, and sub-criteria and find the relative influence of each sub-criteria on the goal. This study contributes to the literature on sustainability by calculating the weights of the relationships between the sustainability dimensions and their enablers. The paper also provides a decision support framework for assessing sustainability practices.

2 - Exploring the Decisive Factors of Port Logistics Service Quality - Using Fuzzy Delphi, ISM with Fuzzy MICMAC and ANP
Jing Li, Chi-Hui Wu, Chien-Ke Huang, Tzu-Yuan Hsu

Port Logistics Service Quality is the key factor to affect the competitiveness of every country's trades. Port Logistics Service Quality includes multiple characteristics and complexly intertwined relations. It is the port authorities' important issue on how to gather up resources and develop effective logistic service qualities precisely under limited resources. Therefore, this research applies ISM with Fuzzy MICMAC and ANP to analyze decisive factors and weight relations which affect the port logistics service quality in order to gather up resources and develop effective logistics service qualities precisely for port logistics dealers and to provide port authorities with the administration references. This research retrospects to the past literatures and invites a few experts and scholars to assess the relevant relations that affect logistics service qualities and to analyze the relation between cause and effect on the dimensions and criteria with ISM and Fuzzy MICMAC so as to ensure decisive factors that affect the port logistics service quality. Finally, use ANP to evaluate the weight relations that affect the port logistics service quality in order to find out the weight relations of the dimensions and criteria.

3 - Exploring the Decisive Factors of Influencing Learners' Learning Behaviors and Outcomes in University Music Education Applying Information Technology
Fang-Jie Shiu, Jing Li, Chi-Hui Wu

This article applies the Fuzzy Delphi, the Fuzzy DEMATEL and the ANP to analyze and explore the decisive factors and weight relation of learners' learning behaviors and outcomes which affected by applying IT to assist music course teaching. The learners' learning behaviors and learning outcomes contain multiple characteristics and have complex and entangled tendencies. This study aims to clarify the causal relationship between learners' learning characteristics and learning's important key factors which under the application of IT-assisted music teaching, to provide introduction or improvement of teaching strategies and curriculum design for the integrating IT into music teaching to educational institutions and schools, meanwhile, to trigger learners' learning behaviors and improve learners' learning outcomes. The research results show that, in terms of dimensions, the IT-assisted music teaching is a decisive dimension that affects learners' learning behaviors and learning outcomes, and it affects the other six dimensions; Among the criteria, music performance, instrument teaching, and music research courses of IT-assisted music teaching are the decisive criteria that affect learners' learning behaviors and learning outcomes. Therefore, before designing music courses and teaching materials that incorporate information technology, the learners' learning background, experience, and abilities.

■ MA-22

Monday, 8:30-10:00 - Y229c

Circular and Bio-Based Economy

Stream: Sustainable Supply Chains
Invited session
Chair: *Régis Chenavaz*

1 - Measuring the Circular Economy: an application to European Union countries
María Borrego-Marín, Laura Riesgo

The circular economy is a model of production, distribution and consumption in which the value of products, materials and other resources remains for as long as possible (e.g., recycling, repairing, etc.), in order to increase the sustainable and efficient use of such resources and minimize waste generation. Measuring the circularity is of great relevance in the transition from a linear to a circular economy. This work aims at analysing a novel available indicator for measuring the circularity focused not just on environmental but on economics, social and governance criteria to assess its applicability in European Union countries using data from Eurostat. The methodology applied is based on a multicriteria decision method called unweighted TOPSIS (UWTOPSIS). This approach handles criteria weights as decision variables in a set of optimization problems where the objective is to maximize the relative proximity of each alternative to the ideal solution. The result is a new relative proximity index which is a function depending on the values of the weights. This index will allow the valuation of circularity of countries which may play a significant role in helping European Union toward a more resilience and sustainable future.

2 - An optimization model to support the supply network design for a packaging extended producer responsibility system
Pablo Andrés Maya Duque, Jesus David Galarcio Noguera, Gloria Ramirez

The linear paradigm of production and consumption which is based on the idea of "taking, using and disposing", is being challenged by the circular economy. This upcoming paradigm aims at retaining as long as possible within the system, the use and value of resources, materials and products. The adoption of the different strategies of the circular economy imposes new challenges for the supply chain and operation management. We describe an optimization model to support the design of supply networks for the operation of an extended producer responsibility (EPR) system within the packaging sector. The EPR translates to the producer the responsibility of managing the end of life of the products (in this case packaging of the products) that they put into the market. To do so, producers usually gather together into an external organization that deploys a supply network to fulfil the requirements of the EPR. The proposed model considers the location decisions related to the definition of the required supply network, takes into account the possible flows of material, and the needed strategies, such as paying deposits and refunding them, to make the system sustainable. A case study inspired on the data for a region in Colombia is used to validate the model.

3 - Sustainable seaweed supply chains: establishing farms and enterprises towards responsible sourcing
Mariana Cerca, Amanda Sosa, Fionnuala Murphy

Seaweed supply chains have wide applications related to food and food-related industries, pharmaceutics, cosmetics, as well as prospects in the production of bioplastic, biofuels and other novel products. Based on its potential of meeting sustainability goals, innovative business models and supply chains based on the sourcing of seaweed as raw biomass material have been increasing. However, the supply of marine macroalgae in the European context is mostly relies on the sourcing of wild stocks, which is perceived as unsustainable considering further expansions of the sector and the need for establishing cultivation. In alignment with sustainability strategies for the development of responsible supply chains, we applied a modified business model canvas to qualitatively analyse emerging seaweed farms in Ireland. The findings indicate that businesses components are closely aligned to environmental and social value propositions, although in economic terms it is still volatile and connected to public funding and support schemes, business diversification, farming-scale, market opportunities and vertical integrations of the supply chain. This study contributes to a better understanding of seaweed supply from farming systems in the European context, adding to the blue circular bioeconomy debate and towards further advancements of socially responsible sourcing and sustainable bio-based supply chains.

4 - Does the Circular Economy Fuel the Throaway Society? The Role of Opportunity Cost
Régis Chenavaz

The efficient use of natural resources is considered a necessary condition for their sustainable use. Extending the lifetime of products and using resources circularly are two popular strategies to increase the efficiency of resource use. Both strategies are usually assumed to contribute to the eco-efficiency of resource use independently. We argue that a move to a circular economy creates opportunity costs for consumers holding on to their products, due to the resource embedded in the product. Using an analytical model, we show that in a perfectly circular economy, consumers are incentivized to discard their products more quickly than in a perfectly linear economy. A direct consequence of our finding is that extending product use is in direct conflict with closing resource loops in the circular economy. We identify the salvage value of discarded products and technical progress as two factors that determine the impact that closing resource loops has on the duration of product use. The article highlights the risk that closing resource loops and moving to a more circular economy incentivizes more unsustainable behavior.

■ MA-23

Monday, 8:30-10:00 - Y307

OR in Agriculture

Stream: Specific Applications of OR in Agriculture, Forestry and Fisheries
Invited session
Chair: *Victor M. Albornoz*
Chair: *Alejandro Mac Cawley*

1 - Applications of Deep Learning and OR in pig production
Lluís Miquel Plà-Aragonès, Yun Bao

During last years the applications of Artificial Intelligence has beed spreading over a number of fields. Deep Learning in particular has proven useful as a non invasive method for controlling different aspects in a farm by image analysis. In this presentation we review different Deep Learning applications and the opportunity of OR to interact dealing with different farming problems.

2 - Multi-Stage Stochastic Optimization for a Biorefinery Supply Chain in Spain
Adrian Serrano, Luis Cadarso, Aitor Ballano Biurrun, Bartosz Sawik, Javier Faulin

Nowadays, biofuels are evolving as renewable and sustainable energy sources, especially on developed countries, due to the neutral CO2 emissions within their complete cycle. Regarding this topic, a biorefinery is considered to be set in Northern Spain. The problem considers uncertainty in biomass prices and availability, therefore, a stochastic optimization approach is needed to reduce the risks of the project. The optimization is represented as a three-stage scenario tree, composed of strategic and tactical nodes. The former refers to location of the biorefinery, while the latter refers to the rent of different warehouses.

Additionally, operational nodes are rooted to the strategic and tactical nodes forming two-stage operational scenario trees. In these operational nodes, decisions related to the biomass acquisition are made. Meaningful insights are obtained from the application of stochastic optimization at all levels: strategic (the facility location problem), tactical (warehouses strategy) and operational (biomass purchases), highlighting a superior performance than the deterministic equivalent model.

3 - An integrated approach for the zoning and crop rotation planning problem with adjacency constraints
Victor M. Albornoz, Gabriel Zamora

This contribution tackles management zone delineation and crop rotation planning problems in an integrated precision agriculture framework in a context of organic agriculture. The zoning problem defines homogeneous management zones regarding their soil properties, and for which specific rates of agricultural inputs are necessary. From a sustainable point of view, the crop rotation planning problem considers cropping of species from different botanic families in adjacent zones at the same time. With this in mind, we present a linear binary integer program for an integrated zoning and crop planning problem with adjacency constraints. In this model, we maximize the incomes of the crop plan for a given planning horizon subject to zoning and adjacency constraints on crop families. The proposed model is efficiently solved using an optimization algorithmic strategy based on a decomposition method and computational results from a set of instances are presented to show the impact of the adopted methodology.

4 - Optimization of an agricultural supply chain to increase farmer food security and promote rural development
Jorge Vera, María Margarita López, Lluís Miquel Plà-Aragonès, Jorge Recalde

Many rural areas in the world are occupied by peasants with low incomes, deficient access to technology, and other limitations, which translates into poverty and, overall, lack of food security. This situation is a severe problem in developing countries where small farmers allocate most of their crops for self-consumption, embarking in a condition where poverty increases, and nutrition requirements are not fulfilled. However, several government programs in some countries are trying to push incentives for better decisions on crop rotation and exchange of crops between farmers, as well as better access to markets. Still, these actions require coordination and planning as decision-making in a system like this is complex. In this paper, we propose the use of a mathematical optimization model to help decision-making in this environment. Our model considers decisions on crops, product allocation to markets or self-consumption, and contemplates economic objectives, as well as nutritional ones. We test our model in a case developed for the Department of Caazapá, in Paraguay, where 80% of the population is rural, and 42% is poor. We considered instances with different requirements and organizations, showing results for various scenarios. The results allow to analyze the effects of cooperative structures and crops on revenue and food security. We expect the model to be helpful in the design of public policies to support rural farmers and increase food security.

■ MA-24

Monday, 8:30-10:00 - Y307a

Queueing

Stream: Queueing and Stochastics (contributed)
Contributed session
Chair: George Mytalas

1 - Stochastic analysis of multi-server queue with working vacation and imperfect service
Anshul Kumar, Madhu Jain

A multi-server Markovian queueing system with bi-level service, imperfect service during working vacations, and a second optional service is investigated in this study. This research dealt with a general cost optimization queueing model for retail stores that operate in a hybrid mode with numerous semi-attended checkout counters. Various performance indicators, including queue length distributions are calculated using the matrix geometric technique. By framing the expected cost function, the particle swarm optimization technique was employed to investigate cost minimization. The sensitivity analysis was carried out to validate the model using appropriate examples. The suggested analytical methodology enables a proper balance between operating expenses and service quality to be achieved by the optimal design of system descriptors.

2 - Firefly Algorithm for Cost Optimization of FM/FM/1/WV Retrial Queue with Catastrophes
Sibasish Dhibar, Madhu Jain

This investigation deals with the performance analysis and cost optimization of Markovian retrial queueing model in generic set up by incorporating the working vacation and customers' discouragement behaviour. The server rendering service to the customers in subject to breakdown and can be recovered after getting repair. The governing system of difference equations has been framed to derive the queue length distributions and performance indices at steady state.. The fuzzified parameters are used to develop the fuzzy FM/FM/1/WV model. To determine the optimal design parameters, the cost minimization problem has been solved using the firefly algorithm and quasi-Newton's method. The suitable illustration is taken to facilitate the numerical results of performance indices and optimal service rates.

3 - Markov decision processes and partial conservation laws
José Niño-Mora

Conservation laws are fundamental invariance relations holding in a variety of stochastic scheduling systems, which allow to characterize their performance region and explain the optimality of index policies. In a 2001 paper, the author introduced the framework of partial conservation laws for such purposes in binary-action Markov decision processes. This talk will present an extension of such an approach to general, multiple-action Markov decision processes, introducing a partial conservation laws framework in such a general setting and deriving from it strong structural and algorithmic properties, including optimality of index policies and an adaptive-greedy index algorithm. Applications and examples will also be presented.

4 - Design of control charts for queueing systems with server breakdown
George Mytalas

We develop control charts for monitoring the service times and system size in queuing systems suffering from server interruptions. Such systems very often model real-life situations so controlling the parameters in the system is an important characteristic. In this study, we develop control charts for monitoring the expected system size or the total waiting service time in a Markovian queueing system with server interruptions-breakdowns. Target is to maintain the stability, by noticing changes and action re-designing the system parameters. A method of system parameters estimation associated with approach for control limit calculations are provided. Statistical constraints are also considered to enhance the statistical properties of the control chart.

■ MA-25

Monday, 8:30-10:00 - Y308

Location Analysis I

Stream: Location Analysis
Invited session
Chair: Jose Fernandez

1 - Competitive location: a new continuous model with attractiveness adjustment and/or closing of the existing chain-owned facilities
Jose Fernandez, Boglárka G.-Tóth, Laura Anton-Sanchez

When a chain has some budget to expand its presence in a given geographical region, it may (1) open new facilities (2) modify the quality of its existing facilities, up or down, or (3) closing some of its existing facilities in order to allocate the budget devoted to them to other chain-owned facilities (or to the new one, in case it is open). In this paper, a continuous location model is proposed which encompasses all those possibilities. The demand is assumed to be fixed, the attraction function of the customers towards the facilities is given as quality divided by a function of the distance, and the patronizing behavior of the customers is probabilistic. The qualities of the new and the existing facilities are assumed to be continuous variables. The resulting model is a MINLP problem. Most existing solvers for MINLP problems fail at solving even small instances of the model. Only BARON seems to be able to handle it, although it is time-consuming. That is why we propose an exact branch-and-bound algorithm which makes use of interval analysis tools. The new algorithm, which is an adaptation of classical interval branch-and-bound methods for continuous problems to MINLP problems is able solve small to medium instances in a short time.

2 - A Discrete Competitive Facility Location Model with Sequential Customer Choice Rules
Pascual Fernandez, Algirdas Lančinskas, Blas Pelegrin, Julius Žilinskas

An entering firm wants to compete for market share in a geographic area by opening some facilities selected from a finite set of potential locations. Customers are concentrated in a few demand points, their demand is fixed and known, and the products are essential. When it comes to purchasing essential items (food, drinks, sanitary products, cleaning items, etc.), customers usually buy them in different establishments in the same area, and their purchasing power is distributed among all of them in proportion to their attraction. But if there are no attractive enough establishments in your area of influence, they usually opt for a single establishment where purchase all the products and that offers a large number of services that make it more attractive to the customer. In this paper we are going to consider two customer choice rules, but sequentially, that is, first we will apply the proportional rule to all customers for which there are establishments with a minimum attraction threshold set for each one of them, and then, and only for customers to whom the proportional rule cannot be applied, we will apply the binary rule to identify the facility or facilities that will meet their demand. The first formulation is presented as a nonlinear binary programming problem, then it is linearized, and a heuristic procedure is applied to approximate the optimal solution using real geographic coordinates and population data of the municipalities of Spain.

3 - Multiple Obnoxious Facility Location - the Case of Protected Areas
Malgorzata Miklas-Kalczynska, Pawel Kalczynski

Most existing obnoxious facility location models use points to represent locations of demand centers and facilities. These points are typically centroids of polygons that constitute boundaries of geographical areas, such as cities or protected wildlife areas. Representing areas with points is convenient for the development and analysis of location models, but it may hinder the models' practical applications. Many protected areas, such as national parks, stretch across hundreds of miles and tend to have irregular shapes. Therefore, in the context of obnoxious facility location, a centroid-based representation is not ideal. It may lead to locating an obnoxious facility far from the centroid but near the actual boundary or even inside a protected region. We address this issue by enhancing the existing continuous location models. We represent protected areas as polygons rather than centroids while keeping the models compatible with commercial solvers. This approach ensures the location of obnoxious facilities around protected areas and not on or inside their boundaries. We also show how to leverage the existing point-based continuous models. Our approach can be applied to a wide range of obnoxious facility location problems. The effectiveness of the proposed technique is demonstrated with a case study involving state and national parks in the State of Colorado.

4 - Optimising Locations on a Network
Mindaugas Kepalas, Julius Žilinskas

The general problem of locations on a network is presented: suppose we want to place K facilities, which are restricted to be on a (road) network. This placement induces a load (cost) on each facility: e.g., we have a vector-valued cost function. We make some assumptions about this vector-function: it is not required to have an analytical form, but is assumed to be continuous and differentiable. The goal is to minimise the total cost of the placement. We present our ideas for finding a "good" solution of the formulated problem: the purpose of the research is to develop efficient methods, which aim to find globally-minimal cost. Our formulated problem is also a generalisation of a problem from building engineering: in this problem, building foundation contour (aka "network") is supported by K poles (aka "facilities"). The goal here is to place the poles in such a way, so that the weights, induced on them by the building, are as equal as possible.

■ MA-26

Monday, 8:30-10:00 - Y309b

Optimization modelling in humanitarian logistics

Stream: EWG HOpe, EURO working group on Humanitarian Operations
Invited session
Chair: *Christophe Duhamel*
Chair: *Andréa Cynthia Santos*

1 - Integrated Reinforcement and Repair of Interdependent Infrastructure Networks Under Disaster-Related Uncertainties
Tugce Canbilen, Sakine Batun, Melih Celik

Natural or human-inflicted disasters may cause large-scale disruptions in the services of infrastructure networks including power, water, and telecommunication. Restoring the services of these infrastructures is vital in the aftermath of the disaster, so that search-and-rescue activities, relief transportation, and restoration efforts can be efficiently facilitated. On the other hand, operations of these infrastructures may depend on receiving services from one another, resulting in an interdependent network structure. Thus, addressing the decisions of network reinforcement before the disaster and the repairs in its aftermath need to consider this interdependent structure, as well as the uncertainties arising from the timing, location, and magnitude of the disaster. This study introduces the Stochastic Infrastructure Reinforcement and Repair Problem, which considers the pre-disaster reinforcement of interdependent network components and post-disaster repair scheduling in an integrated manner. In making these decisions, the uncertainty on which network components will be disrupted is incorporated into the problem definition. The problem is modelled using scenario-based two-stage stochastic programming. A heuristic based on a genetic algorithm and partial optimization is proposed to solve the problem. Computational experiments show that the heuristic is able to find near-optimal solutions within reasonable times, and they are also utilized to help derive managerial insights.

2 - Searching victims in post-disaster areas: A decentralized approach for the Drone Swarms Routing Problem
Matheus Nohra Haddad, Andréa Cynthia Santos, Christophe Duhamel, Damien Olivier

Recently the world has witnessed several disasters involving many victims, such as the explosion in the port of Beirut. Considering post-disaster management, the search for victims is one of the most important tasks and it must be carried out as efficiently as possible. In this context, the use of drones stands out, as they can easily access hard-to-reach places and still act cooperatively, making the search for victims safe and efficient. This work introduces a decentralized approach for the Drone Swarms Routing Problem (DSRP), in which drones operate in collaboration to search for victims in post-disaster areas with the objective of maximizing the number of identified victims. In the DSRP, the range of each drone is only given by its battery capacity. Furthermore, drones can fly in V-shaped formation with leader replacements, which reduces their energy consumption and consequently increases flight time. Every search area is represented by a vertex of a grid graph constructed over the affected area. Each vertex has an estimated number of victims and a related identification probability function. The DSRP is NP-hard, thus a dynamic heuristic algorithm is proposed to solve it. Each drone is modeled as an agent able to compute its route based on real-time information and also to decide when it is convenient (or not) to work cooperatively in a drone swarm. Experiments demonstrate the great performance of the method on several instances, including the ones based on Beirut.

3 - The probabilistic drone routing problem applied to large-scale disasters
Amadeu Almeida Coco, Andréa Cynthia Santos, Christophe Duhamel

In the last years, several major industrial disasters happened around the world. One example is the collapse of a mining dam in Brazil in 2019, where a tide of mud containing water and toxic mining residues rushed down a valley, killing about 270 people. Rescue operations pinpointed the complexity to locate the victims, as the accident prevented access by land vehicles to the impacted area. As such, using a homogeneous fleet of drones equipped with thermal and optical sensors mitigates these issues and allows covering a large area as quickly as possible, with priority regions. We define a centralized approach, named the Probabilistic Drone Routing Problem (PDRP), which aims to scan a post-disaster area, searching for targets. The area map is divided into cells and transformed into a complete graph. Each node corresponds to a cell and a total number of persons yet unidentified before a visit. It also has a probability of an individual identification, estimated with a probabilistic function. Constant travel speed is assumed on each arc. Due to its range, each drone has to return to its base to perform recharging. To avoid collisions, a node can only be scanned by one drone at a time. PDRP consists in defining a sequence of routes for each drone, starting and ending at its base, in order to maximize target identification. Nodes can be scanned several times according to their interest. Several variations of an ALNS are proposed and compared on realistic instances.

■ MA-27

Monday, 8:30-10:00 - Y313

Advances in Splitting and Preconditioning Methods

Stream: Splitting and ADMM Methods
Invited session
Chair: *Cong Bang Vu*

1 - Convex Minimization and Monotone Inclusions with Nonlinear Compositions
Luis Briceño-Arias, Patrick Combettes

We first investigate the duality properties of a minimization problem involving the sum of a nonlinearly composed convex function, a linearly composed inf-convolved convex function, and a convex function. A Kuhn–Tucker operator is constructed for this problem as an extension of that arising in classical Fenchel–Rockafellar duality theory. We show that the composite problem and its dual can be solved by finding a zero of this Kuhn–Tucker operator. On the basis of these results, we then study more general inclusion problems mixing subdifferentials of nonlinear composite functions with various monotonicity-preserving combinations of monotone operators. The proximal algorithms we propose to perform this task fully split all the constituents of the problem.

2 - A nonlinearly preconditioned forward-backward splitting method and applications
Cong Bang Vu, Dimitri Papadimitriou

In this paper, we prove the weak convergence of the iterates generated by the nonlinearly preconditioned forward-backward splitting method for the sum of a maximally hypermonotone operator A and a hypercocoercive operator B under several suitable conditions. We provide several choices of the non-linear preconditioners for solving nonlinearly composed inclusions. In particular, the backward-forward splitting method is recovered by the nonlinearly preconditioned forward-backward splitting method with a special choice of the non-linear preconditioner.

3 - A Nonlinearly preconditioned forward-Douglas-Rachford splitting method and applications
Dimitri Papadimitriou, Cong Bang Vu

Preconditioning provides a prevailing tool to unify the convergence analysis of existing splitting methods. It also aims at improving their convergence profiles and the computing of resolvents. Hence, splitting algorithms involving an adequate preconditioning operator W provide a suitable technique making them more practical. We develop a nonlinearly preconditioned forward-Douglas-Rachford (DR) splitting method for finding the zero points of the sum of three operators (2 hypermonotone and 1 hypercocoercive with respect to W). Several important particular cases are recovered including a nonlinearly preconditioned DR and forward backward splitting method. The weak convergence of the iteration is proved. Several applications are discussed such as image denoising and image restoration.

4 - A preconditioned interior point methods approach for linear programming problems with dense columns
Catalina Jaramillo Villalba, Aurelio Oliveira

Interior point methods applied to linear programming problems give raise to linear systems to be solved at each iteration. This work proposes a preconditioner for the linear systems arising from interior point methods where the constraint matrix has dense columns. When not considering dense and sparse columns separately may deliver linear systems with almost full matrices, which implies a large amount of floating point operations to be performed or even memory difficulties to deal with large-scale problems. The aim of using the preconditioner is to improve the numerical stability of problems to be solved by the conjugate gradient method and to reduce the number of operations performed in each interior point method iteration. Numerical experiments with problems containing dense columns are presented showing the advantages of the proposed approach.

■ MA-28

Monday, 8:30-10:00 - Y405

Data Science and Analytics Methods 1

Stream: Data science and Analytics (contributed)
Contributed session
Chair: *Gerrit Liedtke*

1 - A New Mixed Integer Programming Approach for Inverse Correspondence Analysis
Rick Willemsen, Wilco van den Heuvel, Michel van de Velden

Correspondence analysis (CA) is a dimension reduction technique for categorical data in a two-way contingency matrix. The aim is to optimally depict the relationship between categories for both variables in a low-dimensional representation. We investigate inverse correspondence analysis (ICA), which uses the low-dimensional CA solution to retrieve the original data matrix. We propose a new mixed-integer programming formulation for the ICA problem based on so-called transition formulae, which link the row and column coordinates in a CA solution. We show that this new formulation has better theoretical characteristics than the existing formulation in the ICA literature. In addition, we introduce a novel iterative method, which uses a measure of how well a point is represented in the low-dimensional space. This iterative method is compatible with both the existing and our newly proposed formulation. By incorporating known CA results into our methodology, we are able to solve larger ICA instances. In our computational experiments we always retrieve a unique data matrix, corresponding to the original data. Since the original data set may contain sensitive information, researchers should be careful with disclosing published CA results.

2 - Playing with Thresholds on the Forward Linear Threshold Rank
Maria J. Blesa, Maria Serna

Social networks have become the natural media for the spreading of information and influence. Several theoretical models capturing that diffusion process have been proposed, being the most popular the Independent Cascade (IC) model and the Linear Threshold (LT) model. The IC model is probabilistic while the LT model relies on the susceptibility of an actor to be convinced, the so-called influence threshold.

Although the LT model contemplate individual thresholds, the studies so far have always considered an homogeneous threshold of 0.5 for every actor to be influenced (i.e., a simple majority). We start the study on how the dissemination of information on networks behaves when we consider other options for setting those thresholds and how many network actors end up being influenced by this dissemination.

We consider a recently introduced centrality measure based on the LT model: the Forward Linear Threshold Rank (FLTR). We experimentally analyze the behaviour of the FLTR for several common networks under three different types of influence thresholds: uniform, random, and determined by the value of another centrality measure on the actor. Under this latter scheme, the PageRank and the FLTR are the ranks providing better thresholds' assignments. Our results show that the setting of the thresholds have a clear impact on the ranking of the nodes, even quite significant and abrupt in some cases.

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3 - Analyzing count data using a time series model with an exponentially decaying covariance structure
Soudeep Deb

Count data appears in various disciplines. In this work, a new method to analyze time series count data has been proposed. The method assumes exponentially decaying covariance structure, a special class of the Matern covariance function, for the latent variable in a Poisson regression model. It is implemented in a Bayesian framework, with the help of Gibbs sampling and ARMS sampling techniques. The proposed approach provides reliable estimates for the covariate effects and estimates the extent of variability explained by the temporally dependent process and the white noise process. The method is flexible, allows irregular spaced data, and can be extended naturally to bigger datasets. The Bayesian implementation helps us to compute the posterior predictive distribution and hence is more appropriate and attractive for count data forecasting problems. Two real life applications of different flavors are included in the paper. First one is related to road accidents in Great Britain, while the second one is related to modeling bike rental dataset from Washington DC. These two examples and a short simulation study establish that the proposed approach has good inferential and predictive abilities and performs better than the other competing models.

4 - Recurrent Double-Conditional Factor Model
Gerrit Liedtke

We propose a new type of dynamic factor model in which both latent dynamic factors and the factor loadings are estimated using observable instruments. Specifically, the latent factors, which follow a full vector autoregressive process, may depend on macroeconomic conditions and the factor loadings may depend on microeconomic conditions. We call our model the recurrent double-conditional factor model (RDCFM). Due to the conditioning of both factors and factor loadings, we achieve a factor model with low parametrization, resulting in improved generalizability (i.e., out-of-sample performance). Accordingly, the low parametrization allows estimating the RDCFM even if the time series and the cross-section are large. We apply our model to a financial research challenge, namely asset pricing, and find by applying the Clark-West test that all features of our RDCFM (i.e., conditional factors, conditional factor loadings, dynamic factor process) contribute to overall model performance, resulting in outperformance against several benchmark factor models (i.e., empirical factor models, principal component analysis (PCA), and instrumented principal component analysis (IPCA)). Additionally, we show how permutation importance and impulse-response analysis can be used to identify what determines the relevance of a certain feature.

■ MA-30
Monday, 8:30-10:00 - M237

Novel Approaches in Project Scheduling

Stream: Project Management and Scheduling
Invited session
Chair: Norbert Trautmann

1 - An integrated project and personnel scheduling problem with resource transportation and preemption
Brede Sørøy, Benjamin Buan, Anders N. Gullhav

We look at an integrated project and personnel scheduling problem. This problem consists of scheduling the order of activities in one or several projects, as well as allocating personnel and equipment to satisfy the activities' demands. The activities are preemptive and multimodal. This means that activities can be interrupted after they have started and resumed later when appropriate, and that there are various ways to fulfil the activities, possibly varying in duration and resource demand. The required resources are personnel from a heterogeneous workforce and different types of equipment that can be transported between activities and projects. Hiring in extra resources from an external supplier is allowed. Our objective is to complete all activities in the given time horizon while minimising the total costs given that all demand is satisfied.

We formulate a mathematical mixed-integer programming (MIP) model and implement an adaptive large neighbourhood search (ALNS) procedure to solve this problem.

The project and personnel scheduling problems have been researched separately for several decades, while the integrated problem has received limited attention. Since the integrated problem always has an equally good or better solution than solving these two problems separately, we investigate how beneficial it is to solve the problems simultaneously. Also, we present the performance of our ALNS implementation compared to using a commercial MIP solver.

2 - A Novel Continuous-Time Mixed-Integer Linear Programming Model for the Multi-Mode Resource-Constrained Project Scheduling Problem
Nicklas Klein

Project scheduling has become a vital component of many businesses across different industries. In many real-world projects, the durations and resource requirements of activities are not fixed, but there may be tradeoffs between higher resource requirements and smaller processing times. These tradeoffs can be represented through multiple execution modes of the activities, which is considered in the multi-mode resource-constrained project scheduling problem (MRCPSP). In the MRCPSP, a set of precedence-related project activities is given, which each have different possible execution modes. Depending on the mode, the activities require time and scarce resources to process. Sought are the start times and execution modes of the activities such that the project completion time (makespan) is minimized.

We present a novel continuous-time mixed-integer linear programming (MILP) model for the MRCPSP, which is based on activity order. Specifically, we use mode-selection variables, and two kinds of order variables to determine an optimal solution. In contrast to the current state-of-the-art MILP models from the literature, the new model has a polynomial number of variables and constraints. A computational comparison to MILP models from the literature shows promising results, indicating that the novel model outperforms the current state-of-the-art models on benchmark instances with long activity durations.

3 - Resource-constrained project scheduling with multiple sites: a continuous-time MILP-based approach
Norbert Trautmann, Tamara Bigler, Mario Gnägi

The execution of a project often requires resources which are distributed among multiple sites, and therefore transportation times must be considered for moving some mobile resource units or the output of some precedence-related activities. Example applications arise in a make-to-order production that is carried out by several partners in a supply chain, and in hospital clusters that are sharing pools of medical personnel and medical devices. We present a MILP-based approach for minimizing the duration of such a project subject to completion-start precedence and renewable-resource constraints.

4 - Efficient Algorithms for Project Scheduling with Autonomous Learning
Alessandro Hill, Thomas Vossen

We study a class of novel project scheduling problems that incorporate autonomous learning. In these models, certain jobs can be completed in a reduced amount of time if scheduled after jobs that lead to acquiring relevant experience. We consider single-and multi-predecessor learning and present corresponding learning mechanisms. We discuss the the structure and complexity of these combinatorial problems and devise efficient algorithms to solve them. In a computational study, we show the potential scheduling benefits that can be obtained when integrating learning compared to classical project scheduling.

■ MA-31

Monday, 8:30-10:00 - M240

Lot-sizing: exact solution approaches

Stream: Lot Sizing, Lot Scheduling and Production Planning
Invited session
Chair: Wilco van den Heuvel

1 - Economic Lot Sizing Problem with Tank Scheduling
Mehmet Onal, Wilco van den Heuvel, Erinc Albey

We introduce a multiple item economic lot sizing problem where items are produced through the fermentation of some raw materials. Fermentation takes place in specialized tanks that have finite capacities. Duration of the fermentation process is item dependent. We analyze this problem under various assumptions on the number of items and tanks. In particular, we show that several cases of the problem are (strongly) NP-hard, and we propose polynomial time algorithms to some single item cases. In addition, we propose a quick and simple heuristic approach for a multiple item case.

2 - Valid inequalities and extended formulations for single-period relaxation of lot-sizing and scheduling problem
Younsoo Lee, Kyungsik Lee

In this study, we propose new valid inequalities and extended formulations for the lot-sizing and scheduling problem with sequence-dependent setups, which are derived by investigating the single-period substructure of the problem. By conducting a polyhedral study on the single-period substructure, we derive two new families of valid inequalities and identify their facet-defining conditions. Additionally, we demonstrate that these inequalities can be separated in polynomial time. We provide new extended formulations, called time-flow formulations and compare the theoretical strengths of the various formulations and valid inequalities, including the proposed ones. We conduct computational experiments to demonstrate the effectiveness of the proposed inequalities and formulations. The test results indicate that the proposed inequalities and extended formulations facilitate tightening the linear programming relaxation bounds.

3 - An Optimal Order Fulfillment Planning for Mixed Model Assembly Line
Mahesh Gudipati, Bhagyesh Patil, Satyam Sahay, Rahul Kale

The recent Industrial 4.0 (I-4.0) vision focuses on incubating a 'Smart Manufacturing Concept' for industrial processes. One important facet of I-4.0 is an optimal production order-fulfillment planning (OFP). In OFP, considering market demand, raw material availability and feasible production capacity, a required daily, weekly, and monthly production plan is generated. Traditionally, in many industries, years of experience-based process planner in person derives this production plan. We note this human experienced based planning is completely intuitive and often results in a sub-optimal production plan. In a view of improving this OFP experience for a planner, our work presents a holistic approach based on the principles of Data Analytics and Operations Research. We transform operational requirements into functional constraints, introduce binary variables for material availability to ensure optimal use of materials which are used across different product families. Further, to factor market demand stochasticity and to ensure maximum demand is planned, we chose cost function as to minimize deviation between planned production plan and desired demand. As an outcome, a comprehensive mixed-integer linear programming (MILP) model for OFP exercise will be demonstrated. With a real-world case study from India Factory, the session shall offer approach to handle dynamic constraints in a manufacturing environment to improve on the production planning efficiency and agility.

4 - A partial decomposition approach for solving the stochastic uncapacitated lot-sizing problem
Safia Kedad-Sidhoum, Franco Quezada, Céline Gicquel

We study the uncapacitated lot-sizing problem with uncertain demand and costs. The problem is modeled as a multi-stage stochastic mixed-integer linear program in which the evolution of the uncertain parameters is represented by a scenario tree. To solve this problem, we propose a new extension of the stochastic dual dynamic integer programming algorithm (SDDiP). This extension aims at being more computationally efficient in the management of the expected cost-to-go functions involved in the model, in particular by reducing their number and by exploiting the current knowledge on the polyhedral structure of the stochastic uncapacitated lot-sizing problem. The algorithm is based on a partial decomposition of the problem into a set of stochastic sub-problems, each one involving a subset of nodes forming a sub-tree of the initial scenario tree. We then introduce a cutting-plane generation procedure that iteratively strengthens the linear relaxation of these sub-problems and enables the generation of additional strengthened Benders' cut, which improves the convergence of the method. We carry out extensive computational experiments on randomly generated large-size instances. Our numerical results show that the proposed algorithm significantly outperforms the SDDiP algorithm at providing good-quality solutions within the computation time limit.

■ MA-32

Monday, 8:30-10:00 - F101

Mathematical Models in Macro- and Microeconomics 1

Stream: Mathematical Models in Macro- and Microeconomics
Invited session
Chair: *Alexander Vasin*
Chair: *Gernot Tragler*

1 - Consumption as precommitment
Petr Krautwurm

Precommitment, an activity in which an individual restricts his own feasible set of choices in order to maximize utility, was usually considered as a conscious ex ante operation of consumer by which he intends to avoid his time inconsistent behavior. Current empirical evidence suggests that people do precommit themselves in certain situations. However, this paper shows that precommitment is a more general phenomenon than previously thought. It argues that precommitment emerges as a necessary part of consumption. Multiple examples from different branches of human behavior are presented to show that consumption without precommitment is almost impossible. Key thesis of this paper is that decision makers do not precommit themselves only because they want to, but rather because they need to. Adjustments to basic microeconomic model of consumer's behavior are then offered to make its assumptions more realistic from the perspective of precommitment nature of consumption.

2 - Treasury Auction Format
Aleksandrs Smilgins

The choice of auction format for government bond auctions varies by country, with uniform or discriminatory sealed-bid auctions with preapproved bidders (Primary Dealers) being the most prevalent. We compare performance of Danish and Swedish government bond auctions, and how it relates to the auction pricing rule: Denmark uses uniform pricing, while Sweden uses discriminatory pricing. Additionally, we develop models to estimate and predict the distribution of the auction price(s) in these auctions.

3 - Multi-site harvesting under quotas when a Stackelberg leader exists
Petros Xepapadeas, Yiannis Mourtos

We study a harvesting allocation problem consisting of a given number of fishers and a given number of fishing sites. We develop a framework in which one fisher is designated as the Stackelberg leader while the rest are followers. The presence of a Stackelberg leader when a fishery operates under a maximum harvesting allowance system is a novel approach not only in the sense of extending outcomes obtained in resource allocation problems, but also in indicating the structure of markets that might emerge, which include the possibility of full elimination of followers and the associated policy implications. Allocation of fishing effort in the presence of a Stackelberg leader is compared to previously established methods without a Stackelberg leader, specifically the sequential multi-agent resource allocation and the simultaneous allocation (cooperative and competitive), in which each fisher tries to maximize its profit given the best response of the others. Factors considered include vessel capacity, allowable catch per fisher and per fishing site, travel costs and congestion costs. While the allocation methods vary in design and execution, all of them aim to maximize profits, either for each individual fisher or for the whole system. Results are derived both in terms of a numerical example and an actual case of mussel harvesting. Insights gained from allocations when a Stackelberg leader exists could be useful for policy design regarding the regulation of a fishery.

4 - The bitcoin miners' game
Gernot Tragler, Tim Crailsheim

We present a model to analyze the incentives for "proof-of-work" miners, in the case of bitcoin. In the next step we create a game between the miners where they optimize their cost/profit functions under a given budget constraint, by choosing a certain technology level, comparable with the amount of mining computers. Like in the real bitcoin protocol, after a certain time the difficulty adjusts and a new computational power has to be or can be chosen. As expansions of that game, we let the bitcoin price change over time and include a fluctuating energy price.

We solve this game by means of simulation techniques and may expect that most miners have to quit over time, due to their personal budget constraints and irregular payout.

As a result, we study the benefits of mining pools under a game theoretic aspect and why they are so common. We will also motivate this aspect in our analysis of the game.

■ MA-33

Monday, 8:30-10:00 - F102

Equilibria, Games and Applications

Stream: Variational Inequalities, Equilibria, Games and Multilevel Optimization
Invited session
Chair: *Patrizia Daniele*
Chair: *Laura Rosa Maria Scrimali*
Chair: *Giancarlo Bigi*

1 - A dynamic equilibrium model of the Closed-Loop Supply Chain Network Equilibrium for second-hand collectibles
Georgia Fargetta, Laura Rosa Maria Scrimali

This paper investigates a closed-loop supply chain network equilibrium problem for second-hand collectibles in which all the given data are time-dependent. The network consists of manufacturers, retailers, demand markets, and one online second-hand platform engaging in forward and reverse logistics competition. Thus, the optimal behaviors of all the decision-makers are modeled as evolutionary variational inequality problems, and the governing closed-loop supply chain network equilibrium conditions are given. We verify our model presenting a numerical example solved using the extragradient method for evolutionary variational inequalities.

2 - Generalized Nash games without upper semicontinuity or metrizability of the spaces
Massimiliano Giuli

For Nash games with a countable number of players where the strategy set of each player depends on the strategies of all the other players, we investigate the existence of solutions. The achieved result is an application of a specific selection theorem that we are able to prove even when the range space is not metrizable and the involved set-valued map has not closed values.

3 - Dynamic Multilevel Gas Market Model
Steffensen Sonja

In this talk we present a dynamic multilevel game model for the European gas market. Following a paper by M. Schmidt et al [1] the model considers a gas network where the players can act at the nodes of the network and are given by the technical system operator (TSO) and furthermore the traders, namely the gas buyers and sellers. Moreover, the players decide about the technical capacities and the booking price floors on the one hand (TSO) and the individual gas bookings and nominations on the other hand (gas traders). However, in contrast to [1], we consider a fully dynamic version of the TSO's optimal control problem using a coupled system of semi-linear isothermal Euler equations to describe the time dependent gas dynamics. The dynamics are then coupled to the traders maximization problems, which are considered to be static in each subinterval of the full time interval (0,T). Next to the mathematical modeling of the dynamics and the analysis of the four-level problem, we will present some preliminary numerical results that reveal a turnpike structure of the gas dynamics.

[1] V. Grimm, L. Schewe, M. Schmidt and G. Zöttl, A multilevel model of the European entry-exit gas market, MMOR, 2019, 89:223-255

4 - Lagrange Multipliers and Nonlinear Variational Inequalities with Gradient Constraints
Attilio Marcianò, Sofia Giuffre'

The talk deals with the existence of Lagrange multipliers associated to nonlinear monotone variational inequalities with convex gradient constraints. In particular, first we prove an equivalent result between the problem under consideration and a suitable double obstacle problem. Then, using a new strong duality principle, we obtain the existence of L2 Lagrange multipliers.

■ MA-34

Monday, 8:30-10:00 - T003

On-demand passenger mobility and city logistics

Stream: Smart Mobility and Logistics
Invited session
Chair: *Seyma Bekli*

1 - Demand-oriented railway timetabling and rolling stock composition for integrated freight and passenger trains
Krissada Tundulyasaree, Layla Martin, Rolf Van Lieshout, Tom van Woensel

Integrating freight into urban passenger transportation is a sustainable logistics solution to manage the increasing demands for urban freight. Such a system transforms vacant space of an existing system, such as the metro or tram, to deliver freight shipments. While railway operators aim to maximize profits from freight deliveries, freight delivery can deteriorate the service level. Thus, it is important to determine its impact on service quality. We formulate the integrated timetabling and rolling stock planning problem for integrated passenger and freight trains as a mixed-integer linear programming model. We simultaneously determine train departure, arrival time, number of carriages for passengers and freight of every train trip, and the required number of trains for the schedule. Moreover, we consider the undersaturated case, in which passengers can always board the next train because this system provides enough capacity. In addition, passenger demands are time-dependent, and we approximate them using a continuous approach. We show that integrating freight increases the quality of the system during the off-peak period: passengers experience a shorter average waiting time since the train frequency increases.

2 - Can Mobility-on-Demand Services Compete with Cars, Public-Transport and Bikes: A Case of Netherlands
Subodh Dubey, Oded Cats, Serge Hoogendoorn

In this study, we analyze the individual's willingness to use Mobility-on-Demand (MoD) services (in the Netherland) and the likelihood of changing departure time window as a function of mode attributes and service reliability. To facilitate data collection, a pivot design SP survey utilizing Google Map APIs was designed using the Qualtrics platform. It is a longitudinal survey with 5 alternatives and 15 choice occasions. The alternatives are a combination of mode and departure time window. In the survey, we use a feedback mechanism to inform users about the difference between expected and actual travel and pick-up times. We analyze the choice task from an information processing (IP) perspective. In the IP strategy, the user solves the choice task by processing attributes in a sequence such that attributes that offer the highest amount of information are utilized first followed by the remaining attributes in descending order of information availability. The sequence depends on the individual and the context. We model this behaviour using Choquet Integral. The results indicate that service reliability plays an important role for car and train/metro users. Cost is the determining factor for bus/tram users. Car and train/metro users show potential for departure window change. Overall, the potential for the shift is highest among car users followed by train/metro. On the other hand, bus/tram and bike users are unlikely to make the shift.

3 - Incorporating User Acceptance Probabilities in Optimizing Profit of One-Way Electric Carsharing Systems
Seyma Bekli, Burak Boyaci, Konstantinos G. Zografos

One-way electric carsharing systems (OECS) offer comfortable and flexible travel by providing short-term access to private vehicle fleets. In OECSs, the users book the vehicle from an origin station to a destination, which might not coincide, for a short period of time in advance or at last minute. Allowing the arrival and departure stations to be different might result to spatial imbalance. To manage these issues and serve more customers, OECSs hire personnel to relocate the vehicles along the stations. Therefore, the cost of the relocation operations constitutes a significant part of the operational costs of OECSs. The relocation operations can be reduced by giving incentives to alternative trips offered to the users that promote better alignment of the vehicle distribution and the demand characteristics. In this study, we propose a novel reservation-decision framework that allows users to book in advance or at last minute while considering the probability of users rejecting an alternative offer. The framework consists of a simulation that treats each trip demand separately on a mixed integer linear programming (MILP) model which aims to find the optimal offer to be made to the customers, considering the acceptance probabilities. Due to computational complexity on the MILP, we propose a heuristic algorithm that decreases the number of relocation variables created. We have tested the framework on a real-life OECS data and achieved promising results.

■ MA-35

Monday, 8:30-10:00 - T004

Mobility, sustainability and equity: new paradigms and approaches I

Stream: Transportation
Invited session
Chair: *Michele Ottomanelli*
Chair: *Aleksandra Colovic*

1 - A Contiguity-based Optimization Model for Vehicle Routing in Sustainable Solid Waste Management
Mario Marinelli, Mariano Gallo

Waste management is closely linked to environmental protection, which must not be considered a limitation to development, but the fundamental premise of a new and more correct economic growth. In this context, waste vehicle routing represents a crucial step in supporting sustainable waste collection. There is a wide scientific literature on this topic where different optimization models, usually multi-objective, were proposed in conjunction with heuristic solution approaches. Most of these models are based on the minimization of operative and environmental costs, the number of used vehicles, workload. In this work, we propose an arc-based integer linear programming model that includes the maximization of spatial contiguity of served arcs, to ensure the practicability of solutions for operators in conjunction with costs minimization. The proposed model was developed in Python for

QGIS (PyQGIS) using Google OR-Tools. We applied the optimization model to a real case study located in the city of Benevento (Italy). Results show the effectiveness of the proposed model when compared to a basic formulation, obtaining more homogeneous routes with the same costs, resulted to be about 35% lower than the current solid waste collection costs. As a practical consequence, the proposed model can serve as a useful tool for waste management providers in planning both sustainable and optimal collection strategies.

2 - Modeling and Solving a Real-Life Crowdsourced Delivery Problem

Shqiponja Ahmetaj, Fabian Eichhorner, Nysret Musliu, Patrick Taschner

Crowdsourced delivery offers a better ecological and economical alternative to classic deliveries by using existing capacities of private drivers. A large part of daily transit consists of commuters from rural areas to their workplace in city centers and there is a huge potential to make use of this group for delivering small packages. In this paper, we analyze the feasibility for a company to use daily commuters for crowdsourced package delivery in their supply chain network. We give a formal definition based on a real-world scenario, which considers a central depot from where the packages are picked-up and aims to minimize the deviation of daily commuters from their original route. We provide a solver independent model in MiniZinc and evaluate it on randomly generated instances.

Based on open-data and behavior assumptions, derived from collected data, we build a simulation of the daily commuter traffic along the route from the central depot to the workplace. Using this simulation we develop and evaluate greedy algorithms that assign shipments to daily commuters, such that they are able to deliver them and without exceeding their time and resource constraints. Furthermore, we use the derived results from this simulation to create regression models for future capacity planning to estimate the daily delivery capacities of daily commuters. We show that, for the given use case, a significant amount of daily shipments can be delivered by daily commuters.

3 - Supporting sustainable mobility by the fair distribution of road network capacity

Aleksandra Colovic, Luigi Pio Prencipe, Leonardo Caggiani, Michele Ottomanelli

The large use of private cars for travelling in urban areas is considered as one of the main issues of transport systems in terms of sustainability. Recently, the international policies are urging to reduce the car usage by moving towards new and more sustainable mobility paradigms (i.e., post-car cities, 15min cities, MaaS, etc.). Private car is the most preferred alternative due to lower attractiveness, efficiency, as well as the lack of infrastructure facilities of the other mobility alternatives. Capacity and layout, in most of the urban road network, are devoted to car mode, while the network itself is designed for reducing the car users perceived travel cost. There are several papers in the literature that proposed the cycling infrastructure systems as an adequate solution, but only few of them focused on connection of both cycling and transit systems from network perspective. Therefore, we introduce a novel bicycle network design model by focusing on the design of reserved lanes that would increase their average speed, and for example, the use of bicycle mode versus private car. In particular, the network design aims at determining a fair distribution of network capacity that would increase the attractiveness of sustainable mobility modes compared with private car mode. The proposed model is applied on a test network adapted to our formulation. The preliminary results are encouraging and push towards further developments.

■ MA-36

Monday, 8:30-10:00 - U006

Emergency Department

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: *Melanie Reuter-Oppermann*

1 - A 3-player game theoretic model of a choice between two queueing systems with strategic managerial decision making

Michalis Panayides, Vincent Knight, Paul Harper

The main focus of this research is the construction of a 3-player game theoretic model between two queueing systems and a service that distributes individuals to them. The resultant model is then used to explore dynamics between all players.

The first aspect of this work is the development of a queueing system with two consecutive waiting spaces. The strategic managerial behaviour corresponds to how individuals use these waiting spaces. Two modelling techniques were used: discrete event simulation and Markov chains. The state probabilities of the Markov chain system have been used to extract the performance measures of the queueing model (e.g. mean time in each waiting room, mean number of individuals in each room, etc.).

This particular system can be applied in a healthcare scenario where it captures the emergent behaviour between the Emergency Medical Service (EMS) and the Emergency Department (ED). This will be used to investigate the impact of target measures on patient welfare.

2 - Simulation of the emergency room of a public hospital in Uruguay

Antonio Mauttone, Ignacio Aristimuño, Valentina Larzábal, Pedro Piñeyro, Maria Eugenia Silvera

We present a Discrete Event Simulation model for the emergency room of a public hospital in Uruguay. Patients are modeled as entities who arrive to the system, are classified (triage) into five categories representing their degree of severity and then are routed through several sections (e.g., quick attention, specific studies, attention boxes, revival). Main resources which constrain the entities' activities are the equipment (radiography, tomography), the quick attention section, regular attention boxes, doctors and nurses. The model was implemented in the AnyLogic software package. We generate random arrivals of patients according to the daily empirical distribution of arrivals, and patients then are classified based on historical percentages as well. Activities' durations are modeled using triangular distributions. Outputs of interest are mainly waiting times for each activity, discriminated by the patients' category, and resource usage. The scenarios simulated include duplication of the triage, sensitivity to the number of doctors and nurses, and special events like mass accidents and pandemics, which affect the rate and category of incoming patients. We run several independent replications, including detection of the steady state. The analysis of results allows for: (i) identifying the change of level of service due to infrastructure investment and slight modification of patient flows protocol, (ii) identifying underutilization of some resources.

3 - Exploring critical factors for walkout rate in an emergency department

Alessandro Nonis, Ernst-Jan Camiel Wit, Clelia Di Serio

Patients satisfaction is a key factor in the healthcare services industry and several methods and ad-hoc questionnaires have been proposed to assess the quality of service in an Emergency Department (ED). One of the most straightforward indicator is the waiting time before the visit. In this work we focus on the people who leave ED before getting visited by a doctor, as this can also be considered a global indicator of satisfaction for the service provided in the ED. In our analysis of a cohort of all the patients admitted in the ED of an Italian hospital during 2018, we found that at triage 4.7% of them are kept under observation without being further treated unless their condition worsens. Among those, the walkout rate is 74.4%. Our analyses focus on the patients who are kept under observation to understand what are the factors that can yield to leave the hospital before getting a treatment. The median walkout time obtained by the reverse Kaplan-Meier estimator is 198 (95 CI [192, 206]) minutes. For the main analysis we applied a survival model via the GAM implementation of the mgcv package in R. We can conclude that most of the examined factors that impact on the decision of leaving the hospital before being visited are not controllable by the management, while the number of people queuing and the crowding affect the decision. Hence a cost-benefit analysis should be undertaken to understand if adding more staff or space to the ED could improve the current situation.

■ MA-37

Monday, 8:30-10:00 - V001

Rich Vehicle Routing Problems II

Stream: Vehicle Routing and Logistics
Invited session
Chair: Patricia Zech

1 - **Green Reverse Logistics: exploring the Vehicle Routing Problem with Pickups and Deliveries with environmental goals**
Diana Rita Ramos Jorge, Maria João Santos, Bruna Mota, Tania Ramos, Ana Paula Barbosa-Póvoa

The Vehicle Routing Problem with Divisible Deliveries and Pickups (VRPDDP) is under-explored in the literature, yet it has a wide application in practice in a reverse logistics context. The problem considers that each customer has both delivery and pickup demands and may be visited twice in the same or different routes. A restriction on the free capacity of the vehicles before starting the pickups to avoid load-shuffling problems may be considered. In this work, we explore the economic and the environmental impacts of the VRPDDP, with and without restrictions on the free capacity, and compares the savings achieved with splitting customers visits with the traditional Vehicle Routing Problem with Simultaneous Deliveries and Pickups (VRPSDP). The solutions are obtained with an exact method and an ALNS. A multi-objective approach based on the augmented ϵ-constraint method is applied to obtain and compare solutions minimizing costs and CO2 emissions. The results demonstrate that the higher is the importance of CO2 emissions in the objective function, the higher is the benefit of splitting customers. Moreover, the percentage savings of the VRPDDP are higher for instances with a random network than with a cluster network of customers, in comparison to the VRPSDP.

2 - **Optimizing the long-term costs of an IRP using linear relaxation.**
Homero Larrain, Agustin Chiu, Gustavo Angulo

The Inventory Routing Problem arises in logistic operations when routing and inventory decisions are made simultaneously. Traditionally, the IRP works with a limited planning horizon, so in practice it is commonly used in a "rolling horizon" fashion, i.e., the IRP is solved at the beginning of each period with a limited planning horizon, but only the first period of the plan is executed each time. However, by doing this, we are solving a difficult problem that optimizes short-term costs, and then we are using these results as a heuristic that should lead us to good long-term operational costs. In this work, we explore ideas to improve the long-term performance of the rolling horizon strategy. First, we test three simple modifications to the IRP to improve its long-term performance: using safety stocks, defining minimum final levels of inventory, and using an artificial discount rate on the objective function. We use this improved IRP as a benchmark. Then, we introduce a solution strategy where we use a linear relaxation approximation of the IRP on the final periods of the planning horizon. Using a simulation, we calibrate our algorithm and compare it to our benchmark on a set of 180 randomly generated instances with up to 30 customers, 3 vehicles, and 20 periods. We show that our algorithm is in average three times faster than our benchmark, and that under favorable conditions (fewer vehicles, high inventory costs) it can yield savings of around 5% in long-term costs.

3 - **Aggregating large-scale vehicle routing problems**
Patricia Zech, Christian Almeder

Distribution or collecting problems with a high number of service points, such as postal services, distribution of newspapers, garbage collection etc. are mostly modelled as arc routing problems because the explicit consideration of each service point would lead to unsolvable large node routing problems. But the representation as a pure arc routing problem often leads to an oversimplification especially in rural or suburban areas. Hence, a flexible aggregation algorithm which allows merging node-based demand into arcs or edges wherever it is necessary is needed. This aggregation results in a capacitated general routing problem (CGRP) where customer demands can be assigned to nodes, arcs and/or edges, serviced by a fleet of vehicles that have a maximum capacity limit. With an adequate aggregation heuristic, it is possible to decrease instance size and transition a node routing problem into a CGRP. The level of aggregation allows to balance between the size of the resulting CGRP and the possible solution quality. To the best of our knowledge there is no research on systematically assessing the impact of the aggregation on the resulting tours. Starting with small instances and by obtaining results with exact solution methods, the impact of the aggregation algorithm can be evaluated. It is expected to find comparable good results for the CGRP without depreciating solution quality and in turn, increase algorithm performance through the reduction of problem complexity.

■ MA-38

Monday, 8:30-10:00 - V002

Surgery Scheduling

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: Daniel Santos

1 - **Surgery scheduling in a military hospital with multiple classes of patients and downstream constraints**
Edilson Arruda, Gustavo Carneiro, Laura Bahiense

This work addresses surgical scheduling in a military hospital in Brazil with multiple distinct patient types. The objective is to optimise a weekly surgery allocation plan under both downstream and patient flow constraints. Not only does the approach propose a weekly scheduling under operational constraints, but it also defines a bed allocation plan to balance demand and capacity provision for different classes of patients belonging to multiple surgical specialties with distinct surgery and recovery times. The case study involves the planning of surgeries from distinct specialties within the hospital's orthopaedic centre, which offers elective and emergency surgical procedures for military personnel and their respective dependents. We used mixed integer linear programming techniques to maximise the weekly utilisation of the operating theatres whilst ensuring that the schedule is robust enough to meet the weekly demand of all pairs of surgical specialties and patient types. This is vital to ensure a smooth operation and guarantee that the waiting queues are kept within reasonable limits for all specialties and patient types.

2 - **Timeslot allocation for waiting list control**
Theresia van Essen, Yanna van der Vlugt, Mijke Carlier

Patients visiting a hospital for elective surgery often have multiple consultations of different types with a surgeon before undergoing surgery. Hospital make a schedule several weeks in advance where outpatient department timeslots are allocated to these different consultation types. Changing the proportion of consultation types affects the patient waiting lists for both consultations and surgery. However, the precise consequences of such interventions are uncertain, as not all patients follow the same treatment pathway. Furthermore, as these planning decisions are made far in advance, they are based on an uncertain prediction of future waiting lists. The goal is to use these interventions to control waiting lists, in order to reduce waiting times for patients and to ensure that all available time capacity in the outpatient department and operating room is used. The problem is modelled as a Markov decision process (MDP). As the state space is very large, the problem does not admit an exact solution. Therefore, least-squares policy iteration is used to find an approximate solution. We also formulate an (integer) linear program which is used to solve a deterministic variant of the MDP, and investigate some simple decision rules. The solution methods are tested on a case study at a hospital in the Netherlands. Based on a simulation study, we find that all methods improve on the static roster method used by the hospital, with the linear program leading to the best results.

3 - Distributionally Robust Optimization of the Integrated Master Surgery Scheduling Problem with Downstream Capacity Constraints
Hayo Bos, *Richard Boucherie*, *Gréanne Leeftink*, *Erwin W. Hans*

The current challenge in health care capacity management is to plan capacities from a holistic and integral perspective. For example by scheduling resources of a department while accounting for resources in other departments. The Master Surgery Scheduling Problem with downstream resource constraints is an example of such a problem. We propose a Distributionally Robust Optimization based approach with the Wasserstein ambiguity set for this problem, which can easily be applied to similar tactical health care related problems where downstream resource constraints are at hand. We test and benchmark our method on both generated data and a real-life case study from a medium sized Dutch hospital.

4 - Optimizing hospital networks and patient allocation for elective surgeries
Mariana Oliveira, *Daniel Santos*, *Ana Paula Barbosa-Póvoa*

High waiting times for elective surgical care are a common problem in countries with a National Health System and can cause harm to patients. This situation, which was exacerbated by the COVID-19 pandemic, forces patients to wait beyond their maximum clinically recommended waiting time before surgery. Long waiting lists can be a consequence of a lack of resources or can arise due to an inefficient management of patients. An optimization model is proposed that, as first-stage decisions, establishes clusters of hospitals that could share waiting lists, intending to balance waiting lists and supply capacity considering different levels of tardiness and distances between hospitals. As second-stage decisions, the model allocates patients to hospitals for different periods considering different costs of internal and external transfers within and between clustered hospitals. This work allows comparing the performance of individual hospitals when waiting lists are centralized or decentralized under different scenarios. A network system perspective grants the opportunity to reduce costs and increase compliance with each hospital's strategic missions, as waiting time targets are considered and, consequently, improved quality of care and access is pursued.

■ MA-39

Monday, 8:30-10:00 - U8

MAI: Speed Networking

Stream: Making an Impact
Invited session
Chair: *Susanne Heipcke*
Chair: *Vladimir Fux*

1 - Speed Networking and the Practitioners' forum
Vladimir Fux, *Susanne Heipcke*

Meet your peers in a friendly, informal way through discussions in groups of 2-3 persons with pairings changing after a fixed time span of a few minutes.

OR is a team business, and knowing people you can turn to for ideas, feedback and support makes all the difference. But it is not always easy building your network, especially if you are shy or feel that you are an outsider. This welcoming session is a way of overcoming the barriers to networking, and enjoying yourself while you do it.

You may find it easier if you come with an idea of how you can introduce yourself to others in just two minutes. But don't worry if you don't have time to prepare - you'll soon pick it up. Of particular interest to other participants may be any experiences you are willing to share regarding successes, failures, or surprising outcomes of OR projects, best practices of communication with users/stakeholders, and learnings from interaction or collaboration with researchers from outside of your organisation.

The session will start with an introduction from Ruth Kaufman, chair of the EURO Practitioners' Forum, who will present the activities of this forum, in particular with respect to networking opportunities, and give an overview on the Forum's upcoming events and activities.

Monday, 10:30-12:00

■ MB-01

Monday, 10:30-12:00 - A

Daniel Kuhn

Stream: Keynotes
Keynote session
Chair: *Juan Miguel Morales*

1 - On Robust Optimization, Blackouts and the Law
Daniel Kuhn

Vehicle-to-grid is a concept for mitigating the growing storage demand of electricity grids by using the batteries of parked electric vehicles for providing frequency regulation. Vehicles owners offering frequency regulation promise to charge or discharge their batteries whenever the grid frequency deviates from its nominal value, and they must be able to honor their promises for all frequency deviation trajectories that satisfy certain properties prescribed by EU law. We show that the relevant EU regulations can be encoded exactly in a robust optimization model, and we use this model to demonstrate that the penalties for non-compliance with market rules are currently too low. This suggests that "crime pays" and that the stability of the electricity grid is jeopardized if many frequency providers abuse the system, which could ultimately result in blackouts. The decision problem of a vehicle owner constitutes a non-convex robust optimization problem affected by functional uncertainties. By exploiting the structure of the uncertainty set and exact linear decision rules, however, we can prove that this problem is equivalent to a tractable linear program. Through numerical experiments based on data from France, we quantify the economic value of vehicle-to-grid and elucidate the financial incentives of vehicle owners, aggregators, equipment manufacturers, and regulators. The proposed robust optimization model is relevant for a range of applications involving energy storage.

■ MB-02

Monday, 10:30-12:00 - B

EDDA

Stream: EURO Doctoral Dissertation Award
Award Competition session
Chair: *Yves Crama*

1 - From vertical to horizontal structures: New optimization challenges in electricity markets
Jérôme De Boeck

The use of electricity in our society has dramatically evolved over the past decades as well as the way we address problems related to the electricity supply chain. The electricity supply chain consists of several components: production, trading, distribution, and consumption. From a general perspective, the electricity supply chain is shifting from a vertical to a horizontal structure due to new decision mechanisms. This thesis studies several evolving problems in the electricity supply chain.

The first two problems studied are Bidding Problems (BPs) related to the introduction of Deregulated Electricity Markets (DEM). Such markets have been introduced to avoid dominant positions from producers and decrease the price of electricity as much as possible for the end consumer. Nevertheless, electricity producers face increasing uncertainty in such markets, having to plan the electricity production before knowing if it will be sold and without knowing the selling price. Bidding Problems (BPs) in DEM from the perspective of a GC have been widely studied with very strong hypotheses. They are most often formulated as bilevel optimization problems with the bidding GC as leader and the market operator of the DEM as follower. Only small instances our solved with state-of-the-art methods.

The first BP studied considers the Price Coupling of Regions (PCR) introduced in Europe consisting of coupling several DEM. A bilevel formulation that integrates transmission constraints between markets is proposed. KKT conditions are used to reformulate the problem into a non-linear single level formulation. A discretization of optimal bidding prices considering PCR is presented leading to a MILP formulation. New valid inequalities are proposed reducing significantly the LP gap of previous formulations. Two heuristic methods are proposed as well, including a general method for MILPs containing Special Ordered Sets of type 1. Numerical results focus on illustrating the highly negative impact of simplifying market mechanisms of BPs as done in price-taker formulations or ignoring transmission constraints in PCR.

The second BP considered uncertainty over competitor bids (SBP). We prove the problem to be NP-hard and introduce a novel dynamic programming (DP) framework for SBP. This framework is adapted to solve SBP for fixed bidding quantities. Instances of considerably larger size than in previous studies are solved to optimality in comparison to state-of-the-art methods. Furthermore, a DP polynomial algorithm is proposed which computes an upper bound on the SBP considered. A heuristic method is proposed as well, providing solutions under 1% of optimality in numerical experiments.

A third problem considers trading electricity with Micro-Grids (MGs). MGs are composed of several households which are partially autonomous regarding their electricity production. A Contract Proposition Problem is studied in which a GC must propose contracts to MGs which will select the contract at their best advantage. This problem is formulated as a bilevel optimization problem containing binary variables at the second level, formulations for which no general reformulation technique exists. We propose a novel heuristic reformulation technique lifting the classical optimistic assumption of bilevel formulations and providing a single level formulation. Numerical results illustrate our method provides near-optimal results.

The last problem studied in this thesis is the Minimum Margin Problem (MMP) consisting of assigning electricity consumers to power generators in a local transmission network. The goal is to maximize the minimum margin of the generators to prevent blackout situations. A hop constraint is considered to limit the number of edges between customers and their generators. We model this problem on layered graphs and introduce novel preprocessing techniques for layered graphs reducing their size by 50%. Our model solves instances of considerably larger size than state-of-the-art methods.

2 - Faster algorithms for Steiner tree and related problems: From theory to practice
Daniel Rehfeldt

The Steiner tree problem in graphs (SPG) is one of the most studied problems in combinatorial optimization. Many applications can be modeled as SPG or closely related problems. In the last decade, the SPG has seen impressive theoretical advancements. However, the state of the art in (practical) exact SPG solution, set in a series of milestone papers by Polzin and Vahdati Daneshmand, has remained largely unchallenged for almost 20 years. While the DIMACS Challenge 2014 and the PACE Challenge 2018 brought renewed interest in the exact solution of SPGs, even the best new solvers fall far short of reaching the longtime state of the art.

This thesis seeks to advance exact SPG solution once again. Since many practical applications are modeled not as pure SPGs, but rather as closely related problems, we also aim to combine SPG advancements with improvements in the exact solution of such related problems. Initially, we establish a broad theoretical basis to guide the subsequent algorithmic developments. We provide various new theoretical results for SPG and well-known relatives, such as the maximum-weight connected subgraph problem. These results include the strength of linear programming relaxations, polyhedral descriptions, and complexity results. Next, we introduce many new algorithmic components such as reduction techniques, cutting planes, graph transformations, and heuristics—both for SPG and related problems. Many of these methods and techniques are provably stronger than previous results from the literature. For example, we introduce a new reduction concept that is strictly stronger than the well-known and widely used bottleneck Steiner distance.

The individual components are combined in an exact branch-and-cut algorithm. Notably, all problem classes can be handled by a single branch- and-cut kernel. As a result, we obtain an exact solver for SPG and 14 related problems. The new solver is on each of the 15 problem classes faster than all other solvers from the literature (including problem- specific ones), often by orders of magnitude. In particular, the new solver outperforms the long-reigning, but non-public, state-of-the-art SPG solver by Polzin and Vahdati Daneshmand. Even geometric Steiner tree problems can be solved much faster than previously possible when the new solver is combined with the full Steiner tree generation provided by the software GeoSteiner. Finally, with our new solver, many benchmark instances from the literature for several problem classes can be solved for the first time to optimality—some containing millions of edges. These problem classes include the SPG, the prize-collecting Steiner tree problem, and the maximum-weight connected subgraph problem. Even several Euclidean Steiner tree problems from the 11th DIMACS Challenge that could previously not be solved after one week of computation by the leading geometric Steiner tree solver GeoSteiner can now be solved for the first time—within three minutes.

The software developed for this thesis, named SCIP-Jack, has been made freely available with source code for academic use (https://scipjack.zib.de/). Already a previous and significantly slower version of SCIP-Jack obtained top rankings in all tracks of the PACE Challenge 2018. Finally, SCIP-Jack is heavily used in several industrial projects, for example, at Open Grid Europe, one of Europe's largest transmission systems operators.

3 - Feasibility for Maximal Uncertainty Sets in Robust Optimization with Application to Gas Networks

Johannes Thürauf

Robust optimization is a popular approach to protect an optimization problem against uncertain data within a user-specified set of scenarios, the so-called uncertainty set. In many cases, the choice of the uncertainty set is driven by the application. In general, it can be elusive to assume that the exact "size" of the uncertainty set can be specified prior to the optimization process. Overly large sized uncertainty sets can lead to infeasible robust optimization problems. To avoid robust infeasibility due to the choice of the uncertainty set, it is useful to know the maximal "size" of a given uncertainty set such that feasibility of the robust optimization problem is still guaranteed. We study maximal uncertainty sets that guarantee robust feasibility for general mixed-integer linear problems (MIPs) and in the context of gas networks in this cumulative dissertation.

For general MIPs, we consider a specific notion for the maximal size of a given uncertainty set: the radius of robust feasibility (RRF). We introduce and study the RRF for MIPs under common assumptions from the literature and then extend the RRF to include "safe" variables and constraint, i.e., variables and constraints that are not affected by uncertainties. We further develop methods for computing the RRF of linear and mixed-integer linear problems with safe variables and constraints and successfully apply them to instances of the MIPLIB 2017 library. Based on our results, we propose a framework to integrate choosing the size of a given uncertainty set in the optimization process, which provides decision makers with a new tool to avoid too conservative robust solutions, i.e., to control the price of robustness, by adjusting the size of the uncertainty set.

Moreover, we study the two-stage robust problems of deciding the feasibility of a booking as well as of computing maximal technical capacities within the European entry-exit gas market system. A booking is a capacity-right contract for which the transmission system operator has to guarantee that every balanced load flow below the booking can be transported through the network. Maximal technical capacities bound these bookings and, thus, describe maximal bookable capacities. Except for some technical subtleties, these robust problems lead to deciding the feasibility as well as solving a specific two-stage robust nonlinear optimization problem. The main goal of this problem consists of computing a maximal uncertainty set of balanced load flows so that each of these load flows can be transported through the network. We study this problem algorithmically with focus on nonlinear models of gas transport. For deciding the feasibility of a booking, we develop a polynomial-time algorithm for single-cycle networks consisting of pipes. We further prove that deciding the feasibility of a booking is coNP-hard in general pipe-only networks. For active networks including compressors and control valves, we develop a bilevel model to decide the feasibility of bookings, in which the lower level is nonlinear and nonconvex. Under the assumption that no compressor or valve is part of a cycle, we derive several single-level reformulations of this problem.

Based on the results for bookings, we provide results for computing maximal technical capacities in tree-shaped networks. These results enable us to solve a multilevel model of the European entry-exit gas market system from the literature for tree-shaped networks and a nonlinear flow model. This is the first time that the considered market model has been solved for a real-world sized passive network and a nonlinear gas flow model.

Finally, we note that the results for bookings and technical capacities can also contribute to other potential-based network problems, which we demonstrate by computing a robust diameter selection for tree-shaped hydrogen networks with demand uncertainties.

4 - Mathematical optimization for social network analysis: Influence maximization and community detection

Michael Kahr

Online social networks have become crucial communication channels recently. Millions of people participate in such networks including entities with commercial interests such as companies. The latter increasingly incorporate campaigns promoted via social networks into their marketing mix. Fundamental problems that arise in quantitative social network analysis in the context of (viral) marketing include (i) the identification of influential network nodes that may trigger a large information propagation cascade referred to as influence propagation, and (ii) the identification of homogeneous communities referred to as community detection. In this thesis, we address the aforementioned problems that are naturally subject to uncertainty regarding the input data. Reasons include that the strength of social ties and the homogeneity of individuals can only be roughly quantified by empirical observations. In particular we study three problems from the domain of influence propagation and one community detection problem. The focus is on the development of solution algorithms that allow to obtain optimal solutions or at least worst-case gaps to optimal solutions with methods from mathematical optimization. We thereby contrast with the majority of the related literature in which heuristic methods are used. The proposed algorithms employ techniques from mixed integer (non-)linear programming including column generation and (generalized) Benders decomposition that are both embedded into a branch-and-cut framework. We also employ a Frank-Wolfe type solution algorithm for solving quadratic programs. Most of the proposed algorithms are accompanied by heuristics. The performance of the proposed algorithms is evaluated in extensive computational experiments on artificial and on real-world social network graphs from the literature as well as on new instances that we obtained via the developer interface of Twitter. Besides, several managerial insights are derived. The aforementioned uncertain input data is tackled with methods from stochastic optimization and robust optimization. Particularly regarding the latter domain, we propose and formally study a robust version of the standard quadratic problem that we use for a seemingly novel application, namely, community detection. Here, an uncertain (possibly indefinite) quadratic form is maximized over the unit simplex. We show that the copositive relaxation gap is equal to the minimax gap under some mild conditions on the curvature of uncertainty sets that are widely used in the related literature. We further derive conditions under which the robust version of the problem reduces to a traditional standard quadratic problem. Finally, concluding remarks are given including future research avenues.

■ MB-03

Monday, 10:30-12:00 - C

Machine Learning and Mathematical Optimization in Location and Logistics

Stream: Machine Learning and Mathematical Optimization

Invited session

Chair: *Cristina Molero-Río*

1 - Predict-and-optimize to address uncertainty in logistics: a tailored neural network approach
Nuria Gómez-Vargas, Emilio Carrizosa, Rafael Blanquero

Uncertainty in logistic decisions regarding the multiple parameters that model these problems- demands, travel times, etc.- requires of approaches within Operations Research (OR) that leverage auxiliary data (e.g., congestions or weather) to address decision-making. This falls into prescriptive analytics, which aim is at suggesting the best proactive options in order to get to the desired state in the predicted future. The effectiveness of the prescriptions depends on how well the predictions based on auxiliary information are integrated with the OR problem, in the sense of going from a good prediction to a good decision. For the multiple-output regression we chose neural networks (NNs) due to their ability of learning a continuous function that naturally captures the complex relationships between inputs and also jointly models dependencies in the outputs. We present here a predict-and-optimize approach in the form of a tailored NN model that accounts for the decision objective as training iterates.

2 - A Matheuristic for the Obnoxious p-Median Problem
Tamara Bigler

Facilities that have negative side effects on their close surroundings are called "obnoxious" facilities. Examples for such facilities are waste plants, water purification plants or wind turbines. In the obnoxious p-median problem, a set of clients and a set of potential locations for facilities are given. From the set of potential locations, p facilities must be selected to be open such that the sum of the distances from each client to the client's nearest open facility is maximized. The obnoxious p-median problem has been shown to be NP-hard and in the literature, several metaheuristics have been proposed for it. However, these metaheuristics cannot easily be extended to incorporate additional (e.g., fairness) constraints. To address the shortcomings of the existing approaches, we propose a matheuristic for the obnoxious p-median problem. Our matheuristic generates multiple initial solutions and improves these solutions in parallel. The initial solutions are generated such that different areas of the search space are explored. The improvements are achieved by solving carefully constructed subproblems, which allow the matheuristic to achieve large improvements in short running times, even for large-scale instances. Our matheuristic turns out to be competitive to the leading metaheuristic from the literature on benchmark instances. For larger instances, it substantially outperforms the leading metaheuristic in terms of solution quality and running times.

3 - Operations Research to evaluate public transport performance in the EU
Martina Fischetti, Davide Duma, Stefano Gualandi, Juan Nicolas Ibanez, Claudio Tomasi

One of the main EU policy priorities under the European Green Deal is to achieve climate neutrality by 2050.Transport is a key player in that task, as it is a major consumer of energy, and it contributes significantly to greenhouse gas emissions.Rail and busses, in particular, can represent a more sustainable means of transport. In order to monitor the performance of public transport in the EU,and to be able to inform the relevant policy decisions on the topic, the European Commission uses comprehensive data to compute performance and accessibility-to-opportunities measures associated with different types of public transport.Underneath these measures lies a schedule-based, time-dependent, all-pairs routing problem on very large networks. A main current challenge is to extend this type of analysis to multimodal transit networks, which integrate train,bus,and metro networks.The solution of multimodal time-dependent routing problems faced by European travelers would complement the analysis of public transport performance, especially for countries with reduced rail infrastructure. This paper presents the performance measures in use at the European level to assess and benchmark public transport across EU Member States, and it results from a collaboration between the European Commission's Joint Research Centre and the Department of Mathematics of the University of Pavia to develop a methodology that efficiently tackles the challenges of the abovementioned multimodal routing.

4 - Learning to Solve Electric Vehicle Routing Problems with Nonlinear Charging Functions
James Fitzpatrick, Deepak Ajwani, Paula Carroll

In recent years there has been increasing interest in the development of solution techniques for electric vehicle routing problems (E-VRPs). From a modelling perspective, it is important that these problems reflect reality accurately enough to be useful in practice. This necessitates the introduction of new families of constraints, which make these problems particularly difficult to solve. In many cases it is difficult to identify any feasible solution, let alone good or even optimal solutions.

Attempts have been made to leverage the successes of machine learning (ML) approaches to solve related optimisation problems such as the Travelling Salesman Problem and several variants of the traditional Vehicle Routing Problem. Approaches range from utilising a machine learning model directly as a heuristic or using it as an element of a matheuristic approach. The introduction of piecewise-linear battery charging functions to the problem (E-VRP-NL) has made it difficult to translate these successes to the E-VRP.

We demonstrate the adaptation of these ML-based approaches to solve the E-VRP-NL. In particular we use reinforcement learning techniques to train a heuristic that can identify feasible solutions. We use these solutions as initial solutions for a mixed integer linear programming (MILP) formulation of the problem. We then learn to remove a large fraction of the integer and continuous variables, allowing us to improve the solution by solving much-reduced problems.

■ MB-04

Monday, 10:30-12:00 - D

Machine Learning in Marketing and Behavioral Analytics (II)

Stream: Machine Learning and Mathematical Optimization

Invited session

Chair: *Vinicius Brei*

1 - Non-Parametric Assortment Optimization with Product-oriented Market Segmentation
Milad Keshvari Fard

In this research, we propose a new approach for the non-parametric choice modeling. By clustering the customers based on their consideration sets, our proposed algorithm can calculate the ranking distribution of customers' preference lists with higher accuracy compared to the state of art. We then use these preference lists to find the assortment of products that can maximize the retailer's revenue. Our findings indicate that our algorithm can result in a significant improvement in the retailer's expected revenue. Furthermore, our approach is computationally more efficient than other non-parametric choice modeling approaches.

2 - Direct selling systems improvement through data science
Julián E. Tornillo, Pablo Savian, Andrés Redchuk

Direct Selling is a business model that presents opportunities for personal, professional, and economic development through the generation of their own business based on sales networks. In this scenario, sellers have objectives that transcend sales activities themselves, such as interpersonal relationships and being able to run a business.

In this work we study and improve direct selling systems using transactional data from a case-study database and non-transactional data about seller's personality traits under DISC test. We apply data science techniques such as Principal Component Analysis (PCA), clustering and prediction analysis, combined with a business intelligence platform in order to visualize the information.

Results describe a characterization of sellers and show how personality traits can influence management patterns of sales networks. We have also been able to identify consumption patterns and product life cycle. Besides, we approach the guidelines for an optimal process of sales engineering in this industry. This contribution provides valuable information to strengthen decision-making at the strategic, commercial and operational levels and can be replicated in any organization that uses this business model.

3 - Adjusting a trained support vector machine in the light of new training data
Seán McGarraghy, Milena Venkova

Our motivation is the problem of adjusting an already-trained support vector machine binary classifier in response to new data. New training set data may become available after training a support vector machine: will the same trained machine still work or does it need to be adjusted? If the training set has order m, then the training time required is of order the cube of m, while memory required is of order the square of m, an issue in SVM training. Thus, understanding whether retraining is necessary is advantageous.

Many real-world machine learning problems occur on finite discrete sets with pairwise relationships among data (Zhou and Schoelkopf, 2005). We consider the general setting of data sets with pairwise relationships satisfying the triangle inequality, namely, sets in finite metric spaces; these include a broad range of cases where no linear structure is assumed.

We identify necessary and sufficient conditions for when the data set can be isometrically embedded in an n-dimensional real vector space, in terms of whether the Gram matrix of a kernel built from pointwise distances is positive semidefinite and has rank at most n.

This leads to a procedure for determining whether a new data point can be embedded into the same vector space, that is, when the same embedding can be used for a new data point; or when the dimension of the vector space must increase by 1.

We conclude with some possible research questions and directions.

4 - Forecasting Customers Risk-Adjusted Revenue Using Topic Modelling Applications
Marcos Machado, Salma Karray

In the financial sector, features extracted from text databases can improve the accuracy prediction frameworks for CRM metrics. This paper implements commonly used Topic Modelling (TM) algorithms (LDA, NMF, LSA, Top2Vec, and BERTopic) to extract valuable information from text-based features such as customers' loan descriptions. Our frameworks use the extracted topics as features in individual and hybrid Machine Learning (ML) algorithms to predict customers Risk-Adjusted Revenue (RAR). The individual models refer to various ML algorithms (e.g., Gradient Boosting, Adaboost, etc.) used to forecast RAR while the hybrid frameworks are formed by implementing clustering methods prior to predicting RAR with the same set of individual ML algorithms. Our results show that hybrid ML frameworks can outperform individual ML methods in predictive power and provide managers with many customer portfolios with different levels of risk and return. In particular, hybrid models that cluster customers based on the topics extracted from loan descriptions through the LSA method provide four portfolios with different levels of risk and return. Also, this method combined with decision trees presents an average R' of 94.8% (across the four obtained clusters) against an R' of 92.6% obtained from decision trees alone.

■ MB-05

Monday, 10:30-12:00 - E

Deep Learning Theory and Applications

Stream: Deep Learning and Applications
Invited session
Chair: Melisa Caliskan-Demir

1 - Comparative study of the Isolation Forest and Autoencoder models
Elena Tiukhova, Bart Baesens, Monique Snoeck

Nowadays, businesses rely heavily on data by making decisions based on the insights obtained from it. Anomaly detection is used as both a standalone field of research and an instrument to ensure the high quality of the data. Deep learning models are approaching the boundaries of what they can further achieve, being overparametrized and having high computational costs. A possible alternative to the deep learning models is conventional machine learning methods, such as the iForest model. This research performs a comparative study of the iForest model and the Autoencoder and Deep Autoencoder models and investigates the research question on whether applying deep learning for anomaly detection justifies its costs. Twelve benchmarking anomaly detection datasets and five performance metrics are used to make a comparison of the models. The ranking of the models based on the performance metrics is used to make a final conclusion. The first conclusion is that the iForest model is ranked on average first among all the models. What is more, it is ranked first according to the absolute ranking along the AUPRC, precision and time metrics. That brings us to a conclusion that deep learning models do not outperform conventional methods, namely iForest. Secondly, the Autoencoder model is ranked on average higher than the Deep Autoencoder model according to all the performance metrics. Thus, we conclude that adding more layers to the network does not justify the costs of doing so.

2 - Challenges of Time Series Forecasting Models
Xin James He

This research investigates the challenges of time series forecasting models in terms of data processing, forecasting model selection, computational issues, model validation, and forecasting accuracy. We explore data processing by contrasting automated modeling to manual modeling, model section by looking into traditional time series models versus machine learning models, computational issues by analyzing open source R or Python versus proprietary platforms, model validation by comparing the usual validation techniques with the data splitting into training and test subsets against the time series cross validation scheme with the data splitting into a series of test subsets, and forecasting accuracy by evaluating various forecasting accuracy measurement metrics. In light of the price volatility and time dependency in the financial markets, we consider the U.S. stock market as an example to demonstrate the time series forecasting challenges with respect to model validation and forecasting accuracy, due to the fact that the past performance may not hold for the future and the stock market is very much influenced by geopolitics, economics, seasonality, and psychology.

3 - Capturing complexity over space and time via deep learning: An application to real-time delay prediction in railways
Marijn Verschelde, Léon Sobrie, Bart Roets, Veerle Hennebel

Predictive analytics are increasingly used in managerial decision making. Most of these decisions are driven by approaches which are inflexible over space and time. However, the decisions occur in a dynamic environment which requires a flexible model able to capture the complex settings. In this paper, we propose a deep learning approach to predict train delays in real-time that acknowledges the heterogeneity of train delays over space and time. The advocated deep learning methodology is based on a customized recurrent neural network structure and is implemented in real-time on the total population of railway passenger transportation in Belgium. Our custom-built training data consists of over 1,000,000 sequences per month and includes uniquely rich information on the spatio-temporal interdependence between trains. This sequence-to-sequence LSTM encoder-decoder approach is benchmarked against the currently implemented rules-based approach which highlights its higher performance, especially in more complex settings. In addition, we observe a higher difference between the approaches for higher current delays and we test model performance during the COVID-19 pandemic. Next to the new comparative findings, our deployment of a decision support system within Belgium's national railway infrastructure company Infrabel provides on-site validation of the value of tailored predictive analytics for managerial decision making in complex settings.

4 - VoxelNet for 3D Linear Objects Detection in Point Clouds
Povilas Treigys, Jonas Stankevičius

Point clouds generated by laser scanners are known for high precision in 3D environment description. However, points by design have only 3D coordinates without contextual information about the environment, and therefore, their interpretation becomes a complex task. Recent deep learning algorithms show outstanding achievements in point cloud processing, e.g., state-of-the-art models can detect objects for autonomous vehicle operations in real-time. Academic literature draws considerable attention to single object detection based bounding box methods. In opposite, the paper's authors investigate the task of linear object detection in 3D point clouds; we strive to delineate road curbs, powerlines and lane lines. Authors tackle the 3D line segmentation problem with modified widely known VoxelNet detection backbone. An encoded point cloud is processed by a 3D Unet style network built using sparse convolutions. The model's output is a 3D point cloud scene segmentation denoting three-class line segmentation output and a mesh of coordinates for each line point localization. By calculating Euclidean distance between model extracted and manually labeled points, the proposed algorithm achieves an average 1,8 cm error for power line and lane line point extraction, and average 2,3 cm error for curb line point extraction. This results in a 98% F1 score for powerline segmentation, 96% F1 score for road curbs and 98% F1 for lane line segmentation in 3D space.

■ MB-06

Monday, 10:30-12:00 - U1

Applied Discrete Modelling

Stream: Combinatorial Optimization
Invited session
Chair: Jan van Vuuren

1 - A vehicle routing and scheduling problem for increased driver-route familiarity
Jacobus King, Jan van Vuuren, Stephan Nel

Although the Vehicle Routing Problem (VRP) is one of the most studied and important combinatorial optimisation problems in the literature, practical challenges often arise when implementing solutions that stem from solving VRP instances. Unanticipated traffic conditions can result in increased vehicle travel times and subsequent degradations in supply chain operational efficiency. Moreover, drivers tend to get lost and/or often travel on roads that are not suitable for the delivery vehicles utilised when they are unfamiliar with delivery routes, which typically occurs when these routes differ significantly from one day to the next. A possible solution aimed at streamlining the practical implementation of planned delivery schedules is to generate a set of standard delivery routes visiting each customer along different approaches, called master routes. These master routes may then be used as blueprints for daily planning purposes when actual delivery routes are computed. Delivery vehicle drivers are thus afforded the opportunity to become familiar with the master routes, which is anticipated to increase the efficiency with which they perform deliveries if the actual delivery routes do not deviate too much from these master routes. We derive two mathematical models and metaheursitic solution approaches for the creation of such master routes, and subsequent actual delivery routes. We also analyse the trade-off between driver-route familiarity and transportation cost.

2 - On solving the vehicle-crew-rostering problem in an integrated fashion
Pieter Steenkamp, Jan van Vuuren

A prominent public transport company which provides a passenger transport service in the form of daily timetabled trips in and around the city of Cape Town (South-Africa) currently performs the assignment of buses and drivers to these trips manually. This assignment process is characterised by the solution of three different combinatorial optimisation problems, namely the vehicle scheduling problem (VSP), which entails the assignment of vehicles to trips over a scheduling period, the crew scheduling problem (CSP), which entails the assignment of drivers to trips over a scheduling period, and the crew rostering problem (CRP), which entails the assignment of drivers to trips over a rostering period (whereas a scheduling period typically spans one day, a rostering period typically spans several days). Traditionally, the aforementioned sub-problems are solved separately due to their considerable individual computational complexities. The public transport company in question has, however, launched a research project in which the objective is to develop a metaheuristic for solving all of these subproblems simultaneously (known in literature as the integrated vehicle-crew-rostering problem) while attempting to minimise a cost function. Results obtained when following the suggested solution approach are presented and costs are compared with the status quo in the context of real timetabled trips data obtained from the transport company.

3 - An inventory replenishment model in support of supply chain optimisation
Jurie Zietsman, Jan van Vuuren

Globalisation and the growth of e-commerce have led to retail companies having to manage and control a growing number stock keeping units (SKUs). The success of any retail company depends on how well it can satisfy demand while remaining financially viable. Inventory management systems are typically aimed at balancing the conflicting objectives of achieving good customer service levels and minimising inventory and operating costs. As the number of SKUs a company holds increases, so does the complexity of this balancing problem. The main decisions in respect of SKU inventory management in a retail warehouse, which affect this balance, are (1) which SKUs need to be replenished, (2) when to place replenishment orders for these SKUs, and (3) the appropriate volumes of SKUs to include in these orders.

In this presentation, an inventory replenishment model is proposed in which orders for SKUs may be placed at discrete, equi-temporal points in time. The objective is to batch SKU replenishment orders together, while accounting for lead times, minimum order quantities and backlogged orders. Model performance is evaluated on the key performance indicators of customer service level and cost, which form the typical trade-off in inventory management. The model draws from and resides within the intersection between time series demand forecasting, inventory management models and packing problems. The model is solved by an exact approach.

4 - A framework for modelling spatio-temporal competition and spread of invasive Acacia species in South Africa
Alexander Flemming, Jan van Vuuren

The study of artificially introduced plant and animal species is important in South Africa, a country rich in indigenous biodiversity and home to three biodiversity hotspots recognised by Conservation International. An introduced species is one living outside of its native distribution range, and has been introduced to a new environment either by accidental or deliberate human activity. Invasive alien species are a sub-category of introduced species that negatively impact the natural species of a particular area. These invasions cause natural functioning ecosystems to break down, leading to further invasions and can ultimately lead to the extinction of the indigenous species of the area. In this presentation, we consider the application of automated discretised processes aimed at conducting spatial analyses of ecosystems in South Africa that contain invasive species. In particular, our study is aimed at adopting a machine learning algorithmic approach towards determining which topographical, spatial and climactic factors are to be attributed to the occurrence and density of invasive species in an ecosystem. This approach allows for predicting regions requiring investigation due to likely unmapped occurrences or predicted future spread, based on the area's suitability to sustain these species. Finally, a spatio-temporal modelling approach is applied to simulate the competition between, and spread of, invasive species within a suitable study region identified in South Africa.

■ MB-07

Monday, 10:30-12:00 - U3

Optimization and Equilibrium Modeling in Energy-1

Stream: OR in Energy
Invited session
Chair: Steven Gabriel

1 - **Tri-Level Equilibrium Modeling in Energy**
Olli Herrala, Steven Gabriel, Fabricio Oliveira, Tommi Ekholm

In this presentation we present new results for solving tri-level equilibrium models. These formulations allow for a regional/national policymaker at the top, a network operator in the middle, and network users at the bottom level. We present both general theoretical results as well as those geared at infrastructure (e.g., energy, the environment).

2 - **Rearranging the Deck Chairs? Coordinating Environmental Policy and Transmission Planning in Decentralised Electricity Industries**
Afzal Siddiqui, Makoto Tanaka, Yihsu Chen

Increased penetration of intermittent variable renewable energy sources (VRES) requires variability management, which often refers to storage and transmission investment. However, the cost of damage from emissions is overlooked in favour of VRES targets. We use a bi-level framework to devise transmission plans that directly include the cost of damage from emissions. Our upper level comprises a welfare-maximising transmission planner who internalises the damage cost. At the lower level, profit-maximising firms invest in VRES capacity and operate their fleet of assets. We implement problem instances for a Western European test network in order to examine how transmission plans need to be adapted to the cost of damage from emissions and imperfect competition in integrating VRES.

3 - **Gains in coordinating the operation of heat, natural-gas and power distribution systems**
Antonio Conejo

We analyze centralized (optimal control) and decentralized (equilibrium) operations of heat, natural-gas and power distribution systems. We identify and discuss the conditions under which centralized and decentralized operations are equivalent. Using a realistic case study, we quantify the gains resulting from different levels of coordination.

4 - **Optimal planning of transmission infrastructure expansion to efficiently integrate renewable energy generation**
Nikita Belyak, Steven Gabriel, Nikolay Khabarov, Fabricio Oliveira

In light of increasing pressure to curb greenhouse gas emissions, many countries have focused on the development of strategies that encourage renewable generation in liberalised energy markets. This paper presents a modelling assessment to plan the renewable-driven expansion of the transmission system infrastructure that accounts for decentralized energy market settings. The mathematical optimisation problem formulation involves the bi-level model in which a welfare-maximizing transmission system operator makes investments in transmission lines at the upper level while considering power market dynamics at the lower level. To account for deregulated energy market structure, we assume the generation companies at the lower level make generation capacity investment decisions as either price takers in perfect competition or being capable to influence the price in a Cournot Oligopoly. Considering alternative levels for transmission infrastructure expansion budget, carbon emission taxes and monetary incentives for renewable generation capacity expansion, we study how various compositions of these three factors affect the share of renewable generation in the total generation mix. The preliminary results suggest the limited efficiency of these measures when applied individually, therefore this investigation aims to identify the best configuration of these measures to meet ambitious CO_2 reduction targets.

■ MB-08

Monday, 10:30-12:00 - U4

Vehicle Routing

Stream: Combinatorial Optimization
Invited session
Chair: Sander Teck

1 - **Chance Constraint Model for Multi-product Multi-vehicle Perishable Inventory Routing Problem with Service Level and Discrete Random Distributions**
Xiyi Chen, Jian-Bo Yang, Dong-Ling Xu

In the perishable supply chain industry, managing inventory and planning delivery schedules are two main yet complicated tasks. In this work, we study a Perishable Inventory Routing Problem (PIRP) with multiple periods, multiple products, stochastic demand, and multiple homogeneous vehicles, in the setting of Vendor Managed Inventory (VMI). In order to mimic real-life situations, we consider 2 extra elements: service level and discrete random distributions. In most retail sectors, maintaining high service levels is a norm, typically above 95%. Keeping an inventor of the right amount to reach a high service level is a key factor to providing good service and strengthening customer loyalty. In our problem, we model the service level as a chance constraint, which is that in each period, the probability of total demand being fulfilled has to reach a targeted service level. Besides, most IRP papers published assume continuous distribution functions such as normal distributions, Poisson distributions, etc., which is not realistic. In real life, instead of perfect continuous distribution functions, we see discrete distributions generated from routinely collected data, each demand point with a different probability. This work is one of the few that considers service level and is the 1st one that incorporates discrete random distribution with a large number of unique demand points in the PIRP model.

2 - A two-phased heuristic approach for a capacitated multi-vehicle covering tour problem (m-CTP) with intermediate facilities
David Schindl, Vera Fischer, Antoine Legrain, Meritxell Pacheco Paneque

Door-to-door waste collection often comes with a high fuel consumption, emissions and noise. These can be due to the use of large collection trucks performing an important number of stops. To reduce these impacts, one possibility consists in locating collection sites throughout the municipality such that residents bring their waste to their most preferred location. In addition, intermediate disposal facilities can be installed to accommodate the usage of smaller but more sustainable vehicles, with less capacity.

Our optimization problem consists in selecting the locations to place the collection sites while determining the routes for the small vehicle to visit them in order to collect the waste.

We propose a mixed-integer linear programming (MILP) formulation that exploits the sparsity of the road network. To efficiently solve practical instances, we develop a two-phased heuristic method that addresses the two subproblems the problem is built on: a set covering problem to select the collection sites and a capacitated vehicle routing problem (CVRP) with intermediate facilities to determine the routes. In particular, we solve a minimum clique covering problem on chordal graphs to identify the set covers. To build the routes for a given set cover, we propose a column generation approach. We test both the formulation and heuristic approach on real-life instances and evaluate their performances

3 - Genetic Algorithm for solving Multi-Depot Single Vehicle Routing Problem with Fixed Time constraints
Miguel Salas Zuniga

In this work, the problem of optimising a pre-scheduled routing plan is addressed. The presented approach is useful in situations when a change in the original constraints occurs after the client visits, in a vehicle route problem formulation; have been arranged and an optimised plan is being executed. In most situations, just re-running the optimisation process with new constraints is not enough. The problem we focus on, covers scenarios where the cost of re-arranging customer visits is extremely expensive, impractical, or just partially possible. In this study, a method for identifying changes to an optimised plan is described by improving the routing plan costs and causing minimum disruptions to the current state. Due to their flexibility to generate multiple solutions at each generation, and their efficiency for global searches, a genetic algorithm is used to find optimal solutions to the Vehicle Routing Problem that partially preserve constraints of the original plan (fixed times). A practical implementation is described where each stage of the solution with a genetic algorithm is described in detail and the results discussed. An advantage of this a proposal, is the capability of finding a set of improved solutions for supporting decision makers in the process of finding the solution that best suit their needs. Strategies of what to do when the static-constraints condition changes and a re-optimisation is needed, haven't been discussed enough in current literature.

4 - A Discrete Event Multi-Agent Based Approach to the Scheduling and Routing Problems in a RMFS.
Sander Teck, Reginald Dewil

This paper presents a Discrete Event Multi-Agent (DE-MAS) based approach for solving the scheduling and routing of robots and pickers in a Robotic Mobile Fulfillment System (RMFS). The RMFS is a parts-to-picker system designed for e-commerce warehousing where robots are used to fetch inventory pods from the storage area and transport them to the appropriate workstation where human pickers pick the required number of SKUs for the orders assigned to their work station. It is composed of several hard sub problems like: the order to picking station scheduling, the pod selection, and the vehicle scheduling. The proposed solution approach employs negotiation mechanisms, i.e. auctions, to communicate and distribute picking tasks among all the agents. Various dispatching rules and task allocation mechanisms are developed with the objective to minimize the overall distance travelled and the system makespan. Their performance is compared with one another over a wide set of problem instances of the RMFS with varying numbers of autonomous mobile robots, picking stations, and order sizes. The DE-MAS shows promising results compared to a centralized control algorithm, requiring only a fraction of the computation time. Additionally, a comparison in optimization potential is made between unidirectional and bidirectional lanes, where for bidirectional lanes a collision resolution algorithm is implemented.

■ MB-09
Monday, 10:30-12:00 - U5

MILP approaches to combinatorial optimization problems

Stream: Mixed Integer Linear Programming
Invited session
Chair: *Enrico Malaguti*

1 - On the computation of the maximum Chi-square index by Integer Programming
Davide Duma, Stefano Gualandi, Federico Malucelli

Consider a set of observations consisting of measures on two variables. A statistical test of independence of the two variables is the maximum Pearson's Chi-square index, defined as a Quadratic Transportation Problem (QTP) in [2]. The QTP is an optimization problem derived from the Linear Transportation Problem (LTP), they are both defined on the transportation polytope, but the QTP has an objective function that is quadratic and convex in the flow variables. Due to the convexity, the optimal solution of QTP will be an extreme point of the feasible region, but since the transportation polytope has many extreme points, it is hard to certify the optimality. In the literature, the solutions approaches are mainly based on Lagrangean relaxations [1], except in [2], where three combinatorial optimization heuristics are proposed and evaluated experimentally.

In this work, we introduce a combinatorial relaxation of QTP, and we propose a decomposition method to compute upper bounds, in which the problem is reduced to 0-1 knapsack problems. Finally, we report numerical results that validate the strength of our relaxation.

[1] V. Adlakha & K. Kowalski. On the Quadratic Transportation Problem. Open Journal of Optimization, 2, 3 (2013), 89-94.

[2] B. Kalantari et al. Sharp bounds for the maximum of the chi-square index in a class of contingency tables with given marginals. Comput Stat Data An 16, 1 (1993), 19-34.

2 - Advances on the combinatorics of the Balanced Minimum Evolution Problem
Daniele Catanzaro

The Balanced Minimum Evolution Problem (BMEP) is an APX-hard (inverse) nonlinear network design problem that arises from life sciences and that consists of finding an unrooted binary tree fitting a given input symmetric distance matrix of order n. The problem shares several combinatorial aspects with the Traveling Salesman Problem, The Quadratic Assignment Problem, and the Coloring Problem. Notoriously, instances of the BMEP, even the smallest ones, can be particularly hard to solve in practical time via exact solution algorithms, mainly due to the presence of highly nonlinear aspects that characterize the polyhedral combinatorics of the problem. In this talk we advance on the combinatorics of the BMEP, by addressing a long standing conjecture concerning the constructive characterization of the set of its solutions. This result enables the development of new effective integer programming formulations for the problem able to solve instances of practical size.

3 - A new formulation and a branch-and-cut algorithm for the (weighted connected) Safe Set Problem
Enrico Malaguti, Vagner Pedrotti

Given a connected graph G = (V, E), a Safe Set S is a subset of the vertex set V such that the cardinality of each connected component in the subgraph induced by V S does not exceed the cardinality of any neighbour connected component in the subgraph induced by S. When the vertices of G are weighted, the weight of a component is defined as the sum of the weights of its vertices, and the notion of safe set is extended by considering the weight of connected components in subgraphs induced by S and by V S. We propose an integer linear formulation which can tackle the four variants of the problem which arise by imposing connectivity of the safe set, and by considering weighted or unweighted vertices, respectively. Differently from alternative formulations from the literature, that require a large number of variables, our formulation only uses one variable per vertex. The formulation has an exponential number of constraints, which are needed to define the structure of the safe set, and can be generated on-the-fly within a branch-and-cut algorithm. We describe linear-time separation procedures for these constraints, as well as families of additional inequalities based on cliques and on minimum weight cut separators, and discuss separation algorithms. A branch-and-cut algorithm that solves the proposed formulation is computationally compared with the state-of-the-art alternative formulation from the literature, and shows faster in solving most of benchmark instances.

4 - A Numerically-Exact Algorithm for the Bin Packing Problem
Stefano Coniglio, Roberto Baldacci, Fabio Furini

We propose a numerically-exact algorithm for solving the Bin Packing Problem (BPP) based on a branch-and-price-and-cut and a pattern-enumeration method. Key to the algorithm is a novel technique for the computation of numerically-safe lower bounds for the set covering reformulation of the BPP (tightened with additional valid inequalities) with a precision that is higher than the one of commercial floating-point solvers. The technique is based on a scaling procedure that guarantees that the floating-point operations carried out within the algorithm be not affected by cancellation errors, combined with the first, to our knowledge, successful adoption of a rational (infinite-precision) linear programming solver in the context of a column (and row) generation method. Crucial for efficiency of our algorithm is the way we circumvent the computational burden of calling the rational solver at every iteration via a two-phase column-and-row generation method where the rational solver is coupled with a more efficient floating-point one. Our branch-and-price-and-cut algorithm relies on an exact integer (fixed-point) label setting algorithm for solving the pricing problem associated with the (tightened) set covering formulation. It can also perform pattern enumeration, thereby generating a reduced set covering formulation containing a superset of the columns (patterns) that are featured in an optimal BPP solution.

■ MB-10

Monday, 10:30-12:00 - U6

Insurance risk management

Stream: Financial Risk Measurement and Management
Invited session
Chair: *Susanna Levantesi*

1 - A R-vine copula based model for multi-peril insurance ratemaking
Mario Marino

Ratemaking is a common actuarial task in Non-Life insurance, and its cornerstone concerns the claims distribution portrayed by the compound Poisson distribution. Then, a standard actuarial model to evaluate the claims is the Tweedie's compound Poisson regression, since the Tweedie distribution allows to model semi-continuous claim occurrences. Regarding multi-peril insurance contracts, ratemaking analysis is typically performed marginally, although a multivariate modeling accounting for claims dependence is necessary to proper manage insured risks. By the mean of copulas, we characterize the multivariate claims distribution incorporating a dependency structure among perils. Our proposal concerns the construction of an actuarial model for multi-peril insurance ratemaking joining: (a) the Tweedie's compound Poisson regression to represent the aggregate claims for each peril, and (b) the Pair Copula Construction method combined to Regular Vine models, to decompose the multivariate loss distribution using pairs of copulas as building blocks. To validate our proposal, we utilize a real medical costs data set related to a multi-peril health insurance contract, illustrating the Regular Vine copula construction, and analyzing obtained loss distribution with respect to the pure premium calculation, the aggregate policy limits definition and the risk capital charges.

2 - Risk Sharing Rule and Safety Loading in a Peer to Peer Cooperative Insurance Model
Gabriella Piscopo, Gian Paolo Clemente, Susanna Levantesi

Peer-to-Peer insurance (P2P) is a modern cooperative insurance system through which a group of participants connected by digital technology share risks and benefits. In order to enter the mutual group, each participant has to pay an initial contribution based on a sharing risk rule. According to the most considered conditional mean risk-sharing rule, the participant has to initially contribute with an amount equal to the expected value of the risk he brings to the pool given the total loss distribution. The entry premium thus defined is actuarially fair. Following the established practice of traditional insurance schemes, in this paper we propose to add a safety loading to the fair premium, required to each participant according to a risk distribution rule based on the concept of the Shapley value in the framework of a cooperative game. In this way, once an opportune risk measure is defined, for each participant the safety loading is proportional to its own marginal contribution to risk. In a second phase, when the losses have been realized and the claims have been repaid, any remaining positive capital is distributed to the participants in the form of cashback or any losses is charged. The allocation rule must take into account the marginal risk that each participant brought to the scheme net of how much of this risk has already been initially paid through the safety load. A numerical application is presented to show how the model works.

3 - Mixed ABM for NDC pension schemes in presence of demographic and economic uncertainty
Massimiliano Menzietti, Jacopo Giacomelli

The crisis of the pension systems based on PAYG financing has led to the introduction in some countries, including Italy, of so-called Notional Defined Contribution (NDC) pension accounts. These systems mimic the functioning of defined contribution systems in benefit calculations while remaining based on PAYG financing. Despite many appealing features, NDC accounts cannot automatically guarantee the system's financial sustainability in the presence of demographic or economic fluctuations. The literature proposes Automatic Balance Mechanisms (ABMs) on the notional rate applied to contribution and the indexation rate applied to pensions. ABMs may be based on two indicators: liquidity ratio and solvency ratio. Such ABMs may strengthen the system's financial sustainability but may produce strong fluctuations in the adjusted notional rate and undermine the social adequacy of the system. In this paper, we introduce a mixed ABM based on both liquidity ratio and solvency ratio and identify the optimal combination that guarantees the financial sustainability of the system and, at the same time, maximizes the return paid to the participants at fixed levels of confidence. The numerical results show the advantages of a "mixed" system over those based on a single indicator.

4 - A simulation approach to robust risk management of derivative products.
Bertrand Tavin

This paper considers the problem of assessing and hedging the risk carried by a portfolio of non-standard derivative products managed with a parametric model. We first formalize the problem and define the framework in which it can be solved by using a constrained simulation approach with respect to model parameters. Our approach is suitable for an agent who may be agnostic with respect to a prior model and who may wish to account for expert views on the range of possible model parameters. Instead of breaking them into several sub-problems, the proposed methodology has the important advantage to answer the risk measurement and hedging question in one step. Namely, the agent needs to run the simulation just once to get the desired answers. We present numerical results obtained with recent market data when applying the method to a portfolio of variance swaps and forward-start options valued with models belonging to the Heston family.

■ MB-11

Monday, 10:30-12:00 - U7

Preference Learning

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Salvatore Greco*
Chair: *Roman Slowinski*

1 - Learning the preferences of tourists through the analysis of social media data
Jonathan Orama, Antonio Moreno, Joan Borràs

Recommender systems must know the preferences of their users to provide appropriate personalised suggestions. In the case of Tourism Recommender Systems it is hard to know these preferences, as tourists are not very keen on giving this information explicitly. However, it is possible to analyse the abundant trace left by tourists on social media to discover their interests. After retrieving the tweets from the visitors of a city and analysing their content and location, it is possible to represent each user with a numerical vector that provides information on her interest in different kinds of attractions (culture, sport, shopping, etc.). The analysis also includes other aspects, like the language of the users, their interest on popular points of interest, their degree of mobility, or their preferred time of the day for visiting the city. A clustering process is then applied to obtain the profiles of different kinds of users, which include their cultural interests, travel habits and interest in popular attractions. After that, the sequences of points of interest visited by the tourists in a single cluster are analysed to find association rules, which highlight the most usual connections between points of interest for that class of tourists. These association rules are then used by a recommender system to provide personalised suggestions. The developed system has been evaluated with data from visitors of the city of Barcelona, obtaining promising results.

2 - Active learning with additive value models
Grzegorz Miebs, Jonas Gehrlein, Matteo Brunelli, Miłosz Kadziński

We propose an active learning approach enhancing the UTA method for solving a ranking problem in multiple-criteria decision analysis. Within this framework, an optimal question for a pairwise comparison maximizing information gain is calculated and presented to a decision-maker. By using carefully selected questions, the number of required iterations with the user is reduced. When searching for an optimal question previous choices of the decision-maker are taken into account, and thus the selection of questions is done sequentially and individually for each decision-maker. What is more, by using an optimization algorithm fictitious alternatives can be created to increase information gain even further. Our approach is tested on a real-world problem in the realm of blockchains. In such an environment, so-called "nominators" need to select "validators" on the ground of their reliability and profitability. In particular, validators, representing alternatives, are assessed with respect to six criteria.

3 - Modelling optimism and pessimism in Stochastic Multicriteria Acceptability Analysis
Salvatore Greco, Sally Giuseppe Arcidiacono, Salvatore Corrente

We propose a methodology to take into account optimism and pessimism of a Decision Maker that, using Stochastic Multicriteria Acceptability Analysis, evaluates alternatives based on a plurality of weight vectors. With this aim we consider specific families of probability distributions in the space of the feasible weight vectors discussing the results they provide. We also propose a methodology to elicit the probability distributions. We discuss the results obtained through our methodology in the domain of composite indicators.

■ MB-12

Monday, 10:30-12:00 - U9

Modeling uncertainty in energy markets

Stream: OR in Energy
Invited session
Chair: *Iegor Riepin*

1 - A Benders decomposition approach for solving a two-stage local energy market problem under uncertainty
Franco Quezada, Fernando García, Sebastián Dávila

This article presents a new two-stage stochastic programming model to address a scheduling day-ahead problem of an energy community operating under a peer-to-peer (P2P) energy trading scheme.

The formulation proposed i) considers the network technical constraints, ii) prevents the energy buying and selling by users simultaneously, and iii) allows the prosumers to act as buyers or sellers depending on their load consumption and self-generation.

In order to reduce the shared information by consumers/prosumers that trade energy in the local energy market (LEM), the proposed model is decomposed into a master problem (MP) that manages the network technical limitation and subproblems (SPs) that handled the LEM. With this purpose, the Benders decomposition approach is implemented using the recently introduced Strengthened Benders cuts to address the binary variables related to the market and battery operation present in the SPs.

The model and the algorithm are tested in the 69-bus radial distribution system, considering from 3 to 39 agents trading energy to measure the model scalability and the algorithm convergence showing that the proposed methodology reduces the LEM's shared information without increasing the energy community cost.

2 - Making transmission system planning robust to extreme weather events - an application of adaptive robust optimization
Maximilian Bernecker, Iegor Riepin, Felix Muesgens

In this paper, we suggest an approach for electricity transmission system reinforcement planning robust to extreme weather events, like cold Dunkelflaute, aka anticyclonic gloom characterized by calm winds and overcast conditions combined with coldness.

We use the ARO approach to formulate a robust electrical transmission network expansion problem under extreme weather events in the German energy system. Mathematically, we formulate a three-level mixed-integer optimization problem, which we convert to a bi-level problem via the strong duality concept and solve using a constraint-and-column generation algorithm. We use cardinality-constrained uncertainty sets to model the effects of extreme weather realizations on supply from renewable generators (wind and solar photovoltaics) and electricity demand. This approach is promising because worst-case scenarios like the Dunkelflaute can be identified and addressed by the optimization algorithm endogenously. Furthermore, the ARO model allows controlling the degree of conservatism of the solution and is computationally tractable both practically and theoretically.

In sum, we contribute to the large research stream on transmission network expansion problems with the approach of planning electrical network expansions that are robust to extreme weather events like the Dunkelflaute.

3 - Adaptive robust optimization for European strategic gas infrastructure planning
Iegor Riepin, Matthew Schmidt, Luis Baringo, Felix Muesgens

The European natural gas market is undergoing fundamental changes, fostering uncertainty regarding both supply and demand. This uncertainty is concentrated in the value of strategic infrastructure investments, e.g., projects of common interest supported by European Union public funds, to safeguard security of supply.

This paper addresses this matter by suggesting an adaptive robust optimization (ARO) framework for the problem of gas infrastructure expansion planning that considers long-term uncertainties. This framework confronts the drawbacks of mainstream methods of incorporating uncertainty in gas market models (i.e., stochastic scenario trees), in which the modeler predefines the probabilities and realization paths of unknown parameters. The ARO model endogenously identifies the unfortunate realizations of unknown parameters, and suggests the optimal investments strategies to address them. We use this feature to assess which projects are valuable in maintaining system resilience amid cold-winter demand spikes, supply shortages, and budget constraints.

We show that robust solutions point to consistent preferences for specific projects. Results highlight that real-world construction efforts have been focused on the most promising projects from a business perspective. However, we also find that most projects of common interest are unlikely to be realized without financial support, even if they would serve as a hedge against stresses in the European gas system.

4 - Stochastic optimization-based community energy trading approach to offer reactive power from distributed energy resources for ancillary services market
Fernando García

A two-stage stochastic programming energy trading model is presented in this article to measure the distributed energy resources capability to provide reactive power as ancillary services to the distribution system operator under a day-ahead and intraday markets. The centralized energy trading model uses the second-order cone relaxation of the optimal power flow to represent the network technical limitations and considers community batteries to study the effect on the global cost under a collaborative scheme. Besides, the formulation prevents the simultaneous buying and selling of energy in the local energy market by agents and identifies the extra energy absorbed and injected by the agents' batteries to face the uncertainty related to the intraday market, as an agents' flexibility service for the community. The model has been programmed in Python-Pyomo and tested in the IEEE 33-bus radial distribution system under three different scenarios showing that the DERs can i) self-satisfied the reactive power demand, ii) provide reactive power to the DSO, and iii) decrease the community cost significantly in an eventual ancillary services market.

■ MB-13

Monday, 10:30-12:00 - U119

Applications in Discrete Optimization I

Stream: Discrete Optimization and Algorithms (contributed)
Contributed session
Chair: Richard Lusby

1 - Solar Farm Cable Layout Optimization as a Graph Problem
Sascha Gritzbach, Dominik Stampa, Matthias Wolf

We introduce the Solar Farm Cable Layout Problem (SoFaCLaP), the optimization problem of finding a cost-minimal cable layout in a utility-scale solar farm. A given set of photovoltaic strings must be connected to transformers via other electrical devices such as inverters. Each device has a capacity on the number of strings that can use this device. For each connection in use, one of several cable types has to be chosen. The cable types are defined by their thermal capacity and their installation costs per unit of length. This gives rise to a step-cost function on each connection.

We model SoFaCLaP instances as a layered graph where each layer represents one type of electrical device and edges define pairs of devices in adjacent layers that can be connected. A feasible solution is a subforest of the graph in which each string is connected to a transformer such that all capacities are respected. The costs of a solution are the costs for the cables on all edges of the forest and the cheapest possible solution has to be found. It is already NP-hard to find a feasible solution. We introduce a Mixed-Integer Linear Programming formulation for SoFaCLaP and a publicly available set of synthetic instances based on real-world parameters.

SoFaCLaP shares points of similarity with classical problems such as the Steiner Tree Problem on graphs and the Multi-Level Facility Location Problem. SoFaCLaP readily allows various extensions such as installation costs for electrical devices.

2 - Cutting Plane Techniques for Robust Kidney Exchange Models
Danny Blom, Christopher Hojny, Bart Smeulders

Kidney exchange programs (KEPs) play a growing role in treating end-stage renal patients, offering living donor kidneys to recipients with a willing, incompatible donor. The aim is to identify such donor-recipient pairs that can exchange donors leading to feasible transplants for each recipient.

Unfortunately, planned transplants may be canceled for a variety of reasons, hence it is crucial to plan exchanges while considering failures and recourse options. In this paper, we reconsider a robust optimization model with recourse proposed in Carvalho et al. (2020), taking into account the event that a number of donors leave the KEP. In the recourse step, the goal is to maximize the number of recipients matched in both the initial and recourse solution. Current algorithms do not allow us to find optimal solutions for this model for realistic-sized KEPs within a reasonable time frame.

We propose a new variable and constraint generation method for solving a large-scale mixed-integer programming formulation based on cutting planes. We characterize this method based on two widely used integer programming models for KEPs. Furthermore, a lifting technique is proposed to obtain stronger cuts to speed up computation. Computational results show that our algorithm is very competitive, improving the running time of the state-of-the-art method by an order of magnitude. Furthermore, our methods are able to solve a large number of previously unsolved instances within the same time limit.

3 - A heuristic approach to integrate train timetabling, platforming, and railway network maintenance scheduling decisions
Richard Lusby, Qin Zhang, Pan Shang, Xiaoni Zhu

Train timetabling, platforming, and network maintenance scheduling are three highly interdependent problems that are crucial in the planning of railway operations, and each is normally addressed separately. In this paper, we simultaneously optimize these problems for a high-speed railway network that is comprised of multiple railway lines and stations. We model the railway network on a mesoscopic level and formulate a 0-1 binary integer programming model that minimizes the total train weighted running cost and any deviation from ideal maintenance task start times. A heuristic procedure, which dynamically updates the available time windows for each of the trains, is used to control the number of train paths in the mathematical model. The mathematical model is repeatedly solved, and at each iteration we gradually modify the set of train paths available. Four different strategies to modify train time windows are used in the train path modification step and their selection depends on the solution to the mathematical model. Computational results for three networks of different sizes conclusively demonstrate that there is not only benefit in integrating these problems, with improvements of as much as 30%, but also that the proposed solution approach is highly effective. Compared to the commercial solver CPLEX, the proposed approach is able to more quickly find better quality solutions within a given time limit.

■ MB-14

Monday, 10:30-12:00 - U261

Network Optimization: Theory and Applications

Stream: Network Optimization
Invited session
Chair: *Clemens Thielen*
Chair: *Jan Boeckmann*

1 - Algorithms for weighted global defensive vertex and edge alliances

Kacper Wereszko, Michał Małafiejski

Global defensive alliance (GDA), global edge alliance (GEA) and global 2-complete alliance (G2CA) are graph theory problems related to dominating sets. A defensive, edge, or 2-complete alliance in a graph is a subset of vertices for which every vertex, edge, or clique of size up to 2, respectively, is secured in this alliance.

Decision versions of these problems are known to be NP-complete, even when the input is restricted to subcubic graphs. Weighted GDA and GEA problems have some interesting practical applications. While for weighted GDA there are some studies regarding complexity and fixed parameter tractability, for weighted GEA and weighted G2CA these questions remain open. Also, there is a lack of methods that could solve weighted GDA, GEA or G2CA problems efficiently in general graphs. Moreover, in the literature there are no mentions of approximation algorithms for (weighted) GDA, GEA and G2CA that achieve a constant approximation ratio.

In this talk we want to present our work of designing efficient algorithms that, for an arbitrarily given simple graph, yield a subset of vertices of the graph, which is a legal weighted global defensive alliance, global edge alliance or global 2-complete alliance, with size close to the optimal one. We formulated weighted GDA, GEA and G2CA as ILP problems and we designed, analyzed, implemented and tested a Local Search (LS)-based heuristic for both problems.

2 - Shortest Path Interdiction on Temporal Graphs

Jan Boeckmann, Clemens Thielen, Alina Wittmann

Temporal graphs are a generalization of static graphs where the vertex set is fixed, but the edge set changes over time. Despite broad applicability, little is known about interdiction problems like the shortest path interdiction problem on temporal graphs. Whereas the shortest path interdiction problem is NP-hard in the static case, there exist, depending on the definition of "shortest", exact polynomial-time algorithms in the temporal case.

For various meaningful definitions of "shortest" paths on temporal graphs, we present corresponding complexity results or exact polynomial-time algorithms for the shortest path interdiction problem on temporal graphs. To the best of our knowledge, we are the first to investigate the highly relevant shortest path interdiction problem on temporal graphs.

3 - Using pseudo cuts to solve the sharing problem with conflict graphs

Abdelkader Sbihi

We study the sharing problem with incompatibility graph (SPCG) defined on disjoint classes of elements and whose objective is to maximize the total outcome guaranteed under resources constraint. SPCG considers conflict constraints between pairs of elements. This problem is particularly interesting when conflicting decisions appear for certain optimization problems. We recall that the sharing problem considers items distributed on disjoined classes and whose objective is a fair sharing of resources between the different classes. Given a graph G=(V, E), we say that two items i and j are incompatible if the edge (i,j) of E a subset of VxV represents an independent set constraint. It is clear that considering a subset of pairs of incompatible elements per class represents a conflict graph. We propose several algorithms to solve SPCG. A first approach is a constructive greedy heuristic that iteratively builds a feasible solution. A second approach is a Relax-and-Reduce (RR) matheuristic technique.

We solve a series of relaxed problems which, in turn, lead to a series of reduced problems. Then, to improve the performance of the RR algorithm, we introduce: (i) valid inequalities to accelerate the solution of reduced problems and (ii) an approach chosen to reduce the gap between the lower and upper bounds.

Experimental tests show the efficiency of incorporating valid pseudo valid cuts for this problem.

■ MB-15

Monday, 10:30-12:00 - U262

Decision Making Under Uncertainty

Stream: Decision support (contributed)
Contributed session
Chair: *Fatima Almaghrabi*

1 - Salvage Logging Under Uncertainty

Constanza Lorca, Rodrigo A. Carrasco

The rise of wildfires worldwide depicts a severe threat for the forestry sector affecting their primary income source. The "Salvage Logging Problem" stems from this scenario, where the major challenge for the forestry company is to decide between claiming certain forest stands to the insurance companies or harvesting the burnt timber. In the latter, there is a limited timeframe before the wood loses its value due to staining and decomposition. The post-fire strategy aims towards optimizing forestry's financial metrics. However, given that the harvesting schedule is based on estimations of wood availability, errors might place the company in an unfavorable position at the end of the harvesting period. Our research study introduces a novel stochastic optimization model for scheduling activities under uncertainty. The introduction of chance constraints aims to stabilize the company's financial position, as well as reduce the unharvested wood inventory, considering the estimation errors inherent to this problem. Additionally, this approach can increase the personnel's utilization rate, which in turn reduces the risk of losing their jobs. Through real forest instances and simulations, we examine the chance constraint's impact and the performance of our model's key metrics. The decisions made through this approach can improve the workforce's planning, providing a suitable solution for the forestry, regarding their operational constraints and adverse circumstances.

2 - Strategic Workforce Planning with Deep Reinforcement Learning

Sandjai Bhulai

We present a simulation-optimization approach to strategic workforce planning based on deep reinforcement learning. A domain expert expresses the organization's high-level, strategic workforce goals over the workforce composition. A policy that optimizes these goals is then learned in a simulation-optimization loop. Any suitable simulator can be used, and we describe how a simulator can be derived from historical data. The optimizer is driven by deep reinforcement learning and directly optimizes for high-level strategic goals. We compare the proposed approach with a linear programming-based approach on two types of workforce goals. The first type is operational, consisting of a target workforce that is relatively easy to optimize for but hard to specify. The second type is strategic and is a possibly non-linear combination of high-level workforce metrics. These goals can easily be specified by domain experts but may be hard to optimize for with existing approaches. The proposed approach performs significantly better on the strategic goal while performing comparably on the operational goal for both a synthetic and a real-world organization. Our novel approach based on deep reinforcement learning and simulation-optimization has a large potential for impact in workforce planning. It directly optimizes for an organization's workforce goals that may be non-linear in the workforce composition and composed of arbitrary workforce composition metrics.

■ MB-16

Monday, 10:30-12:00 - U264

Conceptual Real Options and Real Options Thinking

Stream: Real Option Analysis
Invited session
Chair: Mikael Collan

1 - Real Options view to Firm Resilience - Additive Manufacturing Point-of-View
Mikael Collan

Resilience is the ability of firms to cope with sudden and dramatic changes in the business environment. Typically firms with the flexibility to change the way they are operating in terms of what they produce and how they operate are less vulnerable to dramatic changes than companies with fixed architectures and product sortiments. In the field of manufacturing resilience is a topic that has risen in importance with the pandemic. Digital additive manufacturing, commonly known as 3D-printing, is a highly flexible digital manufacturing process capable of producing parts with highly complex geometries by using metals, plastics, and resins. An additive manufacturing unit is substantially a "universal production machine" capable of producing any geometry within its limits. This means that the owner of the unit has flexibility to decide what to produce - flexibility that a single purpose machine does not carry. When a fleet of additive manufacturing machines is used, a company can flexibly and with relatively low costs, change their production according to demand. This makes flexible manufacturing companies robust and resilient. The flexibility is not automatic that is, it has to be constructed by way of preparing processes and the personnel for possible fast changes and by obtaining access to libraries of digital "recipes" for a wide range of products. We take a strategic real options and dynamic capabilities view on these issues.

2 - Real optionality of flexible policies - designing a long-term sustainable approach for adoption of new technology
Mariia Kozlova, Mikael Collan, Julian Scott Yeomans

Many countries have run down their renewable energy support schemes. This development has been due to market evolution and the lack of flexibility within the policies. When policies are suddenly cancelled the effects may be negative on the investment climate, especially if cancellations are retroactive in the sense that their effects touch investments that are already in place with sunk costs. In this respect, it would make sense to have policies in place that adapt to the changing environment and thus any changes can be ex-ante understood and valued by investors - interestingly such adaptive policies are still rare and there is a research gap with regards to such policy architectures.

In this research, we study adaptive policy architectures and ex-ante analysis of renewable energy support policies from the point of view of policy flexibility. The tool used for the analysis is the Monte Carlo simulation together with Simulation Decomposition. The method used is able to consider combinations of factors and intuitively present results. As real-world cases, we study the flexible Russian renewable energy policy and the inflexible Finnish biofuel support policy. We also outline the importance of considering other support instruments that may affect policy efficiency. Our conclusion is that adaptive policies can be more long-standing and thus more sustainable from the point of view of investors, especially in terms of lowering political risks associated with policy changes.

3 - Why Real Option Valuation Fails in the Context of Managerial Investment Decision Making
Jyrki Savolainen

This paper discusses some of the underlying assumptions of real option valuation (ROV) -logic to pinpoint some of the main reasons on why and how it has failed to make its way into the managerial investment decision-making practice in projects. As our central claim, we argue that the quantitative ROV represents investment decisions as a gamble without the context of ownership or entrepreneurship. By term gamble, we refer to the assumption that investment decisions would be recurring situations where the risks are hedged out by the current cash position of the player.

We further elaborate on four conditions of investment decision-making and their effect on the "real optionality" of decisions. First, the majority of managers can be considered risk-averse investors who are willing to settle for the investment value provided by the traditional Net Present Value (NPV) calculation. Second, in most cases, there is limited availability of financing for risky projects and if it is available, the funding is heavily concentrated on certain market players. Third, many companies operate close to monopolistic "winner take all" -markets suggesting that many investment outcomes are viewed by managers as win-lose binary outcomes instead of continuous numbers. Lastly, the value of projects is tied to the existing capabilities of the companies which inhibits their formulation as explicit ROV problems.

4 - Industrial Utilization or Storage of CO2? A Compound Real Options Valuation for the Retrofitting of Coal-Fired Power Plants
Reinhard Madlener, Qinghan Yu

We investigate the sequential investment in carbon capture and storage (CCS), i.e. the case of retrofitting of a coal-fired power plant, and carbon capture and utilization (CCU) for methanol production. A (nested) compound real options model based on a backward recursive dynamic programming algorithm is used for the analysis. The options to invest in CCS and CCU are investigated individually first, and then sequentially, leading to a hybrid CCUS plant that enables both methanol production and CO2 storage. The prices of electricity, carbon and methanol are considered as stochastic and correlated with each other. Managerial flexibility exists regarding a postponement of the investment decision and the real-time optimization between selling methanol to the market or storing CO2 for earning carbon credits after establishing the CCUS plant. We find that at today's relatively high CO2 prices CCS investment is economically rational, whereas CCU for methanol is not. Combining CCS with CCU increases the overall investment probability and potential for larger profits. Since methanol is more valuable than CO2, CCU can be expected to dominate the value of the compound option for the case of favorable market conditions (i.e. sufficiently high methanol and CO2 prices).

■ MB-17

Monday, 10:30-12:00 - U356

Accounting 2

Stream: Operational research in financial and management accounting
Invited session
Chair: Lukas Benjamin Heidbrink

1 - Improving discounted cash flow-based valuations with random forests
Lukas Benjamin Heidbrink

Accounting regulations as well as company valuations require discounted cash flow (DCF) based valuations and hence cash flow forecasts. Traditional methods for the preparation of such forecasts are often either highly subjective and not comprehensible or simple extrapolations of historical data. This talk discusses random forests (Breiman, 2001) as an alternative forecasting method for use with DCF-methods. It consists of a large number of decision trees to estimate and forecast historical accounting data. While random forests are more difficult to interpret than regressions, they are superior to artificial neural networks in terms of comprehensibility and achieve higher accuracy than extrapolations in many settings. The forecasting performance of presented models is evaluated based on one-step ahead direct forecasts, many-step ahead recursive forecasts and iterative one-step forecasts. Results indicate that random forests predict operating cash flows with higher accuracy than extrapolations, especially in the short term. This systematic forecasting of cash flows hence is a useful alternative to regular methods. It improves the quality of financial statements and company valuation wherever DCF-based methods are applied, at least by providing a further reference value.

2 - Data accounting
Michał Jan Gajda

Error tracing and error-impact estimation has been a holy grail of practical use of automated approaches to risk reporting, large-scale distributed error tracking, automated debugging.

Since processing of risk reports and data analysis pipelines can be frequently expressed using a sequence relational algebra operations, we propose a replacement of this traditional approach with a data summarization algebra that helps to determine an impact of errors. It works by defining data analysis of a necessarily complete summarization of a dataset, possibly in multiple ways along multiple dimensions. We also present a practical experience report and sample implementation in Haskell to better communicate how this error impact tracing also facilitates easier debugging and more efficient development of analysis pipelines.

This approach can also be described as an extension of axiomatic theories of accounting into data analytics, thus dubbed data accounting. We also propose formal properties that allow for transparent assertions about impact of individual records on the aggregated data and ease debugging by allowing to find minimal changes that change behaviour of data analysis on per-record basis.

3 - A cash-flow inventory problem maximising the survival probability with joint chance constraint
Zhen Chen

This paper investigates a multi-period stochastic cash-flow inventory problem maximising the long-time survival probability, which may be the objective of some companies especially in the economic distress periods. In order to avoid too much lost sales, there is a joint chance constraint that the lost sale rate in the planning horizon should be lower than a specified level. We adopt the sample average approximation (SAA) method to solve the problem and construct a statistical upper and strict lower bounds for it. The extended formulation of SAA and rolling horizon approach are also applied to speed up the computation when the problem size is large. Finally, we test the performance of the approaches in an extensive computational study.

4 - detecting companies' financial distress on time: adding business perspectives to machine learning models
Jelena Radovanovic, Christian Haas

Corporate bankruptcies often have severe consequences for all stakeholders, from financial stakeholders losing their investment to employees losing their jobs. Traditional bankruptcy prediction models typically focus on predicting the event of bankruptcy itself, without considering additional criteria such as the volume/lost capital and lost jobs. We improve bankruptcy prediction models by actively integrating the magnitude of bankruptcy into the decision process. For this, we define two new performance metrics: first, the number of jobs that are affected by the bankruptcy, and second, the capital that the investors would not have lost if the financial distress of the company was recognized on time. To estimate the predicted socio-economic costs of different models, we implement several Machine Learning[U+202F]models and compare them to two frequently used statistical methods, multivariate discriminant analysis and logistic regression, the latter serving as a benchmark to show the improvements of the predictions that can be achieved using Machine Learning models. We apply the models on a large real-world data set consisting of information about listed companies in North America from the Compustat database, for the period from 1985 to 2020, with over 190,000 company-year observations. The results show that models that yield the lowest predicted socio-economic costs do not necessarily correspond to the best models on traditional statistical metrics such as accuracy.

■ MB-18

Monday, 10:30-12:00 - U358

Dynamic programming and duality in convex stochastic optimization

Stream: Stochastic and Robust Optimization
Invited session
Chair: Teemu Pennanen

1 - Parametric Stochastic Dynamic Programming. Application to Day-Ahead and Intraday Co-Management of a Power Unit
Michel De Lara, Adrien Le Franc, Pierre Carpentier, Jean-Philippe Chancelier

We consider a multistage stochastic optimization problem whose data (stagewise costs, dynamics) depend on a sequence of deterministic parameters. Under a white noise assumption, the problem is amenable to dynamic programming. As a first contribution, under convexity and differentiability assumptions, we display a backward equation for the gradients of the Bellman value functions with respect to the parameter. Second, when the differentiability assumption is not satisfied, we propose two approximation methods for the stagewise costs: one is based on a smooth approximation with the Moreau envelope; the other one on a polyhedral approximation and uses the SDDP algorithm. Third, we provide an application in energy management. We consider a renewable power unit equipped with a battery and engaged in day-ahead load scheduling. The unit manager must submit a day-ahead power production profile (sequence of deterministic parameter) prior to every day and, by operating the battery (intraday decisions), is engaged to deliver power accordingly and is charged penalties if the delivered power differs from the submitted profile. The production profile affects the optimal value of the intra-day management of the battery, where the photovoltaic production induces stochasticity. Thanks to the theoretical results above, we provide optimal production profiles and compare them to state of the art approaches (MPC).

2 - Dynamic programming in convex stochastic optimization
Ari-Pekka Perkkiö

This paper studies the dynamic programming principle for general convex stochastic optimization problems introduced by Rockafellar and Wets in the 1970s. We extend the applicability of the theory by relaxing compactness and boundedness assumptions. In the context of financial mathematics, the relaxed assumptions are satisfied under the well-known no-arbitrage condition and the reasonable asymptotic elasticity condition of the utility function. Besides financial mathematics, we obtain several new results in linear and nonlinear stochastic programming and stochastic optimal control.

3 - Duality in convex stochastic optimization
Teemu Pennanen

This paper studies duality and optimality conditions in general convex stochastic optimization problems introduced by Rockafellar and Wets in the 1970s. We extend the applicability of the theory by relaxing compactness and boundedness assumptions. In the context of financial mathematics, the relaxed assumptions are satisfied under the well-known no-arbitrage condition and the reasonable asymptotic elasticity condition of the utility function. Besides financial mathematics, we obtain several new results in linear and nonlinear stochastic programming and stochastic optimal control.

4 - Stochastic Dual Dynamic Programming for Optimal Power Flow Problems under Uncertainty
David Wozabal, Adriana Kiszka

We propose the first computationally tractable framework to solve multi-stage stochastic optimal power flow (OPF) problems in alternating current (AC) power systems. To this end, we use recent results on dual convex semi-definite programming (SDP) relaxations of OPF problems in order to adapt the stochastic dual dynamic programming (SDDP) algorithm for problems with a Markovian structure, employing scenario lattices to discretize the underlying randomness. We show that the usual SDDP lower bound remains valid and that the algorithm converges to a globally optimal solution of the stochastic AC-OPF problem as long as the SDP relaxations are tight. To test the practical viability of our approach, we set up an extensive case study of a storage sitting, sizing, and operations problem under uncertainty about demand and renewable generation using the IEEE RTS-GMLC network. We show that the convex SDP relaxation of the stochastic problem is usually tight and discuss ways to obtain near-optimal physically feasible solutions when this is not the case. Using these results, we demonstrate that the algorithm finds a physically feasible policy with a small optimality gap to the original non-convex problem and yields a significant added value of $27%$ over a rolling deterministic planning policy.

■ MB-20

Monday, 10:30-12:00 - Y228b

Are you SERIOUS?! - Teaching Operations Management through Serious Games

Stream: OR Education
Invited session
Chair: Lissy Langer
Chair: Jens Weibezahn

1 - INSYSTED Workshop - Are you SERIOUS?! - Teaching Operations Management through Serious Games
Kristian Bänsch, Lissy Langer, Jens Weibezahn, Thomas Volling

The open-source platform INSYSTED (Integrated System for European Digital Learning) is currently being developed by a consortium of Technische Universität Berlin, University College London, Politecnico di Milano, and CentraleSupélec in Paris. The INSYSTED platform supports lecturers in creating, playing, and sharing serious games. In this workshop, we want to introduce the INSYSTED framework and illustrate its application using a serious game that focuses on Operations Management.

Operations management is a quantitative core area of Industrial Engineering and Management education where students need to tackle the stochastic-dynamic interdependencies of processes within supply chains. In order to do so, students need to acquire a deep understanding of the underlying theoretical concepts, methods, and tools. This is especially challenging for students at an introductory level. The heterogeneous knowledge and interests as well as the sheer number of participants in typical introductory courses urgently require new solutions for personalized learning. Against this background, a web-based serious game was developed at Technische Universität Berlin. In subsequent game levels, students are confronted with the challenges of everyday production management, experience system dynamics, and improve their analytical skills.

In this workshop we want to introduce the serious game, user management, and learning management system integration in an interactive manner and present insights from using the game in Operations Management education. We will discuss with teachers how they can adapt the game to their individual needs. Teachers will gain access to the platform and will be able to setup and play their own games.

■ MB-21

Monday, 10:30-12:00 - Y229a

AHP/ANP 2

Stream: AHP/ANP
Invited session
Chair: Maria Cristina Pinto

1 - Developing A Model: An Application of Analytic Hierarchy Process Techniques for Couchsurfers
Pin-Ju Juan

This study reports on research in progress on the subject of travelling risk evaluation and relates them to couchsurfers selection process. This study aimed to determine the optimal couchsurfers for a backpacker to be constructed in Asia using analytic hierarchy process (AHP). Finally, a recommended solutions are presented and analyzed based on the strategic plan and can provide valuable insights for academics in international tourism market.

2 - Assessments manipulation in the pairwise comparisons method
Konrad Kułakowski, Michał Strada

Comparing alternatives in pairs is a well-known technique for acquiring preferential information also used in the Analytic Hierarchy Process. Based on such information, a ranking (or recommendation) is built, and a decision is made. If the expert making comparisons and the decision-maker is the same person, the results of comparisons, although perhaps inaccurate, are usually sincere. Generally, the decision-maker will not try to deceive himself. If, however, the roles are played by two different people, there is a danger that the expert may want to express insincere views. Our work is interested in how difficult it is for an expert to be dishonest about the pairwise comparison method. We will propose an effective algorithm of dishonest behavior, and knowing its assumptions, we will consider how to make it ineffective.

3 - Combination of AHP and GIS to select suitable sites for green hydrogen production in North Africa
Maria Cristina Pinto, Emere Arco, Maria Gaeta

To achieve decarbonization, a key step relies on the identification and adoption of appropriate carbon-neutral solutions, requiring structural changes in the energy field that affect society, economy, environment and reshape the geopolitical landscape. Being a multi-disciplinary and spatially-constrained process, energy transition takes effectively place if appropriate methodologies and instruments are adopted, to deliver ad-hoc strategies and support strategic decision-making processes. In this challenging framework, exploiting the synergic combination of the Analytic Hierarchy Process (AHP) with Geographical Information System (GIS) can offer the adequate decision framework to adopt geo-informed interventions, based on different factors and multi-actors perspectives. Specifically, this analysis aims to select suitable sites for the production of green hydrogen, through water electrolysis enabled by renewable electricity. Even if recognized as one of the promising candidates to drive the energy transition, its production relies on several factors, among which the availability of renewable energy, water disposal, adoption of efficient technologies, infrastructure readiness, social acceptance. Focusing on North African areas, the methodology combining AHP and GIS allowed to assess specific drivers and barriers that, belonging to society, technology, environment, geopolitics, and economy, affect green hydrogen adoption, providing potential suitable sites for its production.

■ MB-22

Monday, 10:30-12:00 - Y229c

Climate Resilience in Supply Chain Planning

Stream: Sustainable Supply Chains
Invited session
Chair: *Lukas Meßmann*
Chair: *Lars Wietschel*

1 - Estimating the Carbon Emissions Caused by Electric Vehicle Use in Turkey Using Marginal Emission Factors
Murat Kaya, Tugce Yuksel, Mohamed Maarouf

Electric vehicles (EVs) generate zero carbon emissions during their use; however, the generation of the electricity to charge the EVs does so, the extent of which depends on the primary energy resources used in power generation. In this study, we estimate the carbon emissions caused by the introduction of EVs in Turkey. To this end, we first characterize the EV power demand by the hour based on a simulation model. The model considers EV model characteristics, trip times, and lengths as well as the charging behaviors of EV users. We then characterize the electricity supply in the Turkish power system by determining the marginal power plants and by estimating the Marginal Emission Factor (MEF) for the system. We use real hourly generation data of the country by fuel type, under four different seasons and three time-of-day periods, for years 2014 and 2019. Finally, we bring the supply and demand analyses together to calculate the carbon emission caused by the introduction of the hypothetical EV fleet and compare these emissions with that of ICE vehicles.

2 - A Green-Resilient SC optimization model accounting for uncertainty in demand, disruptions and CO2 prices
João Ribeiro, Daniel Santos, Ana Paula Barbosa-Póvoa

Society has developed an increasing awareness of the importance of resilience and, in particular, the resilience of supply chains (SC). An area of relevance is the relationship between resilience and sustainability and how to approach the issue in a context of uncertainty. For example, reusing products and their re-introduction into the value chain is a sustainability challenge that requires a correct valuation of the societal cost of environmental impact while ensuring that companies and their SC remain competitive and resilient. In this work, a Mixed Integer Linear Programming Model is used to approach the SC design and planning problem. This strategic-tactical model has three sources of uncertainty: 1) Demand 2) Disruptions 3) Price of CO2, through robust optimization. By modelling disruptions and monetizing the environmental impacts of SC in its different components (production, transport, installations and waste) and applying it to a case study, it is possible to obtain reliable results that feed robust conclusions and valuable managerial insights. For this purpose, we provide an analysis of the impact of considering uncertainty in the three mentioned dimensions, using a novel way of modelling uncertainty in the context of resilient SC, and assess the Expected Value of Perfect Information. Additionally, we assess the impact of monetizing CO2 and of applying circular economy principles by comparing forward and closed-loop SC.

3 - Identification of sustainability and resilience attributes for modeling agri-food supply networks in emerging economies: a case of the dairy supply chain in Colombia.
Ilia Rivera, Nicolas Clavijo-Buritica, Andres Gonzalez, Juan Felipe Reyes Rodriguez

The concern to include sustainability and at the same time resilience parameters in the modeling of agri-food supply chains is a challenge for decision-makers. The search for continuity of agri-food network operations in the face of any disruption can generate strategies that negatively impact sustainability. This study characterizes those parameters of sustainability and resilience of the dairy supply chain under a network modeling approach and the potential trade-offs that can emerge between the underlying economic, social and environmental objectives of said parameters. This study constitutes a contribution to both sustainable supply chain and network operations by tailoring a model in a developing country setting, meaning highly dispersed location of its production units and lack of road infrastructure, concerning the achievement of sustainable development goals

4 - Assessment of Resilience and its characteristics in systems and networks
Martin Bruckler, Lars Wietschel, Lukas Meßmann, Andrea Thorenz, Axel Tuma

Multiple global crises have unveiled the fragility of efficiency-driven systems and networks of all kinds over the last decades. Many countries have implemented strategies to lower this risk and increase the resilience of critical infrastructure and supply networks. Several qualitative and quantitative concepts and definitions of resilience in various fields already exist. However, many resilience measurements are dedicated to only one or few aspects of resilience conceptualized in theory. Reviews classifying measurement of system resilience according to theoretical resilience concepts are lacking in literature. We propose a classification framework that generalizes selected resilience measurements for systems and networks following resilience theory. First, these measurements are identified in literature. Subsequently, they are subdivided into fields of application and classified regarding the resilience aspect measured. Third, the classified measurements are generalized to unveil similarities between them, and to assign measurement components to the respective theoretical resilience concept. Our results unveil how resilience characteristics conceptualized in theory are quantified in different systems and networks to close the gap between theoretical resilience concepts (e.g., resilience trapezoid) and quantitative assessments of resilience. This allows for a broader applicability of suitable resilience metrics in infrastructure or supply network optimization models.

■ MB-23

Monday, 10:30-12:00 - Y307

OR in Forestry I

Stream: Specific Applications of OR in Agriculture, Forestry and Fisheries
Invited session
Chair: *Lidija Zadnik Stirn*

1 - OR and sustainability: Quantitative relationships in US national forest plans that may be accommodated in OR efforts aimed at sustainable forest management
Pete Bettinger, Krista Merry, Alba Rocio Gutierrez Garzon

Embedded within US national forest plans is language that may be used to demonstrate forest managers' commitment to follow sustainable forest management principles. Some language may be translated into mathematical relationships that form the objectives or constraints associated with operations research approaches for developing management schedules. Twenty-one recent strategic national forest plans, finalized between 2014 and 2022 under the "2012 Planning Rule", and which range in length from 140 to 658 pages, were selected for this study. The plans indicated that they promote ecological, social, and economic sustainability of the natural resources on lands administered. Contributions to sustainability from these plans may be inferred through traditional financial measures, amenity values, and other non-market mechanisms. The specific quantitative relationships for doing so were extracted from each plan based on a thorough reading of each. The characteristic or statement strength of each observed quantitative relationship was ranked by three experts using a 5-point scale from 2 (strong, clear, sufficient evidence to implement) to -2 (weak, unclear, insufficient evidence to implement). Findings from this work provide guidance to planners in efforts to more formally and clearly state desired future conditions of managed forests, and provide society insight into the various ways in which planners have been considering measurable sustainability criteria on US national forests.

2 - Forest landscape planning under deep uncertainty: an interactive multi-scenario multiobjective approach

Babooshka Shavazipour, Dmitry Podkopaev, Kaisa Miettinen

Decision-making problems of forest landscape planning often have a high dimensionality, involve multiple conflicting objectives and various sources of uncertainty. The decision maker needs decision support tools to deal with such complex problems. Many sources of uncertainty, such as the effects of climate change, cannot be handled through probabilistic models. They, however, might be described as a set of plausible outcomes of future states called scenarios.[U+202F]When decision makers do not have (or cannot agree upon) the likelihood of these scenarios to occur (also known as deep uncertainty), they can be supported to find robust decisions that perform satisfactorily in a wide range of scenarios. Here, support is needed in balancing the tradeoffs of conflicting objectives and scenarios. [U+202F] We propose a novel interactive multi-scenario multiobjective approach to support sustainable decision-making under multiple sources of uncertainty. It incorporates domain expertise of a decision maker and includes a preference simulation technique to ease her/his preference elicitation process. We demonstrate the useability of the proposed approach as a decision support tool with a case study of forest landscape planning with a 50-year planning horizon involving four objectives and twelve scenarios.

3 - Heuristic approaches for forest road and timber transportation problems.

Marta Mesquita, Miguel Constantino, Susete Marques, Jose Borges

Planning forest roads and timber transportation can be a challenging problem due to real world problems size and complexity. We considered a forest case study that extends over 7623 ha located in Northwest Portugal. A harvest scheduling plan that encompasses ten 10-years periods is known. The plan conveys information about the stands to harvest in each period as well as about timber volume to be transported to sawmills and pulp plants. Based on GIS information a forest road network linking potential timber loading sites to national or municipal roads is designed. A MILP model is proposed aiming to minimize forest road building and maintenance costs as well as timber loading and transportation costs, over the planning horizon. A straightforward use of a solver (CPLEX) for this MILP model was not able to provide good solutions. The dimensions of the instances were too large, in terms of the number of vertices, edges and arcs, and the linear programming relaxation bounds were weak, due to a set of big-M variable upper bound constraints, that force a forest road to be built or maintained if timber flows through it. To overcome these issues, we develop and compare different heuristic procedures based on network model simplifications and/or clustering approaches, to estimate tighter variable upper bounds. We present and discuss computational experience considering different harvesting scheduling plans for the case study.

4 - Socio-ecological and economic conflicts in forest management: adapting risk into a group multicriteria method based on fuzzy logic

Lidija Zadnik Stirn, Špela Pezdevšek Malovrh, Vasja Leban

Remarkable research interest is initiated in forest management because of conflicts deriving from social, economic, climatic, ecological, and other changes. Society's demands conflict with forest capabilities, and economy conflicts with ecology and social elements. Further, forest planning is confronted by risk and uncertainty. Conflict and risk reduction play an important role when performing proper forest management strategies. Thus, the offered model that investigates management scenarios which foster resilience of forests and adjacent areas and respects the public acceptance of decisions works with unstructured problems, inaccurate data, uncertainty, conflicting interests, and vagueness of human thoughts. The three-phase decision model is established on participatory, multicriteria and dynamic methods based on fuzzy logic. The first step is the selection and prioritization of members of a decision-making group. In the second step the selected members determine the forest management scenarios, goal, criteria, and sub-criteria. Fuzzy linguistic scales within fuzzy AHP are used for evaluation of the criteria. A special attention is paid to weigh the risk of criteria by transformation of fuzzy numbers through α-level cuts. The outcomes are input for the third phase, where a network in the sense of DP is plotted, and optimal sequence of alternatives through the network is calculated. An example dealing with a small urban forest in Slovenia illustrates the proposed model.

■ MB-24

Monday, 10:30-12:00 - Y307a

Stochastics Models

Stream: Queueing and Stochastics (contributed)
Contributed session
Chair: Sonja Otten

1 - A novel approximation scheme for multidimensional queueing models

Marko Boon

Multi-dimensional queueing systems are a fundamental building block in the modeling and understanding of a plethora of dynamic processes, with an extremely broad range of applications, yet (exact) results for such models are typically very hard to obtain or are even lacking. Steady-state distributional results are thus not generally available and even (good) approximations tend to be difficult to derive or to compute for higher dimensions. In this paper, we focus on a novel approximation scheme, ultimately leading to a better understanding of the stochastic systems at hand. We make use of a functional equation for the probability generating function of the joint queue-length distribution. This functional equation contains several unknown functions which are typically hard to find. We approximate these unknown functions with polynomials, allowing us to approximate the unknown functions by considering the roots of a so-called kernel equation, leading to a solvable set of linear equations. We show the merits of our approach by applying our method to several queueing models from the literature, such as k-limited polling models. We obtain approximations for the joint queue-length probabilities and several other performance measures for multi-dimensional processes.

2 - On the Specification of Dynamic Score-Driven Models

Petra Tomanová, Vladimír Holý

The dynamic score-driven models assume that the time-varying parameter of any underlying probability distribution follows a recursion consisting of the autoregressive term and the scaled score of the logarithmic observation density. Even though the updating mechanism follows a defined rule, two decisions have to be made: (i) to choose a proper underlying distribution and its parametrization, and (ii) a scaling function of the score. The underlying distribution should be sufficiently flexible to model the time series process correctly. Its selection is rather natural, however, the 'right' choice of its parametrization might be ambiguous. It is commonly driven by criteria such as favourability of the parameter interpretation and the ability to ensure that the parameter values satisfy given constraints. However, the choice of the parametrization alongside the scaling function is rather arbitrary with an unclear impact on model performance and stochastic properties. We discuss a wide range of specifications of dynamic score-driven models and investigate the impact of the parametrization and scaling functions on the model performance and stochastic properties. We present the results from the simulation as well as empirical studies such as modeling of arrivals to the queueing systems and modeling of returns and trade durations in financial markets.

3 - The continuous (S,Se,s) inventory model with dual sourcing and emergency orders
Yonit Barron

This paper considers an inventory system of a retailer who uses a continuous review base-stock policy to manage the inventory. We introduce two types of different demand process patterns: a Markov-modulated fluid demands with linear rates, and batch size demands that arrive according to a Markov additive process (MAP). In addition, two different supply policies are considered: (i) a single regular supply follows an (S,s) policy with stochastic lead times under lost sales assumption, and (ii) an additional sourcing of supply that serves as an emergency one, and brings the inventory up to level 0

4 - Load balancing in a network of queueing-inventory systems
Sonja Otten

Production processes are usually investigated using models and methods from queueing theory. Control of warehouses and their optimization rely on models and methods from inventory theory. Both theories are fields of Operations Research (OR), but they comprise quite different methodologies and techniques. In classical OR these theories are often considered as disjoint research areas. Today's emergence of complex supply chains (=production-inventory networks) calls for integrated queueing-inventory models, which are focus of our present research. We consider a supply chain consisting of production-inventory systems at several locations which are coupled by a common supplier. Demand of customers arrives at each production system according to a Poisson process and is lost if the local inventory is depleted ("lost sales"). To satisfy a customer's demand a server at the production system needs raw material from the associated local inventory. The supplier manufactures raw material to replenish the local inventories, which are controlled by a continuous review base stock policy. The routing of items depends on the on-hand inventory at the locations with the aim to obtain "load balancing". We develop a Markov process model for this production-inventory system and show that the stationary distribution has a product form of the marginal distributions of the production subsystem and the inventory-replenishment subsystem.

■ MB-25

Monday, 10:30-12:00 - Y308

Location Analysis II

Stream: Location Analysis
Invited session
Chair: *Filipe Alvelos*

1 - Stochastic programming for positioning wildfire suppression resources under wind uncertainty
Filipe Alvelos, David Neto, André Bergsten Mendes, Eduardo Cunha, António Vieira, António Bento-Gonçalves, Sarah Moura

We consider the problem of deciding the position of a set of available firefighting resources (e.g. teams of firefighters) in a landscape after a fire ignition occurs. We propose a stochastic mixed integer programming (MIP) model where scenarios are associated with the wind direction (its intensity is set to a worst-case value) and two lexicographic objectives are considered: to maximize the average (weighted) number of locations not reached by the fire and to maximize the average fire arrival time at all the landscape locations. For each scenario, i.e. each wind direction, fire transmission times between adjacent locations are calculated also taking into account slopes and fuels. Using the minimum travel time principle, we integrate fire spread and the positioning of the resources in a single MIP through decision variables associated arrival times and the selection of potential positions. The positioning of a resource is modeled as a large increment in the fire transmission time for adjacent locations. We consider that the time taken by a resource to reach a location depends on its distance to a base location. Two solution approaches are devised and implemented: solving the deterministic equivalent and sample average approximation. We present computational results with data from a real landscape in Portugal (Municipality of Baião). This research was supported by project PCIF/GRF/0141/2019 "An Optimization Framework to reduce Forest Fire", funded by FCT.

2 - Minimizing Noise Pollution from Autonomous Drones through Spatial Arrangements
Pawel Kalczynski, Zvi Drezner

We develop a location model for the spatial arrangement of a swarm of drones operating within a densely-developed campus environment that minimizes the noise level in designated areas: classrooms, meeting rooms, offices, etc. The proposed model is a non-linear non-convex model with a differentiable objective and differentiable constraints, so the analytical gradient, Jacobian, and higher-level derivatives are available. We combine two obnoxious facility location models: the minimax and cooperative, and we formulate a hybrid model in which the drones, separated by the minimum required distance, cooperate in inflicting nuisance (noise) on designated noise-sensitive points. The objective function is derived from sound-propagation formulas. The differentiable constraints to ensure that drones are located outside the physical structures are developed using Heron's triangle formula (for two-dimensional models) and Piero della Francesca's tetrahedron formula (for three-dimensional models). We propose a two-step solution technique in which a relatively simple model finds feasible starting solutions, which are later improved by a local non-linear solver that utilizes analytical derivatives. We test our approach on simulated two- and three-dimensional instances as well as on a real-world instance (a large U.S. university campus).

3 - A Cooperative Covering Location Model for Outsourcing Logistic Services
Silvia Baldassarre, Giuseppe Bruno, Ioannis Giannikos, Carmela Piccolo

Many retail companies have been adopting online distribution channels to fulfil demand requirements. In this scenario, different location-based strategies based on outsourcing logistic services are implemented to increase efficiency and expand the potential market shares. For instance, in some cases, companies are integrating the network of their internal facilities with a set of external pick-up points to deliver their products to final customers. This work aims to analyse outsourcing approaches within the location theory framework and provide a mathematical programming model to support decision-making. The problem is formulated as a cooperative covering location model. In particular, we suppose that external and internal facilities are characterised by different coverage decay functions and operating costs. The objective is to redesign the network by repositioning internal facilities and activating new external ones to satisfy the potential demand with minimum operating costs. The model is tested on a real-world case study related to a distribution network system operating in an urban context. The obtained results are shown and discussed to provide fruitful managerial implications.

4 - Sensor location by joint entropy maximization
Rui Sa Shibasaki, Olivier Péton, François Queyroi, Maria I. Restrepo

We consider the problem of estimating freight transportation flows in an urban road network. For reducing the uncertainty of estimations, sensors can be installed on the network nodes to capture real data. However, for economic reasons, sensors are available in a limited number, thus their location should be optimized. The corresponding problem is called the Sensor Location Problem. We study the case where the freight transportation flows are simulated by solving vehicle routing problems. Given a set of simulation models, the flow captured by sensors can be used to identify which models can better represent reality. We present an approach aiming to maximize the joint entropy of the locations, i.e., the sensors must be placed so that the information is maximized, avoiding redundancy. The information provided by a location is measured by its capability of discriminating the models given the flow data. Decision Tree Classifiers are used for that purpose. We will present results from a case study in Nantes, France, and will compare our results with several location policies encountered in the literature.

■ MB-26

Monday, 10:30-12:00 - Y309b

Logistics optimization after major disasters

Stream: EWG HOpe, EURO working group on Humanitarian Operations
Invited session
Chair: *Andréa Cynthia Santos*
Chair: *Christophe Duhamel*

1 - Collection and sorting management phase of an industrial site after disaster
Félix Combaud, Christophe Duhamel, Andréa Cynthia Santos

Industrial disasters in urban areas provide an additional level of complexity due to the proximity to the population. It requires efficient management of hazardous materials and strong mitigation of the impacts. Our work focuses on the reverse logistics of dismantling the disaster area. This is done in two phases : the on-site extraction and sorting of materials, then the workflow of waste management and recycling. Our work considers the first phase of this research project.

After an industrial disaster, the affected site is an aggregate of materials and we aim to schedule the cleaning of the site's sectors. Precedence constraints between sectors model the fact that some areas are not accessible at first, and also some collapsed wastes cover others materials. In addition, several techniques can be used to perform the extraction on each sector. This impacts the quality of extracted materials, the cost and time of extraction. The extraction problem is modelled as a multi-mode and multi-objectives RCPSP. The modes correspond to the extraction techniques and the three objectives are (a) the makespan, (b) the total operation cost, and (c) the quality degradation score. We first propose an exact method to compute the Pareto front. Then we present a metaheuristic to compute an approximate Pareto front for larger instances. Each solution is a possible input for the second phase, and it will have an impact on the recycling management workflow.

2 - Scheduling priority tasks: an application on removing dangerous products after industrial disasters
Thiago Jobson Barbalho, Juan Luis Jiménez Laredo, Andréa Cynthia Santos

In 2019, a fire incident at a Rouen industrial site affected tons of chemicals, releasing pollutant smoke with dangerous products throughout an extensive region of Normandy, France, harming the environment and community at large. In such situations, the released pollutants can be absorbed by plants and soil or infiltrate into the ground, contaminating ground waters. Moreover, volatile products may metabolize into other types of - potentially more harmful - byproducts. As a result, the cleaning of polluted areas requires the deployment of specialized teams and equipment. Despite regulations such as the Seveso Directive, accident prevention policies and emergency plans, operation after industrial disasters remains a challenge. This study aims to model the aforementioned situation as a scheduling problem with precedence constraints and sequence-dependent setup times. The set of tasks represents the polluted areas and a priority is given to each task based on its risk level of contamination. The objective is to minimize the operation makespan where tasks must be treated following priority rules. Furthermore, we present a relaxation threshold to find better solutions by partially or completely relaxing priority rules, according to the stated level of strictness. We propose an exact integer linear program and an Iterated Local Search metaheuristic to solve several theoretical instances which allow us to obtain interesting insights to apply to realistic scenarios.

3 - Stochastic Optimization Approaches for Truck-Drone Tandems in Humanitarian Applications
Hannan Tureci Isik, Melih Celik, Ece Sanci

The use of drones to overcome network inaccessibility in the aftermath of a disaster can increase the timeliness of humanitarian aid operations. In this study, we consider independent truck and drone deliveries for post-disaster relief distribution of light-weight aid items such as packages containing first aid kits, vaccine or hygiene kits. We propose a two-stage stochastic programming model to locate depots prior to a disaster considering the subsequent post-disaster relief distribution by routing ground vehicles and drones simultaneously, considering uncertainty on the road network.

4 - Debris recycling in post-disaster management
Christophe Duhamel, Julien Autuori, Andréa Cynthia Santos, Stefan Balev

Technological disasters strongly impact their environment and disrupt human activities. The area clearing is essential for the restart of the economic activity. Securing and rehabilitation is critical in case of hazardous wastes. We consider the debris management of such areas in order to send them into dedicated recycling processes: concrete, metals, sludge and hazardous wastes. It involves injecting large amounts of materials in a short period of time on existing infrastructures. This work takes into account the tactical level of operations on a 1 year time horizon, with a 1 week time discretisation. The problem is modeled as non conservative flows problem on a directed acyclic graph in which nodes are the steps of the process: impacted area, sorting and processing centers, landfill and recycling outputs. Several products are considered in the crisis logistic, thus the modeling relies on a multigraph. Each processing center is equipped with front and back storage. Capacities, processing time, travel time and costs are set to each node and arc. Two criteria are optimized: the integration of products into the circular economy and the total logistic cost. The risk criteria is handled as a constraint, thus allowing to obtain solutions with limited risks. The Pareto front is computed with the Simplified AUGMented E-CONstraint algorithm and results are provided on realistic instances. The C++ language with CPLEX API is used for development.

■ MB-27

Monday, 10:30-12:00 - Y313

Primal-Dual Methods

Stream: Splitting and ADMM Methods
Invited session
Chair: *Cong Bang Vu*
Chair: *Dimitri Papadimitriou*

1 - The Primal-Dual Method with a Mismatched Adjoint
Felix Schneppe

In recent years primal-dual methods have themselves established as algorithms to solve various optimisation problems. In many cases the given data is created by a linear mapping of a ground-truth signal. One of the most well-known examples of such algorithms is the primal-dual method of A. Chambolle and T. Pock, which uses both the forward linear operator as well at its adjoint. However, in practical applications like computed tomography, it is often computationally favorable to replace the adjoint operator by a computationally more efficient approximation. This leads to an adjoint mismatch in the algorithm.

We analyse the convergence properties under the presence of a mismatched adjoint. We present an upper bound on the error of the primal solution and derive step-sizes and mild conditions under which convergence is still guaranteed. Furthermore we present convergence rates similar to these without the adjoint mismatch. Moreover, we illustrate our results in a few examples with real-world application.

2 - Accelerated Bregman Primal-Dual methods applied to Optimal Transport and Wasserstein Barycenter problems

Juan Pablo Contreras, Antonin Chambolle

This paper discusses the efficiency of Hybrid Primal-Dual (HDP) type algorithms to approximate solve discrete Optimal Transport (OT) and Wasserstein Barycenter (WB) problems without smoothing. Our first contribution is an analysis showing that these methods yield state-of-the-art convergence rates, both theoretically and practically. Next, we extend the HPD algorithm with line-search proposed by Malitsky and Pock in 2018 to the setting where the dual space has a Bregman divergence, and the dual function is relatively strongly convex to the Bregman's kernel. This extension yields a new method for OT and WB problems based on smoothing of the objective and the solution that also achieves state-of-the-art convergence rates. Finally, we introduce a new Bregman divergence based on a scaled entropy function that makes the algorithm numerically stable and reduces the smoothing, leading to sparse solutions of OT and WB problems. We complement our findings with numerical experiments and comparisons.

3 - Hidden convexity in a class of optimization problems with bilinear terms

Meike Reusken, Bram Gorissen, Dick den Hertog

In this paper we identify a new class of nonconvex optimization problems that can be equivalently reformulated to convex ones. These nonconvex problems can be characterized by convex functions with bilinear arguments. We describe several examples of important applications that have this structure. A reformulation technique is presented which converts the problems in this class into convex and tractable problems. We show that this reformulation technique can be used to develop the dual of robust nonlinear optimization problems that are convex in the optimization variables and concave in the uncertain parameters. To find the dual of such problems we employ the 'primal worst equals dual best' technique, where the uncertain parameters become variables in the dual. We show that the 'dual best' formulation has the hidden convexity structure studied in this paper, and therefore can be reformulated into a tractable convex optimization problem. Additionally, we show that inverse optimization problems for general linear and nonlinear optimization problems also have the hidden convexity structure, and hence can also be reformulated as convex problems. The value of the reformulation is illustrated by several numerical experiments for the nutritious food supply chain model for the World Food Programme.

4 - Cone of univariate polynomials non-negative on a bounded interval

Jakub Hrdina

Polynomial optimization problems are problems of optimizing a multivariate polynomial over the feasible set defined by a finite number of polynomial inequalities. It encompasses many problems within various fields of mathematics, e.g. binary optimization, mixed-integer linear programming, global optimization and partial differential inequalities. Problems of polynomial optimization can be equivalently reformulated as problems over the convex cone of non-negative polynomials. We study the decomposition of univariate polynomials non-negative on a bounded interval. We also provide a characterization of the convex cone of univariate polynomials non-negative on a bounded interval and its dual cone.

■ MB-28

Monday, 10:30-12:00 - Y405

Data Science and Analytics Methods 2

Stream: Data science and Analytics (contributed)

Contributed session

Chair: Paulito Palmes

1 - Instance Density-based Adaptive Hybrid Oversampling to Imbalanced Classification Problems

You-Jin Park

One of the important issues in various machine learning applications is the class imbalance problem. This problem occurs when the number of instances of a class is much smaller (or larger) than that of the other classes. To handle the imbalanced classification problems, many useful approaches have been developed and used, for example, synthetic minority oversampling technique (SMOTE) (Chawla et al., 2002). As a data pre-processing task, it is known that the SMOTE works well for most imbalanced classification problems. However, the SMOTE is often sensitive to the predetermined k value, i.e., the number of nearest neighbors that is used to generate the new minority class instances. For example, if the k value is moderately large, some of the synthetic instances generated by the SMOTE would be located close to a decision boundary or even within the majority class area and thus these can be treated as unnecessary noises. Thus, in this study, we propose an efficient oversampling algorithm called IDAHO (instance density-based adaptive hybrid oversampling) to improve the classification performance by generating instances that are closer to the minority class than the majority class while reducing the number of noise instanced oversampled. Through the experimental analysis, it is shown that the proposed method outperforms the traditional oversampling methods with respect to AUC and F-measure for most of the imbalanced datasets regardless of classification models.

2 - Exploring the Possibilities of Geometric Multidimensional Scaling for Large-Scale Data

Viktor Medvedev, Martynas Sabaliauskas, Gintautas Dzemyda

Multidimensional scaling (MDS) is a well-known and widely used technique for mapping data from high-dimensional to lower-dimensional space and data visualization. In our case, the data set consists of points from a multidimensional space. Although MDS demonstrates considerable flexibility, the traditional MDS approaches are limited in the analysis of very large datasets as they require large amounts of computational and memory resources. An alternative is to consider the multidimensional scaling from the geometric point of view. A new method, known as Geometric MDS, has been developed to minimize MDS stress by an iterative procedure where coordinates of a particular point of the projected space are moved to the new position defined analytically. It is proved that coordinates of any point of the projected space may be recalculated in parallel, independently of the remaining points. Geometric MDS has the advantage that it can use the simplest stress function, and there is no need to normalize it according to the number of data points and the scale of proximity. Geometric MDS is compared experimentally with SMACOF, which is one of the most popular realizations of MDS. We investigate how the computational time consumption for data dimensionality reduction depends on the dimensionality and size of the data. Geometric MDS outperforms SMACOF in most cases. This research has received funding from the Research Council of Lithuania (LMTLT), agreement No S-MIP-20-19.

3 - Clustering with a Decision Tree Algorithm

Ioannis Tsiligkaridis

This work focuses on the presentation of a type of a Decision Tree (DT) named Projection Algorithm (PA) and the creation of a cluster (PACL) based on this algorithm. PA, a top-down DT inducer, with the next splitting node criterion (CNN) is based on the purity metric using conditional probabilities.

It works in two phases, the one that discovers the root node and the second one that locates the next nodes. In the first phase, we aim at discovering the node with the maximum homogeneity searching for the feature with the lowest impurity. The second phase (branch selection) is based on the preparation of a table with the conditional probabilities for the next node considering all the feature values from the previous node.

The PACL is based on the PA and it can be used on the fly while the DT is being created. The data of the nodes are included in a set of subsets. The data of subsets are injected into lists. The lists' update with new data is performed after every new split using a hash table. Nodes from the first split create the initial set of lists. After a new split, there is an update of the hash table with the additional feature value.

The complexity of PACL depends on the height of the tree to be created. Comparison with K-means shows the superiority of the PACL.

4 - Scaling-out AutoML Pipeline Search with K8s Cluster
Paulito Palmes, Akihiro Kishimoto, Radu Marinescu, Elizabeth Daly, Parikshit Ram

For a given classification or regression task, AutoML involves finding the best machine learning pipeline consisting of preprocessing elements, ML model, and their hyperparameters. Due to the nature of the search space which is exponential, a common approach to speed up the search is to use bayesian sampling to focus the search in certain promising regions instead of searching exhaustively. The time budget is often employed to regulate the large search space involving continuous hyperparameters. To speed up the search, we discarded the hyperparameter search by using the default hyperparameters of the pipeline elements and formulated a two-stage pipeline search strategy. The first stage starts with a surrogate ML model and searches the corresponding best preprocessing pipeline by cross-validation. The second stage uses the best preprocessing pipeline to search the corresponding best ML model using cross-validation. Each pipeline configuration is independent and can easily be parallelized. By leveraging Julia's distributed API together with K8s distributed architecture, we implemented a distributed framework of the two-stage pipeline search strategy and our results indicate that the best pipeline found is as good and sometimes better than the results of other algos employing the hyperparameter search. Our two-stage approach also took significantly less time by scaling out with K8s cluster and discarding the hyperparameter search.

■ MB-29
Monday, 10:30-12:00 - M1

Planning and Scheduling under Uncertainties

Stream: Industrial Production, Planning and Inventory Management
Invited session
Chair: Boualem Rabta

1 - Optimal Truck Scheduling of Air Freight using Collaborative Planning
Berend Markhorst, Rob van der Mei, Elenna Dugundji

Air cargo has emerged as an essential pillar in the airline industry and will probably grow even more in the coming decades. Therefore, airlines need to efficiently use their resources to meet the increasing demand in volumes and speed. This study focuses on the export stream of goods, especially the acceptance of deliveries at the warehouse just before departure. Most clients' trucks arrive unevenly divided over the week. Combined with limited unloading capacity, this results in heavy congestion at peak hours, which is undesirable for the client and the airline. Currently, most airlines serve the trucks roughly on a first-come-first-serve basis. Yet, there is room for improvement in sequencing the trucks - sticking to a traditional policy as FCFS is not beneficial with such a complex problem. This study proposes both an exact model and a heuristic that strongly reduce the waiting times, increase the acceptance rate and take the uncertainty of arrivals into account via robust optimization. Also, it compares performance between the heuristic and the exact model, both in computation time and quality of the solution. The results show that collaborative planning (i.e. information sharing) in this sector, such as required unloading time and expected time of arrival of the trucks, can considerably increase the throughput and efficiency in a complex supply chain.

2 - Dynamic programming for the management of an oil production network under partial observation
Cyrille Vessaire, Jean-Philippe Chancelier, Michel De Lara, Pierre Carpentier

An oil production network is composed of one or more reservoirs (geological formations containing oil) connected through a network of wells and pipes. At the beginning of the reservoir exploitation, we have only partial knowledge of the content of the reservoir, namely a probability distribution of its initial state.

We propose a formulation of the management of an oil production network, where the reservoir is modeled as a partially observed controlled dynamical system. This approach leads to a well-known class of problems: Partially Observed Markovian Decision Process (POMDP).

However, general POMDPs are often untractable due to the curse of dimensionality. In the case of the proposed formulation, we only need to consider a subclass of POMDPs, so-called deterministic-POMDPs (deterministic transition and observation). We highlight and exploit structure in the deterministic-POMDP formulation to push back the curse of dimensionality. Then, we are able to use Dynamic Programming to find the optimal production planning. We present numerical applications and compare the results with state of the art methods such as SARSOP.

3 - Analysis of stochastic manufacturing systems with unreliable operations
Boualem Rabta

We consider a stochastic manufacturing system in which defects can occur at different stations. Inspection can be performed at selected process steps to ensure nonconforming units are removed/reworked prior to shipment to the customer. In addition, the reliability of the inspection method at a given process step is taken into account via its defect detection rate. We build a model for the evaluation of quality control decisions in manufacturing systems based on queueing network decomposition method. We evaluate a set of quality control policies in terms of financial and non-financial measures and provide managerial insights.

■ MB-30
Monday, 10:30-12:00 - M237

Project Scheduling under Uncertainty and Risk

Stream: Project Management and Scheduling
Invited session
Chair: Maria Elena Bruni

1 - A project scheduling problem with discounted cash flow under uncertainty of payments
Maria Elena Bruni, Oncu Hazir

In this research, we study a variant of the project scheduling problem with discounted cash flow. This problem addresses sequencing of interrelated activities, which are usually related by precedence constraints, while maximizing the net present value (NPV) of the cash flows. Many studies have modelled the deterministic version of this problem. A few have been conducted to address uncertainty cash flows, mainly considering the variability in the amounts received or paid. To the best of our knowledge, the uncertainty of the timing of the payments has not been addressed in the scheduling context so far. In this paper, we opt for addressing the problem of maximizing the NPV in the presence of the above-described uncertainty and considering different payments models under both a risk-neutral and a risk-averse perspective.

2 - Uncertainty-based sensitivity metrics
Fernando Acebes, Jm González-Varona, David Curto, Javier Pajares

The measurement of the sensitivity of project activities is a problem that has received significant attention within project management. A commonly used simulation technique in project scheduling and control is Schedule Risk Analysis (SRA), which has been shown to provide realistic information on the sensitivity of project activities that can be used to perform project control activities. Several metrics are used in the literature (CI, CrI, SI, SSI, ...), which are used to measure different variables of the activities. Since SRA only manages the aleatory uncertainty of project activities to estimate the sensitivity of activities, the standard SRA metrics do not accurately depict the activity sensitivity for projects with identified risks. Beyond the different possible uncertainty definitions, several authors distinguish between four uncertainty types: aleatoric uncertainty (described by variability), epistemic uncertainty (due to ambiguity or imperfect knowledge), stochastic uncertainty (also called 'event risk') and ontological uncertainty (unknown-unknowns). In this paper, traditional sensitivity metric calculations of project activities are extended to include all uncertainty types (aleatoric, stochastic and epistemic). As a result, we propose a new uncertainty-based sensitivity metric (U-SRA). We conducted a computational experiment to validate the results, identifying the activities with the highest sensitivity value and using the proposed new U-SRA metric.

3 - A simheuristic to solve a multi-objective flexible flow shop problem with stochastic machine breakdowns.
Daniel Rodriguez, Daniela Cruz Vargas, David Hernando Gonzalez Estupiñan, Daniel Esteban Delgado Merchan, Eliana Maria Gonzalez-Neira

This study proposes a simheuristic that hybridizes NSGA-II with Monte Carlo simulation to solve a multi-objective flexible flow shop problem with stochastic machine breakdowns. In real contexts, machine breakdowns generate negative impacts such as loss of time, delivery delays, decreased productivity, accumulation of orders, among others. That is why in this study the times between failures and repair times are considered as stochastic parameters, following an exponential distribution. Three objectives are considered that are expected makespan (EM), expected tardy jobs (ETJ), and standard deviation of tardy jobs (SDTJ). The performance of the simheuristic was evaluated through 50 small instances and 209 large instances. The results for small instances were compared to the simulated solutions given by the mathematical model, providing a GAP of -24.96%, -26.29% and -57.79% for EM, ETJ and SDTJ, respectively. This means that our stochastic solutions are much better than the simulated solutions of mathematical model. Moreover, the average running time of the simheuristic was 30s, whereas for the mathematical model was 1428s. The performance for large instances was evaluated in comparison to the simulated solutions given by seven dispatching rules (EDD, SPT, CR, AVPRO, ATC, NEH, NEhedd). The average improvement provided by the simheuristic was 47.65%, 48.34% and 30.19% for EM, ETJ and SDTJ, respectively.

■ MB-31

Monday, 10:30-12:00 - M240

Stochastic lot-sizing problems

Stream: Lot Sizing, Lot Scheduling and Production Planning
Invited session
Chair: Silvio Alexandre de Araujo

1 - Integrated lot sizing and blending problems under demand uncertainty
Silvio Alexandre de Araujo, Maurício Gonçalves, Raf Jans

Integration of problems and optimization under uncertainty are topics that have generated interest in the operational research community. In this paper, we address two-stage stochastic models of integrated blending problem and multi-item capacitated lot-sizing problem with setup times, shortage costs and stochastic demand. Demand cannot be backlogged, but can be totally or partially lost. Our modeling for the blending problem considers items as end products that must satisfy predetermined proportions of qualities (nutrients, chemical compounds, etc.) and are produced directly from a blend of components which contain known proportions of these qualities. Regarding the addressed two-stage stochastic models, we explore different possibilities for the first stage decisions. An optimization package is used to solve the mathematical models considering computational results with small-sized instances. The quality of the proposed approaches is assessed by means of two-stage stochastic indicators, such as, expected value of perfect information (EVPI) and value of stochastic solution (VSS).

2 - Tactical production and collection planning in the blood supply chain
Maria Meneses, Daniel Santos, Ana Paula Barbosa-Póvoa

Collection plays a critical role in the blood supply chain as blood is a limited and scarce resource. Given their perishability, production should closely mirror demand requirements to guarantee an adequate supply and avoid wastage. Such planning activities are tainted by uncertainty, which adds complexity to the management of the blood supply chain. To deal with the stochastic environment whilst keeping the desired service level, it is of utmost importance to develop appropriate tools to address mid-term collection plans coupled with production balancing requirements that achieve some balance between shortages and wastage. To that end, this paper presents an optimization model for collection and production of blood products at the tactical level, under supply and demand uncertainties. The proposed model considers an established blood supply chain with multiple facilities, which constrain the collection and production strategies by the limited personnel and resources capacity of the network. So, the model also optimizes the available resources. Besides, the donor pool available and respective allocation to different collection methods is addressed. Given the complexity of the model, a decomposition technique is applied, namely the rolling-horizon. In order to validate the proposed methodology, a case study of a blood supply chain is used to show the usability of the proposed model and compare the performances of the proposed approach against the current practice.

3 - Bi-objective stochastic lot-sizing with coordinated shipments
Wilco van den Heuvel, Marcel Turkensteen, Rommert Dekker

Inspired by sustainable goals, we consider the problem of coordinating shipments in a stochastic lot-sizing setting. In the problem, there are multiple products, which are shipped periodically from a single supplier to satisfy the demands of customers. Demand of customers is dynamic and stochastic, but we assume that demand distributions are known or can be estimated. Costs are associated with the amount of inventory of each product and with each order of a product. Instead of constructing an order plan per product, there is an opportunity to achieve environmental savings by combining orders implying fewer shipments. This leads to a bi-objective lot-sizing problem with coordinated shipments where both the amount of shipments as well as costs need to minimized, such that a service level constraint for each product is satisfied. We study the static-dynamic version of the problem, where first the ordering periods are determined, and given these ordering periods the ordering plan per product should be obtained. The complexity of the problem lies in the fact that not each product may be ordered in a potential ordering period, as fixed ordering costs are incurred for each product order placed. We propose several heuristic approaches for this problem based on dynamic programming and test the performance in a computational study.

4 - Robust Lot-sizing and Supplier Selection under Lead Time Uncertainty
Simon Thevenin, Oussama Ben-ammar, Nadjib Brahimi

We study the single item lot-sizing problem with supplier selection and uncertain lead time. We consider the situation where a company had preselected a set of suppliers for an item, and these suppliers have different prices, different lead times, but also different reliability. We aim to provide a robust optimization approach to decide when to order, how much to order, and from which suppliers, in the context of uncertain delivery lead time. We formulate the robust optimization problem with polyhedral budgeted uncertainty sets. This formulation does not require assumptions on order crossovers, order splitting, or on the structure of the demand or lead times. We propose an exact row and column generation algorithm to solve the considered problem, along with some enhancements including a fast cut generation procedure. To improve the scalability of the approach we propose several heuristics, including a hybrid of the robust counterpart reformulation and row and column generation, and a fix-and-optimize approach in the row and column generation framework. Experimental results show that the fix-and-optimize approach provides good results. Finally, we provide insight into the reaction of the decision-maker to unreliable suppliers. One of the conclusions is that in the considered framework, an extremely risk-averse decision-maker selects a single supplier, namely the most reliable one even if it does not offer the lowest price.

■ MB-32

Monday, 10:30-12:00 - F101

Mathematical Models in Macro- and Microeconomics 2

Stream: Mathematical Models in Macro- and Microeconomics
Invited session
Chair: *Ulrike Leopold-Wildburger*

1 - Extracting values from consumer returns: The role of return-freight insurance for competing e-sellers
Xiang Zhu

In e-commerce, return-freight insurance (RI) has become a significant profit-enhancing tool for e-sellers, which is used to compensate consumers for their return-freight fees. E-sellers can buy RI to offer it to consumers or allow consumers to buy it. This paper develops a duopoly model to investigate how this new practice (introducing RI) affects the pricing strategies and demand of two e-sellers with different qualities and their RI decisions. First, we confirm that the introduction of RI does not necessarily lead to market expansion. The increase in demand of the low-quality e-seller (E-seller L) hinges on its low RI premium, the competitor's high RI premium, and the high return-freight compensation. Counterintuitively, the high return-freight compensation may prevent consumers from buying from the high-quality e-seller (E-seller H) who offers RI. Second, in contrast to E-seller L, E-seller H is inclined to lower the selling price if RI is introduced. In an online platform with RI, offering RI will induce e-sellers will increase their selling prices. Third, e-sellers prefer to offer RI only if the RI premium is low, the probability of product fit is low, and the return-freight compensation is high. The RI premium is the most important, and the probability of product fit is more important than the return-freight compensation.

2 - Influence of regulator on multicriteria decision-making situation in spatial competition model
Patrícia Holzerová, Zuzana Čičková

The company's competitiveness is important for its success in the market. The competitive environment forces companies to proceed strategically from the moment they decide to enter the market. Choosing location as one of the first steps is one of the key factors determining the future of the company. That is why the topic of placement is gaining still more attention. We focus on spatial models in combination with game theory, an effective tool for the analysis of strategic behavior in conflict decision-making situations. Specifically, we present a situation in which two firms decide on the place of their operation, while their decisions, in addition to the behavior of their potential consumers, are influenced by the regulator as an authority pursuing its own interests, which is preferring a certain area. To analyze such a situation, we use multicriteria decision-making methods, defining two goals of the regulator motivating companies to build their branches in its preferred locations and then minimizing the funds invested in the tools that serve it. He chooses subsidies and a consumer-oriented media campaign as effective tools in this case. The formulated situation is solved in two phases, while the result of the first is the placement of firms in preferred locations and the result of the second phase is the minimization of the cost of tools. The problem is formulated as MINLP (Mixed Integer Non-Linear Programming) problem and we used GAMS software to solve it.

3 - Flattening of Organizations- Does Benchmark Matter?
Zvi Winer

It is a well-known fact that improvement in the level of information communication technology (ICT) is a driving force causing hierarchical organizations to flatten. However, relatively little is known about the impact of the organization's initial data on the level of improvement required for the organization to find it beneficial to flatten and to peel a tier of managers. This paper presents a model of hierarchical organization where the problem of moral hazard is embedded, generalization of Calvo and Wellisz (1979), according to which the phenomenon of organizational flattening can be the result of improved sampling probability and better control over workers due to the development of ICT. The results show that the better the utilization of ICT at the starting point, the greater the improvement needed to flatten the organization, and the higher the rent paid to managers, the smaller the improvement needed to flatten the organization.

4 - Forecasting Behavior in Instable Environment
Ulrike Leopold-Wildburger

Time series models face structural instability when applied to real data. Usually, studies yield to applications without the consideration of breaks leads to unreliable results. Progress has been achieved in the theory of identifying, estimation and testing of structural instabilities by our new procedure. The experimental studies show how efficient the so-called bounds & likelihood heuristic can be. The subjects quickly identify breaks and are able to adapt their forecasts in a surprisingly good manner. The subjects can be well explained by the b&l model despite the occurrence of structural breaks. The bounds & likelihood heuristic manages to model average (not individual) forecasts.

■ MB-33

Monday, 10:30-12:00 - F102

Optimization problems intertwined with Equilibria

Stream: Variational Inequalities, Equilibria, Games and Multilevel Optimization
Invited session
Chair: *Patrizia Daniele*
Chair: *Laura Rosa Maria Scrimali*
Chair: *Giancarlo Bigi*

1 - Finite convergence of proximal-gradient inertial algorithms combining dry friction with Hessian-driven damping
Samir Adly

We introduce a new class of proximal-gradient algorithms with finite convergence properties. These algorithms naturally occur as discrete temporal versions of an inertial differential inclusion which is damped under the joint action of three dampings: a viscous damping, a geometric damping driven by the Hessian and a dry friction damping.The function to be minimized is supposed to be differentiable and enters the algorithm via its gradient. The dry friction damping function is convex with a sharp minimum at the origin. It enters the algorithm via its proximal mapping, which acts as a soft threshold operator on the velocities. The geometrical damping driven by the Hessian intervenes also in the dynamic. Several variants of this algorithm are considered, including the case of the Nesterov accelerated gradient method. We then consider the extension in the case of additive composite optimization, that lead to splitting methods. Numerical experiments are given for Lasso-type problems. The performance profiles, highlight the effectiveness of two variants of the Nesterov accelerated method with dry friction and Hessian-driven viscous damping.

[1] S. Adly and H. Attouch, First-order inertial algorithms involving dry friction damping, Math. Prog. Ser. A (2021). [2] S. Adly and H. Attouch, Finite convergence of proximal-gradient inertial algorithms combining dry friction with Hessian-driven damping, SIAM Optim. (2020).

2 - Exploring differences in firm and individual taxation on CO2 emissions
Stefan Wrzaczek, Luca Lambertini

We build a decentralized model with a production sector and a consumer side. The consumers are assumed to have overlapping generation (OLG) structure with exogenous mortality rate implying an asynchronous time horizon. During the production process firms are emitting CO2 emissions, which aggregate over time. The negative effects of the emission stock, however, are suffered by the consumers only. We solve the problem in decentralized and social optimal setting and show the difference concerning the model dynamics. We propose different tax rates (on the consumer side and on the firm side) and analyze the implications. The key point is that the socially optimal solution can not always be achieved. The OLG structure implies that under some circumstances only the socially optimal emissions, but not the socially optimal consumption path is possible.

3 - Bilevel optimisation with single-step inner methods
Ensio Suonperä, Tuomo Valkonen

We propose a new approach to solving bilevel optimisation problems, intermediate between solving full-system optimality conditions with a Newton-type approach, and treating the inner problem as an implicit function. The overall idea is to solve the full-system optimality conditions, but we precondition them such that we alternate between taking steps of simple conventional methods for inner problem, the adjoint equation, and the outer problem. We prove convergence of the approach for combinations of gradient descent and forward-backward splitting with exact and inexact solution of the adjoint equation. We demonstrate good performance on learning the regularisation parameter for anisotropic total variation image denoising, and learning convolution kernels for image deblurring.

4 - Robustness in optimization via generalized Nash games
Giancarlo Bigi

The introduction of uncertainty sets for data allows dealing with uncertainty in optimization problems by linking feasibility with any actual realization of the data while taking into account the worst-case for the objective as well. Problems such production planning under price uncertainty and portfolio selection are exploited to address how to formulate robust counterparts of optimization problems by relying on infinitely many constraints. In turn, semi-infinite programs (SIPs) can be reformulated as Generalized Nash games with a peculiar structure under some mild assumptions. Pairing this structure with a suitable penalization scheme for GNEPs leads to a class of solution methods for SIPs that are based on saddlepoint problems. Any converging algorithm for these latter problems provides the basic iterations to perform the penalty updating scheme. In particular, a projected subgradient method for nonsmooth optimization and a subgradient method for saddlepoints are adapted to our framework and the convergence of the resulting algorithms is shown. A comparison between the two algorithms is outlined as well.

■ MB-34

Monday, 10:30-12:00 - T003

Dynamic Decision-Making in Transportation

Stream: Smart Mobility and Logistics
Invited session
Chair: Kianoush Mousavi

1 - Dynamic taxi-ridesharing with meeting points
Peter Dieter, Miriam Stumpe, Guido Schryen

Increasing urbanization and the associated growth in traffic volumes make innovative mobility concepts increasingly important. Most traditional mobility solutions center around two extreme paradigms: public transport and private transport. Taxi-ridesharing systems are designed to combine the advantages of both these paradigms, i.e., high flexibility at low costs. Critical success factors for such a ridesharing system are high matching rates and minimal inconvenience for customers. Previous literature shows that introducing meeting points, where customers are picked up and dropped off, in ridesharing systems significantly increases the number of matched customers. Additionally, meeting points can avoid detours and thus reduce discomfort caused by longer trips. However, these approaches only consider systems, where all information in a planning horizon is assumed to be known. We contribute to this research gap by suggesting a dynamic taxi-ridesharing system with meeting points where customers receive notifications immediately after their requests enter the system. We develop a parameterized policy function approximation (PFA) with the objective to maximize the total savings of traveled distances. We evaluate the suggested policy on problem instances arising from real-world data and show that it leads to a significant increase in saved distance when compared to myopic policies. The findings underline the importance to anticipate future customer requests in ridesharing systems.

2 - Estimation of the Arrival Time of Deliveries by Occasional Drivers in a Crowd-shipping Setting
Shohre Zehtabian, Christian Larsen, Sanne Wøhlk

The success of e-commerce business offering same-day delivery depends on customer satisfaction. To speed up deliveries and lower costs, some companies have been using private individuals as non-dedicated drivers to perform pickup and delivery tasks for online customers. Such delivery systems are known as crowd-shipping. Customers have come to expect an accurate estimate for the delivery times of their online orders. The coordination of online deliveries with private individuals is done by a crowd-shipping platform. In this paper, we focus on the estimation of pickup and delivery times. This is a challenging job because not only are the requests unknown and submitted dynamically, but so is the pool of drivers, i.e. delivery capacity. We model the problem as a Markov decision process and integrate it into a simulation study. To improve the estimates that can be done by a naive policy, we propose two policies that use lookahead: one with a fixed lookahead horizon and one with a dynamic. Our numerical experiments demonstrate that a lookahead policy with dynamically adjusted horizon outperforms the other two policies in terms of estimation accuracy, which is up to 19% higher in some instances.

3 - Reinforcement Learning Platform for Small and Medium-sized Enterprises in Logistics
Ali Ghezelsoflu, Amin Asadi, Sebastian Piest, Martijn Mes, Maria Iacob

Nowadays, finding cheap and clean fuel is one of the challenging problems due to the energy crisis in Europe and worldwide. Hence, making intelligent decisions about where, when, and how much to refuel can affect many factors such as time, costs, energy, environmental pollution, and even global warming. From the economic perspective, the fuel price may vary significantly over time and various fuel stations, substantially impacting the total cost of vehicle routing schedules. Therefore, finding an optimal refueling strategy for each truck is one of the main goals of logistic and transportation companies. We consider a homogeneous Vehicle Routing Problem with Time Windows and Refueling (VRPTWR) with variable and stochastic fuel prices. We aim to determine an optimal refueling policy on each route (between an origin and a destination), which indicates the amount of fuel and the selected refueling station satisfying the technical constraints of the problem. We process and incorporate the real-world data that reflect a realistic case study of a prominent logistics company in the Netherlands. We propose two mathematical models based on a Mixed Integer Linear Programming(MILP) and a Markov Decision Process(MDP). We suggest a reinforcement learning method to provide high-quality approximate solutions to the MDP model. We also solve MILP using exact and approximate solution methods. Finally, we present and compare our preliminary results and derive managerial insights for the problem.

4 - Approximate Dynamic Programming for Pickup and Delivery Problem with Crowd-shipping
Kianoush Mousavi, Merve Bodur, Cevik Mucahit, Matthew J. Roorda

Crowd-shipping has gained significant attention as a last-mile delivery option over the recent years. However, crowd-shipping operations are subject to a high degree of uncertainty due to stochastic arrival of online orders and availability of crowd-shippers. In this study, we propose a variant of dynamic pickup and delivery problem with crowd-shipping for delivering online orders within few hours. We formulate the problem as a Markov decision process and develop an approximate dynamic programming (ADP) policy using value function approximation for obtaining a highly scalable and real-time decision-making strategy on matching orders to crowd-shippers while considering temporal and spatial uncertainty in arrival of online orders and crowd-shippers. We consider several algorithmic enhancements to the ADP algorithm such as employing hierarchical aggregation and imposing the monotonicity of the value functions, which significantly improve the convergence. We also propose an optimization-based myopic policy and compare it with the ADP policy using various performance measures including operational cost, percentage of served orders and average order postponement. Our numerical analysis with varying parameter settings show that ADP policies can lead to up 25.2 % cost savings and 9.8 % increase in the number of served orders. Accordingly, our findings demonstrate the viability of ADP for addressing the real-time decision-making aspect of this dynamic crowd-shipping problem.

■ MB-35

Monday, 10:30-12:00 - T004

Mobility, sustainability and equity: new paradigms and approaches II

Stream: Transportation
Invited session
Chair: *Michele Ottomanelli*
Chair: *Aleksandra Colovic*

1 - On Sustainability and Stewardship in Transportation Asset Management
Alexander Engau

Transportation systems all over the world continue to grow rapidly and to become increasingly complex. To better program and respond to the many resulting challenges, Transportation Asset Management (TAM) deals with planning, building, operating, maintaining, upgrading or expanding the underlying transportation infrastructure and its physical assets to promote their overall system performance and sustainability as well as the stewardship of all of its users. In this presentation, based on a recent col-laboration with a major public transportation agency, we will focus specifically on the multi-criterion task to prioritize and select among a large set of proposed TAM projects to recommend an optimal project portfolio under limited budgets but with multiple goals, using different approaches from multi-objective goal programming and data envelopment analysis. These alternatives together with their advantages and disadvantages for a useful implementation in practice will be discussed, and some related lessons learned and avenues for further work will be addressed.

2 - The role of attitudes and perceptions in vehicle type choice behaviour
Francesca Bruno, Roberta di Pace, Stefano de Luca

Advances in technology and services in transportation have made it difficult to correctly interpret and forecast users' choice behaviours by pursuing a purely utilitarian approach. The consolidated discrete choice models succeed with a certain degree of reliability in choice contexts where only directly observable variables play a role. Nowadays the decision-making processes not only depends on the choice context but also on individual preferences, psychological factors, and emotional and motivational user status. Since psychological factors play a key role, especially in long-term choices, it is necessary to take them into account for a better interpretation of the phenomena. Hence, the role of attitudes and perception in a choice context concerning the willingness to purchase alternative fuel vehicles (electric or hybrid vehicles) is investigated through Hybrid Choice Models. A multistage survey was designed and many latent factors (consumption perceptions, attitudes towards the environment, attitudes towards technology, social norms, perceived pros and cons of electric vehicles) were taken into account, both individually and jointly. These latent factors played a significant role in defining the utility associated with alternative fuelled vehicles (in a choice set comprising also conventional vehicles and biofuel vehicles), proving the need to consider these and other factors to increase the attractiveness of strategies to achieve more sustainable mobility solutions.

3 - Fuel cell vehicles for road freight transport: possible impacts on greenhouse gas emissions in Italy
Mariano Gallo, Mario Marinelli

The Italian National Recovery and Resilience Plan (NRRP), among other actions, proposes to invest in hydrogen recharging stations to promote the diffusion and use of fuel cell vehicles for road freight transport. This study has the objective of assessing the possible impacts of this action on greenhouse gas emissions, under different hypotheses related to the hydrogen production methods. To this end, a national supply model has been constructed and the road freight transport matrix between Italian provinces has been estimated. This model made it possible to estimate the vehicle-km on the national network of heavy goods vehicles and, consequently, how many of these could be travelled by FCEVs. By estimating the evolution of road transport demand from 2025 to 2040, it was possible to calculate the GHG emissions saved, if the NRRP targets are met. Initial results show significant effects if hydrogen production is carried out entirely from renewable sources, while the effects are more limited in other cases.

■ MB-36

Monday, 10:30-12:00 - U006

Emergency Services and Transportation in Healthcare

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: *Melanie Reuter-Oppermann*
Chair: *Roberto Aringhieri*

1 - A dial-a-ride problem with additional health care services
Jonathan Grimm

In the research area of health care, the dial-a-ride problem and the health care routing and scheduling problem represent well-known and well-studied decision-making problems. Completing requested transportation services for people with reduced mobility is the scope of the dial-a-ride problem. In most cases, costs are minimized while not exceeding a maximum ride-time limit per customer. In contrast, the assignment and scheduling of requested ambulant care services is studied in the home health care routing and scheduling problem. Taking into account recent developments, we present a new simultaneous approach that integrates the service provision of both types. We focus on the dial-a-ride provider's perspective, i.e. we enable the completion of additional health care services while satisfying all transportation requests. This approach leads to a bicriteria integer programming formulation as costs are incurred when accepting additional services. Exact and heuristic methods are presented and applied for determining the respective (approximated) Pareto front. Furthermore, solution trade-offs are analyzed via metrics and further selected findings are presented.

2 - A vehicle routing problem for massive Covid-19 testing in Antofagasta, Chile
Hernan Caceres, Javiera Auad, Andrea Fernández, Blanca Pañaloza, María Soledad Zuzulich

The COVID-19 pandemic has demanded massive and recurrent testing due to the high number of cases that have been found in the last two years. Mass testing requires significant resource management to develop, which is why a useful tool to manage them is optimization. A project was developed in Antofagasta, Chile, to help small businesses to have more control over positive cases in their establishments. A medical team would visit them regularly to have greater control and provide them with more security. To do that efficiently, a vehicle routing problem with multiple time windows was developed to optimize the time of visit routes and medical equipment necessary to carry out the testing.

3 - Multi objective assignment problem for optimising the dispatch of emergency medical services in the presence of non-homogeneous speciality levels of emergency department
Mariusz Drabecki, Eugeniusz Toczylowski, Krzysztof Pienkosz, Marcin Swierad, Klaudia Kułak, Grzegorz Honisz

Operation of the emergency medical services (EMS) is a multistage process. When an emergency call is received the EMS dispatcher must first assess the priority of the case. Then an adequate ambulance must be assigned to respond. Then, the dispatcher directs the ambulance with the patient in, to an emergency department (ED) at a hospital. Currently, assigning the ambulances and the emergency medical departments to patients happens mostly by minimising the time-to-travel criterion - the closest ambulance takes patient to the nearest ED, regardless of availability of proper treatment there. Worst case: the nearest emergency department may lack the treatment capabilities required for a particular urgent-condition patient. Thus, after admittance, the ED may need to redirect the patient to another specialised hospital. This may result in prolonging the time of receiving treatment and in some cases making it too late to get adequate services. In this paper we propose an interactive multi-criteria optimisation problem for matching patients with both ambulances and with EDs (in the second stage), aiming to find the dispatch that maximises patient's overall survival chances. The problem takes into account the specialisations of EDs and ambulances, and possible referral to different hospitals. Additionally, we propose a framework to incorporate the proposed method into emergency call handling process. The approach is tested in simulations and checked with field expertise of SMEs

4 - Emergency Call Prediction via Convolutional Neural Networks
Maximiliane Rautenstrauß, Maximilian Schiffer

Reducing response times is paramount for emergency medical services to provide first aid in a timely manner. Many models exist to optimize operational tasks such as ambulance allocation and dispatching. Including accurate demand forecasts in such models can improve operational decision-making. Against this background, we present a novel convolutional neural network (CNN) architecture that transforms time series data into heatmaps to predict ambulance demand. Similar architectures have been successfully implemented to accurately forecast spatio-temporal traffic data and mobility demand. However, to effectively predict ambulance demand, applying such architectures requires incorporating external features which strongly influence emergency call volumes. We contribute to existing literature by providing a flexible, generic CNN architecture, allowing the inclusion of external features of different dimensions. We integrate historical ambulance demand and external information such as weather, events, holidays, time, weekday, and month. To increase the model performance, we provide a feature selection and hyperparameter optimization approach that utilizes Bayesian optimization. To show the superiority of the developed CNN architecture over existing approaches, we conduct a numerical case study on the example of Seattle's 911 call data and include external information based on real data. Results show that the developed CNN architecture outperforms existing state-of-the-art methods.

■ MB-37

Monday, 10:30-12:00 - V001

Electric Vehicle Routing

Stream: Vehicle Routing and Logistics
Invited session
Chair: *Bülent Çatay*

1 - Routing electric vehicles with a realistic energy consumption through a kernel search based matheuristic
Massimo Paolucci, Maurizio Bruglieri, Ornella Pisacane

Recent advances in the electric automotive sector are incentivizing the diffusion of the Electric Vehicles (EVs). Since the battery autonomy significantly depends on both the load and speed, EVs may need to recharge at Recharging Stations (RSs) even more than once during a trip. Moreover, due to the scarce spread of RSs, EVs trips must be properly planned, including possible stops for recharges, to avoid EVs run out of the battery along their trips. This work addresses the problem of routing a fleet of EVs, characterized by a realistic Energy Consumption Rate (ECR) depending on both the EV load and speed, for serving a set of customers within their Time Windows (TWs), while minimizing the total operational cost. In addition, each EV starts from the depot and returns to it within a maximum time. This problem, denoted as EVRP with TWs and a realistic ECR (EVRPTW-ECR), is modelled by Mixed Integer Linear Programming (MILP), where the speed is a decision variable as well. The proposed model is cloneless, since it allows multiple visits of the same RSs without introducing dummy copies of them. We also propose a matheuristic, based on a randomized version of the Kernel Search. Its performances are compared with those of the cloneless MILP model on a set of benchmark instances. A detailed sensitivity analysis is finally performed considering both the initial solution quality and the time limit of each restricted MILP model solved by the matheuristic.

2 - Charge scheduling and route planning of commercial electric vehicles by considering the effect of battery degradation
Raci Berk İslim, Bülent Çatay

Battery is a critical component of electric vehicles (EVs) due to its limited useful economic life and high production cost. Hence, better recharging and discharging practices through coordinated and improved route and schedule planning decisions may be a remedy for maintaining good battery health and avoiding fast degradation. In this study, we investigate the effect of considering battery degradation-related cost on route and charge planning of commercial EVs within the context of the Electric Travelling Salesman Problem with Time Windows (ETSPTW). First, we model the mathematical programming formulation of the problem, where the objective function minimizes the costs associated with battery degradation and energy consumption. Next, we develop a Variable Neighborhood Search (VNS) algorithm enhanced with an exact solver employed for the post-optimization of heuristic solutions. Then, we perform computational experiments using benchmark instances from the literature to test the performance of the proposed method and analyze the route plans. Our preliminary results show that incorporating battery degradation in the problem may yield significant changes in the route plans. On the one hand, it offers potential for substantial reduction in operational costs compared to the solutions obtained with minimizing energy consumption only. On the other hand, it leads to more route frequent recharges, which brings in additional operational hurdles.

3 - Electric Vehicle Routing Problem with Flexible Deliveries
Mir Ehsan Hesam Sadati, Vahid Akbari, Bülent Çatay

With an ever-growing interest in e-commerce, parcel delivery is taking new shapes by offering a variety of options to the customers such as an option for selecting multiple delivery locations. From another perspective, this increase in demand requires a new fleet of vehicles that should be added to the current capacities of parcel delivery companies. To meet the greenhouse emission requirements imposed by governments, these companies should adapt their infrastructure to use electric vehicles (EVs) more than before. To provide a solution to these concerns, we define the Electric Vehicle Routing Problem with Flexible Deliveries (EVRP-FD), for the first time. In the EVRP-FD, a fleet of capacitated fully charged EVs dispatch from the depot at the beginning of the planning horizon where the depot is equipped with charging facilities. Each customer is associated with multiple delivery locations with non-overlapping time windows and the demand of each customer should be satisfied in one of their locations within its specified time windows. We investigate the case where EVs can return multiple times to the depot for a full or partial recharge en-route. The solution to EVRP-FD finds the number of utilized EVs and their routes that might include returns to the depot for recharging while minimizing the travel costs associated with the utilization of the EVs. We first develop a mathematical model for the EVRP-FD and then propose a hybrid Variable Neighborhood Granular Tabu Search algorit

4 - Electric vehicle routing problem with time windows and on-demand mobile charging system
Bülent Çatay, Mir Ehsan Hesam Sadati

Raising concerns about climate change has accelerated the shift towards zero-emission vehicles, electric vehicles (EVs) in particular. Delivery companies started using EVs in their fleets to reduce their dependency on fossil fuels and improve their carbon footprints. However, range anxiety, long recharge times and insufficient charging infrastructure still restrain the wider adoption of EVs in the sector. Even if public charging stations are abundant in the region, not all of them are freight vehicle friendly. Installing private charging stations, on the other hand, is not a financially viable option. As a remedy, we investigate the use of mobile charging stations that supply energy to the EVs at points of need and introduce the Electric Vehicle Routing Problem with Time Windows and Mobile Chargers (EVRPTW-MC). In this problem, EVs serve the customers within their time windows and MCs are used to recharge their batteries en-route at selected customer locations. The objective is to minimize the total operational cost by using the minimum number of EVs and MCs. We first present the mathematical model of the EVRPTW-MC. Next, we propose a matheuristic approach that combines the Variable Neighborhood Search and exact method. Then, we perform an extensive numerical study to validate the performance of the proposed method and to investigate the potential benefits of utilizing on-demand MCs. Finally, we present a case study based on real data to provide further managerial insights.

■ MB-38

Monday, 10:30-12:00 - V002

Behavioural forecasting and algorithm acceptance

Stream: Behavioural OR
Invited session
Chair: Shari De Baets

1 - Forecasters versus algorithms: Enemy or ally?
Shari De Baets
Forecasting algorithms provide a significant opportunity for forecasters to improve their accuracy. However, once people have seen an algorithm err, they are quick to abandon it. This phenomenon is known as 'algorithm aversion' (Dietvorst, Simmons, & Massey, 2015). However, recently, Logg, Minson, & Moore (2019) have reported the opposite effect: results from six experiments showed that people preferred the advice of an algorithm over that of a person. The authors termed this 'algorithm appreciation'. How can these findings be reconciled?

2 - In planning we trust: Determinants of trust in the human/system interaction
Ignace Decroix, Shari De Baets
This study investigates the trust formation process between humans and systems, focusing on the interaction between Supply Chain planners and advanced automated planning systems. While trust in automation research is well-documented, two caveats exist—first, application to planning; second, bottom-up theorising. Zooming in on this Supply Chain context, we employed grounded theory to construct an empirical model from interviews and determine which determinants influence the trust formation process between planners and the system. The interviews were conducted at a multinational pharmaceutical company that introduced an advanced planning system in the year before the study. The results of our interviews show 3 primary categories: 'human factors', 'machine factors', and 'context factors'. Overall, 26 variables were identified.

3 - Forecasting the success of megaprojects: A behavioural operations approach
Konstantia Litsiou, Yiannis Polychronakis, Stylianos Sapountzis, Konstantinos Nikolopoulos
Abstract

Forecasting the success of megaprojects is a very difficult and important task because of the complexity of such projects, as well as the large capital investment that is required for the completion of these projects. In this research, we employ behavioural operations approaches, most notably judgmental forecasting methods to predict the success of megaprojects through a series of controlled experiments where the participants forecast for megaprojects with Unaided Judgment (UJ), Structured Analogies (SA), Delphi(D) and Interaction Groups (IG) with IG showing the best results since IG>D>SA>SA. We see separately the success in terms of excesses in the budget and the duration of the project. Furthermore, the participants forecast the extent to which the socio-economic benefits are realised. We do analyse three different stakeholder perspectives: that of the a) project manager, b) funder(s), and c) the public. We do control for two levels of expertise - novices, and semi-experts.

Keywords: Behavioural Operations; Judgemental Forecasting; Megaprojects; Structured Analogies; Group Forecasting

4 - Bias, information, noise: The BIN model of forecasting
Ville Satopaa

A four-year series of subjective-probability forecasting tournaments sponsored by the U.S. intelligence community revealed a host of replicable drivers of predictive accuracy, including experimental interventions such as training in probabilistic reasoning, anti-groupthink teaming, and tracking-of-talent. Drawing on these data, we propose a Bayesian BIN model (Bias, Information, Noise) for disentangling the underlying processes that enable forecasters and forecasting methods to improve - either by tamping down bias and noise in judgment or by ramping up the efficient extraction of valid information from the environment. The BIN model reveals that noise reduction plays a surprisingly consistent role across all three methods of enhancing performance. We see the BIN method as useful in focusing managerial interventions on what works when and why in a wide range of domains.

■ MB-39

Monday, 10:30-12:00 - U8

MAI: Fast and furious - lightning talks

Stream: Making an Impact
Invited session
Chair: Ruth Kaufman
Chair: Waldemar Kocjan

1 - Fast and furious - lightning talks
Waldemar Kocjan, Ruth Kaufman, Colin Eden, Nadine-Cyra Freistetter, Fanie (SE) Terblanche, Slawomir Pietrasz, Helena Ramalhinho Lourenco, Stefan Walter, Marijn Verschelde

An intense and fast-paced session with a series of 5-minute talks displaying aspects of OR in Practice from across the whole range. Some of these will be previews of sessions held elsewhere in the conference, some will be your only chance to hear from the speaker. This session has been hugely successful at previous conferences, with audience and speakers alike enthused by the format and content. Full details of speakers and topics will be available shortly before the event, on the Making an Impact webpage

Monday, 12:30-14:00

■ MC-01

Monday, 12:30-14:00 - A

Krzysztof Burnecki

Stream: Keynotes
Keynote session
Chair: Natasa Krejic

1 - Insurance-linked securities as novel natural catastrophe risk management instruments
Krzysztof Burnecki

To date, the majority of losses resulting from natural catastrophes have been due to the increasing insured exposure accumulation (from human and physical assets) that has arisen with economic growth and urbanisation. In the coming decades, climate change will be one of the many factors contributing markedly to the increase in economic, and as a consequence insured, losses.

When a natural catastrophe occurs, triggering a loss of life and extensive damage to infrastructure, the vulnerability of society and its assets is immediately brought to mind. The increasing natural catastrophe related losses experienced by society - in particular insurers, reinsurers and governments - further accentuate the vulnerability and its reach not only into the economic and financial system, but social and political systems as well.

Against this backdrop, it is clear that there is a greater need for novel risk management instruments, processes and techniques. In this regard, insurance-linked securities (ILS) solutions have been at the fore. The talk will consider the treatment of stochastic processes for the modelling of natural catastrophes and construction and pricing of ILS based on these processes. In this context, we will also address the issue of estimation and simulation of heavy-tailed power-law distributions. We will, furthermore, consider simple approximations to the prices of the instruments.

■ MC-02

Monday, 12:30-14:00 - B

EPOCG

Stream: EURO Prize for OR for the Common Good
Award Competition session
Chair: Cathal MacSwiney Brugha

1 - Analytics to improve mobility for elderly and disabled Dutch citizens
Frans de Ruiter, Peter Hulsen

In the Netherlands 450,000 elderly and disabled citizens are eligible for subsidized taxi rides executed by Transvision. The day-to-day planning of 3,000 to 15,000 long-distance rides used to be a complex and daunting task split over dozens of subcontractors. CQM and Geodan developed an analytics solution that combines the rides. Starting January 2020, we increased punctuality and reduced ride times, resulting in 50 percent improvement in passenger satisfaction. Furthermore, we saved 75 million driving kilometers or 7,500 metric tons of CO_2 emission over the five-year contract term.

2 - Novel Health Systems Simulation Modelling to Fight COVID-19 in Care Homes
Itamar Megiddo, Le Khanh Ngan Nguyen, Susan Howick

In this talk, we will discuss the contribution of our systems simulation models to care homes' COVID-19 policy and intervention implementation in the Health & Social Care Partnership Lanarkshire, Scotland (HSCP), and the UK. Care homes, which act as a residence but where most residents are elderly and have complex medical and care needs, have suffered devastating outcomes in the COVID-19 pandemics. They have adopted infection control and prevention interventions and policy from hospitals despite these facilities' differing roles because research is very limited in the setting. With this lack of research, we developed novel agent-based models (ABMs) and hybrid models that combine system dynamics and ABM to model care home operations and COVID-19 spread. Staff interviews at HSCP Lanarkshire and care homes and experts gathered through the Scottish Government's Care Home Data Analysis team aided in developing and validating the models. We also adapted confidence building and validation approaches from the SD and ABM literature to hybrid simulation. We then conducted experiments using the model to explore variation in care home outbreaks and study the effectiveness of policies and interventions in reducing cases and deaths within care homes and across ones connected by agency staff that work across multiple homes. In the talk, we will discuss the models, the evidence our experiments produced, and the policy and intervention decisions they supported.

3 - Supporting Brazilian smallholder farmers decision making in supplying institutional markets
Andrea Tuni, Athanasios Rentizelas, Hélio Fuchigami, Maico Roris Severino, Luísa Queiroz Barbosa

Smallholder farmers are among the most vulnerable communities in developing countries due to poverty and social exclusion, relying on agriculture for subsistence and employment, while still lacking a stable income due to inconsistent access to markets. Aiming to tackle rural poverty, the Brazilian government established the PNAE program (Programa Nacional de Alimentação Escolar - National School Feeding Program), an institutional market for smallholder farmers to supply their produce to schools through a non-competitive bidding mechanism. Nevertheless, smallholder farmers still face challenges in the evaluation of the profitability of participating in each call of the bidding mechanism. As a result, their participation to PNAE is limited due to the challenging decision-making process. Aspiring to contribute towards increasing smallholder farmers' participation, this study aims to support farmers into two key decisions they face during sequential stages of the bidding process, namely whether to bid for each available school and product combination and whether subsequently to accept the awarded bids once the bids' outcome is known. A decision support system (DSS), based on two sequential mixed integer linear programming (MILP) optimisation models, was developed and applied to the case study of Canudos settlement, guiding farmers on the optimal bidding and contract acceptance strategy. The DSS models are theoretically relevant for the Operational Research (OR) community from an application and a methodological perspective. This work contributes to the decision support systems field by applying established OR methods, such as MILP, to a real-life problem within the new context of bid/no-bid DSS, being also the first DSS application for non-competitive bidding. Moreover, it is the first work in the bid/no-bid DSS literature, which defines an optimal bidding strategy for the users thanks to the use of optimisation methods. Finally, the work is also original within the bid/no-bid decision-making area by being the first DSS applied to the agricultural and institutional markets contexts, aiming to facilitate decision-making of smallholder farmers in a developing countries context. The DSS defines efficient school supply regimes for the farmers considering also transportation costs, thus allowing an increased share of the revenue to remain within the smallholder farmers' communities instead of being wasted in unnecessary transport activities or in supplying non-profitable products. The DSS removes subjectivity and intuition from the decision-making process, leading to faster and more effective bidding strategies. Finally, it removes the obstacle of disagreements within the farmers' cooperatives on where to bid and which successful bids to select, due to an objective strategy being defined. The work has a significant social impact for the common good, simultaneously contributing to the UN Sustainable Development Goals, SDG1 "No Poverty", SDG2 "Zero Hunger" and SDG10 "Reduced Inequalities". The additional funds available to smallholder farmers thanks to optimised bidding strategies allow to fulfil the intended social outcome of the PNAE program, by offering increased financial security to vulnerable rural communities, helping them to escape poverty. The real-life impact of this work is enhanced since the DSS models have been embedded into a Progressive Web App, accessible from mobile phones. This social technology, coupled with dedicated training sessions to farmers, aims to make the smallholder farmers independent throughout the PNAE bidding mechanism. After being successfully implemented through a single case study in the Brazilian smallholder farmers' settlement of Canudos, the work could be further applied in additional farmers' communities in the country, with a potential of 1.5 million users in Brazil, thus being highly relevant for rural poverty reduction efforts in the country. Inclusive rural growth in developing countries is a key objective globally, as it allows to concurrently address food security and economic growth as well as alleviating effects of climate change.

■ MC-03

Monday, 12:30-14:00 - C

Supervised and unsupervised learning, and Mathematical Optimization

Stream: Machine Learning and Mathematical Optimization
Invited session
Chair: Kseniia Kurishchenko

1 - Instance-dependent cost-sensitive learning for positive and unlabeled data in fraud detection
Carlos Ortega Vazquez, Jochen De Weerdt, Seppe vanden Broucke

Fraud poses several challenges to the financial institutions: fraud is dynamic, uncommon, and imperceptibly concealed. In this work, we focus on the last two aspects. From a machine learning perspective, fraud detection is often considered as a binary classification task. Recent works have exploited the instance-dependent cost-sensitive (IDCS) learning to deal with the class imbalance and optimize the model in terms of the business objective (i.e., minimizing financial losses). However, fraud detection usually suffers from label uncertainty (e.g., hidden fraudsters) which violates the assumption of complete label information of the binary classification setting. This problem can lead to a failure in implementing an effective fraud detection system as some hidden fraudsters might never be identified. A more realistic setting is learning from unlabeled and positive (PU) data. The PU setting describes that the classifier can only learn from positive (i.e., well-known fraudsters) and unlabeled instances (i.e., seemingly genuine clients); the unlabeled data contains both positive and negative examples. Despite the relevance of the topic, there are no current works that focus on cost-sensitive PU learning in fraud detection. We propose a novel framework that combines IDCS learning and PU learning. This framework allows to adapt well-known classifiers that outperform state-of-the-art methods for fraud data sets with misclassification costs and label uncertainty.

2 - Efficient and robust classification with Lipschitz Neural Networks
Louis Béthune, Mathieu Serrurier

Lipschitz constrained models have been used to solve specifics deep learning problems such as the estimation of Wasserstein distance for GAN, or the training of neural networks robust to adversarial attacks. Regardless the novel and effective algorithms to build such 1-Lipschitz networks, their usage remains marginal, and they are commonly considered as less expressive and less able to fit properly the data than their unconstrained counterpart. We recall some results about 1-Lipschitz function in the scope of deep learning and we extend and illustrate them to derive general properties for classification. First, it appears 1-Lipschitz neural networks are theoretically better grounded than unconstrained ones when it comes to classification. They can fit arbitrarily difficult frontier, making them as expressive as classical ones.

When minimizing the log loss, the optimization problem under Lipschitz constraint is well posed and have a minimum, whereas regular neural networks can diverge even on remarkably simple situations. We study the link between classification with 1-Lipschitz network and optimal transport thanks to regularized versions of Kantorovich-Rubinstein duality theory; and we exhibit a family of Lipschitz classifiers that are optimal for some measure of robustness. Finally we explain how to implement those network in practice the most computationally efficient way; and we derive preliminary bounds on the VC dimension of this architecture.

3 - Feature Selection, Dendrograms, and Minimum Spanning Trees
Marina Leal Palazón, Martine Labbé, Mercedes Landete

Single linkage clustering is a type of agglomerative hierarchical clustering method. Dendrograms are the output of the single linkage cluster analysis. They are a representation of the two-dimensional cluster similarity matrix. It is known that dendrograms can be obtained by solving the Minimum Spanning Tree problem; all the information required for the dendrogram of a set of points is contained in a Minimum Spanning Tree. Dendrograms are useful in a wide variety of fields such as medicine, biology, anthropology or sociology among others. Feature selection is common in data mining for managing large databases. Since dendrograms represent groupings of large databases, they are also likely to the use of feature selection. In this work, we introduce the model for feature selection in minimum spanning trees and analyze their polyhedral properties. We also introduce a theorem that allows the statement of a decomposition algorithm for solving the problem. We illustrate the benefit of the properties and the algorithm with an extensive computational study.

4 - Side-constrained minimum sum-of-squares clustering: mathematical programming and random projections
Benedetto Manca, Leo Liberti

We will present a mathematical programming based methodology for solving the minimum sum-of-squares clustering (MSSC) problem, also known as the "k-means problem", in the presence of side constraints. We will show several exact and approximate mixed-integer and nonlinear formulations based on norm inequalities and random projections, the latter built upon the additive version of the Johnson-Lindenstrauss Lemma. We will discuss the theoretical aspects of the new (exact and approximate) formulations for the MSSC problem and show several computational experiments obtained on randomly generated and real data instances of medium size, but with high dimensionality, showing that, when side constraints make the k-means algorithm inapplicable, our proposed methodology can obtain good solution in limited amounts of time.

■ MC-04

Monday, 12:30-14:00 - D

Machine learning for optimizing business decision-making I

Stream: Machine Learning and Mathematical Optimization
Invited session
Chair: *Wouter Verbeke*
Chair: *Kristof Coussement*

1 - Probabilistic forecasting with modified N-BEATS networks
Jente Van Belle, Ruben Crevits, Wouter Verbeke

We present a modification to the state-of-the-art N-BEATS deep learning architecture for the univariate time series point forecasting problem to make it a probabilistic forecasting model. Next, we propose an extension to this probabilistic N-BEATS architecture to allow optimizing probabilistic forecasts from both a traditional forecast accuracy perspective as well as a forecast stability perspective, where the latter is defined in terms of a change in the forecast distribution for a specific time period caused by updating the probabilistic forecast for this time period when new observations become available, i.e., as time passes. For the M4 monthly data set, we show that this leads to more stable forecast distributions without leading to a significant deterioration in their accuracy. Finally, we present a second extension to the probabilistic N-BEATS model for use in an inventory management context in that also probabilistic forecasts of temporal aggregates, i.e., cumulative demands, are produced by the network. Results are reported for the M4 monthly data set and indicate that large improvements in accuracy can be obtained over basic but well-established methods to produce probabilistic cumulative demand forecasts without negatively impacting the accuracy of the predictive distributions for the demands per period.

2 - Deep Learning for Life Event Prediction in the Financial Industry
Stephanie Beyer Diaz, Kristof Coussement, Arno De Caigny

Event prediction has applications in fields as diverse as healthcare, engineering systems, and politics, among others. In this study, the focus is on the financial sector, where event prediction has been applied for both customer activity, in the form of churn prediction, and business process events such as business failure prediction. This study extends event prediction to capture key life events, such as retirement, formalizing a relationship, purchasing a vehicle, among others. By detecting these events in advance, cross-selling metrics, customer satisfaction and loyalty may be improved. The contributions are the evaluation of deep learning techniques against classic binary classification models, plus the comparison of different featurization approaches. Monthly data from an international financial services provider is used as input for the models. The results are compared using a cross-validated F1 measure. A statistical comparison between the best performing approaches is carried out to confirm the results are generalizable. The study also provides important recommendations for financial services providers, specifically regarding method effectiveness, time horizon depth, and model optimization. The data used consists of around 800K customers and 8 different life events. To the best of our knowledge, our study is the first to evaluate deep learning models performance using different featurization techniques in the financial service sector.

3 - Leveraging uncertainty estimation for trustworthy predictions in decision-making
Arthur Thuy, Dries Benoit

Recent successes across a variety of domains have led to the widespread deployment of neural networks in the field of operations research. Neural networks offer strong predictive performance but are notoriously difficult to interpret, leading to black-box models. As a result, they are poorly suited to be an essential component of larger decision support systems, which rely on trustworthy predictions. In this work, methods from the probabilistic deep learning literature are presented that address this issue by quantifying predictive uncertainty. Well-calibrated uncertainty estimates convey information about when a model's output should (or should not) be trusted, and allow a system to reject decisions due to low confidence. We investigate the added value of the probabilistic methods applied to the task of knowledge tracing, a subfield of educational data mining. We find that they produce well-calibrated uncertainty estimates. Moreover, the methods effectively flag potentially incorrect predictions on shifted data, without compromising on predictive performance.

4 - Learning industry-sensitive language in business communication - Insights in BusinessBERT
Philipp Borchert, Jochen De Weerdt, Kristof Coussement, Arno De Caigny

With recent studies showcasing the added value of pretrained general-purpose language models like Bidirectional Encoders from Transformers (BERT), they are widely adopted across domains. Depending on the field of study, the application of general-purpose models requires extensive fine- tuning steps, due to specialized vocabulary and terminology. By transferring the BERT architecture on domain specific text, related research achieved significant performance improvements in i.e. the biomedical and legal domain. Due to its availability and immediate impact on decision-making, processing textual information is particularly relevant in the financial and business domain. This study introduces BusinessBERT, an industry-sensitive language model for financial and business applications. The model is trained on three large-scale corpora covering a wide range of business communication. We extracted text from 393,542 company websites (0.57 billion words), scientific literature in the business domain (0.32 billion words), as well as the management discussion and analysis section included in SEC filings (0.85 billion words) to train BusinessBERT. We encourage industry-sensitive language and terminology understanding, by extending the pretraining objectives to predict the industry code text documents originate from. The performance of BusinessBERT is benchmarked on multiple datasets, containing text classification, entity recognition, sentiment analysis as well as question answering tasks.

■ MC-05

Monday, 12:30-14:00 - E

Applications of Deep Learning in Industry

Stream: Deep Learning and Applications
Invited session
Chair: *Sureyya Ozogur-Akyuz*

1 - High-frequency Stock Price Movement Prediction Using Machine Learning and Sentiment Analysis
Hakan Gökdaş, Onur Kaya, Emre Çimen

Nowadays, social media has become one of the most important communication tools. Recent studies have investigated the relationship between social media shares and stock price movements and shown that investment decisions are influenced by social media shares. Social media writers with a high number of followers can reach and influence large audiences very quickly and also cause significant effects in the financial markets. In this study, it is aimed to predict high-frequency intraday stock price movements by analyzing social media and financial market data by taking into account the impact of the person sharing it. Social media data collected using the Twitter API was preprocessed with natural language processing methods, and then sentiment analysis was performed for texts and emojis. Regression and classification analyses were performed using machine learning algorithms. Our models use TF-IDF (Term Frequency- Inverse Document Frequency) vector, sentiments, technical indicators and financial stock data along with Tweet statistics to create a better predictive model. Multiple configurations of models are tested for these tasks in order to locate the best-performed models and the results are analyzed based on performance metrics and profitability.

2 - A deep reinforcement learning approach for solving the technician routing problem with stochastic repair requests
Dai Trong Pham, Gudrun Kiesmuller

Extending the lifespans of household appliances is one strategy to reduce the negative impacts of our consumption on the environment. The recent rise of the right-to-repair movement in the US and Europe stipulates that more appliances are expected to be repaired in the future instead of being thrown away. While the environmental benefit of prolonging household appliance lifespans is clear, tackling the attended-home repair tasks remains a considerable challenge to repair service providers. On the one hand, two crucial and connected resources, spare parts and competent personnel, have to be coordinated efficiently to reduce cost. On the other hand, operational uncertainties such as spare parts to replace malfunctioned components and customer locations of future repair requests are unknown to the planner when making decisions. In this paper, we formulate a sequential decision process and propose solution approaches to the planning problem of attended-home repair under uncertainty. In particular, we address the joint planning of the technician's schedule and spare parts inventory on the repair van. We focus primarily on strategies that explicitly account for uncertainties using look-ahead procedures combined with learning. In a detailed numerical study, we show that such approaches are superior to current practice in industry and other benchmark policies that do not explicitly account for future uncertainties.

3 - Analyzing customer behaviour & shopping journey in retail by image recognition in artificial intelligence
Gozde Genc, Gizem Caliskan, Elif Aras

In the retail sector, employees work on such routine operations. In order to obtain shelf fulfillment, detect rotten fruit & vegetables, and prevent out of stock this project is developed. Besides, there is another important point which is analyzing customer behavior & shopping journey. In this scope, image recognition technologies in artificial intelligence solve our problem. The facts that are mentioned can be traced by the cameras that are positioned in the store. This project is conducted by Migros Research & Development Center. The studies that are done so far such as image recognition on store operations, literature review around 15 publications lead us to realize opportunities. The aim of this project is send to real-time notifications to store managers and share reports with related departments. Analyzing the customer's behavior when they choose the product which they would like to buy from the shelf, by image recognition system gives us the result of decisions about ordering and which product on the shelf is preferred or not mostly. The literature studies show that the future is about focusing on the stated topics in this article. Thus, many sectors would improve their operations by working on this solution.

4 - Solar Power Forecasting Using LSTM Networks: Comparative Analysis
Jolita Bernatavičienė, Vaiva Narkutė

Energy from solar power plants is one of the most renewable energy sources. EU countries plan for renewable energy to account for at least 27% of the EU's final energy consumption by 2030. Lithuania's energy sector is also planning to expand the use of renewables and promote the development of solar power plants Therefore, efficient forecasting of the energy produced by solar power plants is particularly relevant. The main reason for accurate forecasting is important to provide information on the likely changes in the energy produced in the near future. This is particularly relevant for planning energy trading on the power exchange. It helps suppliers participate more easily in the energy market and plan their resources efficiently. The need for efficient solar forecasting is growing year by year, and it is one of the keys to staying in the market. Knowing the quantities of energy produced can help plan grid loads and address the challenges that arise. The main objective of this paper is to analyse the theoretical and practical part of forecasting the energy produced by solar power plants from the forecasting of lighting and weather. The analysis is based on datasets of 3 solar power plants located in 3 different areas of Lithuania. The Vanilla LSTM, Stacked LSTM and Bidirectional LSTM models are compared for forecasting the energy produced by solar power plants. The forecasting period - 2 full weeks or 336 values in hourly intervals.

■ MC-06

Monday, 12:30-14:00 - U1

Supply Chains: Modern Issues and Optimization Approaches

Stream: Combinatorial Optimization
Invited session
Chair: *Alena Otto*
Chair: *Erwin Pesch*

1 - A deep learning assisted matheuristic for container assignment in first-mile logistics
Simon Emde, Ana Alina Tudoran

Urban logistics has been recognized as the single most complex and expensive part of e-commerce supply chains. An increasing share of this complexity comes from the first mile, where shipments are initially picked up to be fed into the transportation network. First-mile pickup volumes have become fragmented due to the enormous growth of e-commerce marketplaces, which allow even small-size vendors access to the global market. These local vendors usually cannot palletize their own shipments but instead rely on shipping containers provided by a logistics provider. From the logistic provider's perspective, this poses the following problem: from a given pool of containers, how many containers of what size should each vendor receive when? It is neither desirable to supply too little container capacity because this leads to shipments being loose-loaded; nor should the assigned containers be too large because this wastes precious space. We demonstrate NP-hardness and develop a matheuristic, which uses a mathematical solver to assemble partial container assignments into complete solutions. The partial assignments are generated with the help of a deep neural network (DNN), trained on realistic data from a European e-commerce logistics provider. The deep learning assisted matheuristic allows serving the same number of vendors with about 10% fewer routes than the rule of thumb used in practice due to better vehicle utilization.

2 - Capacity Games with Supply Function Competition
Bo Chen

We introduce a general model for suppliers competing for a buyer's procurement business. The buyer faces uncertain demand, and there is a requirement to reserve capacity in advance of knowing the demand. Each supplier has costs that are two-dimensional, with some capacity costs incurred prior to production and some production costs incurred at the time of delivery. These costs are general functions of quantity, and this naturally leads us to a supply function competition framework in which each supplier offers a schedule of prices and quantities. We show that there is an equilibrium of a particular form: the buyer makes a reservation choice that maximizes the overall supply chain profit, each supplier makes a profit equal to their marginal contribution to the supply chain, and the buyer takes the remaining profit. This is a natural equilibrium for the suppliers to coordinate on, since no supplier can do better in any other equilibrium. We demonstrate the applications of our model in three operations management problems: a newsvendor problem with unreliable suppliers, a portfolio procurement problem with supply options and a spot market, and a bundling problem with nonsubstitutable products.

Co-authors: E. Anderson and L. Shao

3 - Resilient Supply Chain Network Design: Modeling, solving and managerial issues
Francisco J. Tapia-Ubeda, Pablo A. Miranda, Giovanni Giuliano-Guerra

This research explores the need for resilience in a Supply Chain Network under disruptive events, which may interrupt the functioning of one or more warehouses or distribution centers. To do so, a two-stage stochastic programming formulation is proposed based on the well-known Inventory Location modeling structure, while considering a set of probabilistic scenarios, in which located warehouses are not available for a fixed period of time. The proposed formulation is solved at optimality with a tailored Generalized Benders decomposition-based algorithm. The computational experimentation shows that obtained solution significantly differs from those obtained without considering disruptions. Thus, a resilient design for the supply chain network is obtained, which is able to successfully operate during the unavailability of located warehouses. Based on the aforementioned experimentation, significant managerial issues are discussed, enlightening the supply chain network planning process, being able to overcome medium-level disruptive events while expected systemwide cost is minimized.

■ MC-07

Monday, 12:30-14:00 - U3

Risk Management in Private and Public Finance

Stream: Financial Risk Measurement and Management
Invited session
Chair: Loretta Mastroeni

1 - Re-investigating oil-food price co-movements using wavelet analysis
Loretta Mastroeni, Alessandro Mazzoccoli, Greta Quaresima, Pierluigi Vellucci

We exploit the wavelet analysis approach to investigate oil-food price correlation and its determinants in the domains of time and frequency. Wavelet analysis is able to differentiate high frequency from low frequency movements which correspond, respectively, to short and long run dynamics. We show that the significant local correlation between food and oil is only apparent, and this is mainly due both to the activity of commodity index investments and, to a lesser extent, to a growing demand from emerging economies. Moreover, the activity of commodity index investments gives evidence of the overall financialisation process. In addition, we employ wavelet entropy to assess the predictability of the time series under consideration at different frequencies. We find that some variables share a similar predictability structure with food and oil. These variables are the ones that move the most along with oil and food. We also introduce a novel measure, the Cross Wavelet Energy Entropy Measure (CWEEM), based on wavelet transformation and information entropy, with the aim of quantifying the intrinsic predictability of food and oil given demand from emerging economies, commodity index investments, financial stress, and global economic activity. The results show that these dynamics are best predicted by global economic activity at all frequencies and by demand from emerging economies and commodity index investments at high frequencies only.

2 - Untruthful Advisors and Greedy Customers: an Agent-Based Model
Pierluigi Vellucci, Loretta Mastroeni, Maurizio Naldi

Investors usually resort to financial advisors to improve their investment process. Although financial advice is potentially a driving/correcting factor in investment decisions, in the aftermath of the global financial crisis, the media and the regulators have also placed much of the blame on biased advisors for manipulating the expectations of naive investors. Surely, financial advisors (and the bank) exert an influence on their clients to steer them towards a particular investment decision. In extreme situations, biased advisors may exert some effort to manipulate the expectations of naive investors, in return of some tempting incentives. But in general financial advisors also desire to hold their good reputation according to an internal true belief about a particular investment decision proposed to clients. In any case, the role of financial advisors, as well as that of other influencers, is to be properly accounted for in the analysis of personal finance decisions. In this word we define an Agent-Based Model (ABM) based on a game theoretic model of agents' behavior and interactions. In this game there are three classes of agents: a bank, a financial advisor, a set of customers or clients. Our goal is to identify the outcome of this game and examine how investors may be influenced by financial advisor. We obtain the Nash equilibria and the analytic formulation of PoS (Price of Stability) for personal finance game.

3 - Market instability in the era of energy transition
Ivan De Crescenzo

In the last months, energy sector has been fiercely shaken due to the turmoil driven by both the aftermath of the pandemic as well as a fair share of geopolitical instability. Industrials are called to operate in a hyper-volatile environment, asking for a different approach towards risk analysis and hedging policies. The quotation of fundamentals, not seldom far from representing the intrinsic value of relevant assets, are forcing entities to adopt more sophisticated instruments in order to profitably operate in the power markets as well as complying with carbon allowances obligations. The dramatic increase of notional values is also impacting the warranty structure system under which many operators are compelled to manoeuvre across the continent. Liquidity has become an issue hence imposing a major control on cash predictability, forecasting models and the ability to seize cash management solutions suitable in this over-changing scenario. The energy transition is eventually making the equation, if possible, even more complex; the aim of fulfilling a drastic reduction of greenhouse emissions is basically made possible solely by leveraging the carbon market system (the European ETS) whilst natural gas happens to end up being the primal mean to a more sustainable power generation. In this context, volatility is fostering the speculators' appetite, which is eventually fuelling up the tension in the market even more.

4 - The asymmetric impact of the pandemic crisis on interest rates on public debt: Some evidence from the Eurozone

Giovanni Carnazza

The outbreak of Covid-19 has played the role of a 'game changer' in the way countries of the Eurozone have faced the economic consequences of the pandemic crisis. This paper investigates what has happened to the interest rates of the sovereign bond in selected countries of the Eurozone during 2020. While the pandemic crisis can be interpreted as a symmetric shock, we found some important asymmetric consequences both in the sovereign bond market and the credit default swap market. Even though the European Central Bank (ECB) has played a fundamental role in easening tensions, especially with the announce of the Pandemic Emergency Purchase Programme (PEPP), countries with a higher pre-Covid level of the debt-to-GDP ratio have been found to undergo a significant jump in interest rates and a greater perceived risk of default. Important policies implications emerge in relation to the future role of the ECB: even though the paper has provided some evidence that the public debt has not been a major issue during the crisis, the stock of the public debt accumulated by the ECB could be at the time of the maturity. For some member states, the repayment of the whole stock of debt would provide a comparable shock, which could frustrate the efforts made and the impact of the money spent by the European Union on resilience and recovery provisions. This will pose new challenges on the monetary policy of the European Union, which is not likely to end at the end of the pandemic crisis.

■ MC-08

Monday, 12:30-14:00 - U4

Green Scheduling

Stream: Combinatorial Optimization
Invited session
Chair: Ymro Hoogendoorn

1 - Sensor placement in a single-period waste collection problem

Ymro Hoogendoorn, Remy Spliet, Daniele Vigo

A recent development in waste collection is the placement of sensors to reduce uncertainty. However, as placing sensors require both installation and upkeep costs, we want to make an informed decision to place sensors. In addition, sensors are not perfectly accurate and we have to choose between cheaper sensors that give imprecise readings, or more expensive sensors that give precise readings. Given the readings of the placed sensors, the single-period waste collection problem reduces to a vehicle routing problem with stochastic demands (VRPSD). We allow for correlated demand. The VRPSD can be solved exactly by means of an integer L-shaped method. However, to evaluate different sensor placements, the expected costs of a single sensor placement needs to be calculated, which is equivalent to computing the expected cost of many different optimal VRPSD solutions. In this research, we derive theoretical properties of this placement problem, and devise different methods to approximate or upper bound the expected costs of a sensor placement. These expected costs are then used to infer strategies for sensor placements using instances found in waste collection practice.

2 - The European Entry-Exit Gas Market System: A Multilevel Robust Challenge

Johannes Thürauf, Lars Schewe, Martin Schmidt

The European gas market is organized as a so-called entry-exit system with the main goal to decouple transport and trading. It has been modeled in the literature as a four-level problem that includes a nonlinear flow model of gas physics. One of the core challenges of this model consists of computing so-called technical capacities, which leads to adjustable robust constraints that are computationally intractable in general. We provide techniques to equivalently reformulate these nonlinear adjustable robust constraints as finitely many convex constraints including additional integer variables for the case of tree-shaped networks. We further derive additional combinatorial constraints for our reformulation that significantly speed up the solution process. With the help of our results, we can recast the four-level model as a single-level nonconvex mixed-integer nonlinear problem, which we then solve on a real-world sized network, namely a passive version of the Greek gas network, to global optimality. Overall, this is the first time that the considered four-level entry-exit system has been solved for a real-world sized network and a nonlinear flow model.

3 - A Green Two-Echelon Location Routing Problem with Mobile hubs and Multi Commodities

Aria Dahimi, Virginie Lurkin, Tom van Woensel

Two-Echelon (2E) distribution systems have been proposed in city logistics to address the negative externalities of urban freight transport. In particular, mobile depots have emerged to respond to the often prohibitive cost of installing urban logistics infrastructures in city centers. In this study, we formulate and solve a green two-echelon location routing problem with mobile hubs and multi commodities. We allow the first echelon vehicles to do direct delivery and the second echelon vehicles to visit multi pickup and delivery points to increase flexibility. Also, we consider economic and environmental costs, together with efficiency, as our objectives. We develop a mixed-integer linear programming (MILP) formulation for this problem. Then to show the validity of our formulation, we solve the problem exactly using the Gurobi solver for several small instances. Finally, we present an efficient heuristic algorithm to solve larger instances. Results on some well-known benchmarks show the efficiency and effectiveness of the proposed model relative to typical 2E-V/LRPs.

■ MC-09

Monday, 12:30-14:00 - U5

MILP in manufacturing and Logistics

Stream: Mixed Integer Linear Programming
Invited session
Chair: Fabrizio Marinelli

1 - New Exact and Heuristic Approaches for a General Class of Single-Machine Scheduling Problems

Haitao Li

We study a general class of single-machine scheduling problem with setup time/cost and no idle time in the schedule, called order acceptance-scheduling problem with setup times-costs and no idle time (OASP-STC-NIT). The OASP-STC-NIT is NP-hard and includes a variety of NP-hard problems as special cases. In order to obtain and prove optimal solutions for small to medium size instances, we develop two new mixed-integer linear programming (MILP) formulations and derive a simple and effective valid inequality by exploiting the sequencing characteristics of OASP-STC-NIT. We also explore the network structure of OASP-STC-NIT and devise a network flow model by implicitly enumerating all the potential solutions, which is shown to be quite effective for small instances. For medium to large instances, we design and implement a greedy heuristic and a tabu search metaheuristic to obtain quality solutions efficiently. Our TS is implemented upon a new composite solution representation scheme, which integrates the solutions for order selection and job sequencing into one single Hamiltonian tour to facilitate multiple efficient operations of local moves. A comprehensive computational study is performed to evaluate the performance of different algorithms.

2 - Supermarket sizing and placement in the assembly line feeding problem

Ebenezer Olatunde Adenipekun, Veronique Limère, Nico André Schmid

As the number of parts required to feed mixed model assembly lines keeps rising due to mass customization, researchers and practitioners are facing an intricate task of managing assembly systems more efficiently. Much of this intricacy arises due to limited space at the assembly line. So far, researchers have addressed the assembly line feeding problem through various descriptive and optimization models, however, integrating cell (or supermarket) placement and sizing decisions for smooth and efficient logistics flow has received little attention. In this study, a cell is defined as a preparation area located next to each assembly station (line-integrated) or between the warehouse and the assembly line (regular), where parts are repackaged. An optimization model is proposed, integrating the cell placement and sizing decisions into assembly line feeding. More specifically, the mixed-integer programming model assigns every part to one of five feeding policies, i.e., line stocking, boxed supply, sequencing, stationary and traveling kitting, and parts are assigned to a suitable cell (line-integrated or regular). Regular cells may only be used to prepare parts for a single line feeding policy, whereas, line-integrated cells may be used for different line feeding policies. The model minimizes both operational and spatial costs and is solved for some artificial datasets that have been created based on an industrial case study. Preliminary results will be presented.

3 - Optimal allocation of the unloading buffers of a cutting machine in iron manufacturing

Andrea Pizzuti, Pietro Lausdei, Fabrizio Marinelli

This work is inspired by a collaboration with a leading company in the production of automatic machines for iron manufacturing. According to the patterns described by a pre-computed cutting stock solution, bars of given lengths are obtained by a sequential cutter, moved by a conveyor belt and collected into two temporary buffers. Hence, a portal equipped with pliers lifts the items and allocates them through a lengthwise movement in a depot, made by a set of identical parallel buffers of limited capacity. Items belonging to the same order must be piled together and kept on the depot until the order finalization, and the subsequent request from the downstream process steps. The cutter must be stopped if produced bars cannot be allocated in the depot, causing machine idle times. The criticality of the depot resource calls for the optimal management of the portal movements and the allocation of bars. We propose a MILP based approach aiming at both the minimization of the number of portal translations and the fragmentation of packs/orders on different depot areas. Preliminary tests carried out on real-world derived instances assessed the viability and the quality of the obtained solutions.

4 - A MILP approach for a packing problem with defective bins and reconfigurable patterns

Fabrizio Marinelli, Claudio Arbib, Ulrich Pferschy

The standard Bin Packing Problem calls for assigning a set of items of given lengths to a minimum number of bins, regardless the way items are packed into bins. An interesting new aspect arises if unpredictable defects can appear in the bins, so possibly causing some items to be discarded. Indeed, once a defect occurred at a given position t, either the items in the pattern can be rearranged so that the defect falls in an unused part of the bin (and in this case we say that the pattern is t-reconfigurable), or one item must be discarded causing an economic loss. Assuming as random events both the defectiveness of a bin and, if the case, the defect position within the bin, the probability that a pattern is reconfigurable against random defects introduces an intuitive notion of patterns robustness. Taking the expected value over all possible defect positions, we then introduce the Expected Economic Loss (EEL) of a pattern and the Expected Total Revenue (ETR) of a solution. The contrasting goals of material utilization and pattern robustness give rise to two relevant optimization problems for robust bin packing: (i) given a fixed number of bins, find a packing minimizing the total EEL and (ii) find the number of bins that maximizes the ETR. In this work, we discuss the computational complexity of the above problems and devise various heuristic methods, comprising both dynamic programming procedures and MILP-models, for the case of at most one point-shaped defect per bin.

■ MC-10

Monday, 12:30-14:00 - U6

Artificial Intelligence in Finance and Investments

Stream: Financial Risk Measurement and Management
Invited session

Chair: *Peter Schwendner*
Chair: *Alexander Posth*
Chair: *Wolfgang Härdle*
Chair: *Marcus Wunsch*
Chair: *Galena Pisoni*

1 - Investor demand in syndicated bond issuances: stylised facts

Peter Schwendner, Martin Hillebrand, Marko Mravlak

This study analyses investor demand in syndicated EFSF and ESM bond issuances from 2014 to 2020 on an unprecedented granularity level of individual orders. In particular, we investigate three main aspects of order book dynamics: first, we determine the main factors segmenting investor demand. Second, we analyse price dynamics in the transactions and their relation to investor demand. Third, we examine whether there are any indications of order book inflation that might explain the increased volatility in order book volumes. We identify issuance tranche and tenor as the main determinants of investor demand, which are to a large extent anticipated by the envisaged notional amount of the issuance. Further, we note that the pricing of ESM bond issuances is carried out in an economical manner, i.e. the new issue premium tends to be lower in a market context with large demand. Lastly, we look at the drivers of large order books and find a mixture of above-average number and volume of orders. This confirms that there are no indications of order book inflation tendencies in the analysed time period.

2 - Robust Classification via Support Vector Machines

Salvatore Scognamiglio, Ioannis Kyriakou

Classification models are very sensitive to data uncertainty, and finding robust classifiers that are less sensitive to data uncertainty has raised great interest in the machine learning literature [1,2]. This paper aims to construct robust Support Vector Machine classifiers under feature data uncertainty via two probabilistic arguments. The first classifier, Single Perturbation, reduces the local effect of data uncertainty with respect to one given feature and acts as a local test that could confirm or refute the presence of significant data uncertainty for that particular feature. The second classifier, Extreme Empirical Loss, aims to reduce the aggregate effect of data uncertainty with respect to all features, which is possible via a trade-off between the number of prediction model violations and the size of these violations. Both methodologies are computationally efficient and our extensive numerical investigation highlights the advantages and possible limitations of the two robust classifiers on synthetic and real-life financial data.

[1] Huang, X., Shi, L., & Suykens, J. A. (2014). Ramp loss linear programming support vector machine. The Journal of Machine Learning

Research, 15(1), 2185-2211. [2] Huang, X., Shi, L., & Suykens, J. A. (2013). Support vector machine classifier with pinball loss. IEEE transactions on pattern analysis and machine intelligence, 36(5), 984-997.

3 - Using Explainable AI to Understand Bond Excess Returns

Lars Beckmann, Jörn Debener, Johannes Kriebel

Bond excess returns are of major importance for the management of investors' bond portfolios and for the transmission of central banks' monetary policy. Recent studies have shown that price movements of assets such as stocks can be predicted using machine learning methods to a significant extent. A challenge for the adaption of these methods, however, is their lack of transparency. In our study, we analyze the predictability of bond excess returns in the US market using modern machine learning methods. Our preliminary findings indicate that machine learning methods can significantly predict bond excess returns and thereby outperform linear methods. Furthermore, we suggest the use of SHapley Additive Explanations (SHAP), an explainable artificial intelligence technique, to uncover important determinants of bond excess returns. In this way, we can link the predictability of bond excess returns to the structure of interest rates and macroeconomic indicators such as employment and inflation.

4 - Exploring the trends in Cryptocurrencies

Rajhans Mishra

In recent times, cryptocurrencies have emerged as a topic of great interest for both academia and industry. It started with Bitcoin in 2009 as the first practical use case of blockchain-based peer-to-peer (P2P) currency. Post-Bitcoin, Ethereum has come up with its blockchain-based platform and offered Ether as a new cryptocurrency. Later many other cryptocurrencies and tokens were launched and they are used for many P2P transactions. As of now, more than 9500 cryptocurrencies and tokens are active in the market. These cryptocurrencies are used for P2P money transfers, trading and buying blockchain-based digital assets like Non-fungible tokens (NFT). P2P money transfers have also created a new ecosystem termed as DeFi (Decentralized Finance). On the one hand, Cryptocurrencies like Bitcoin, Ether have provided a mechanism for P2P money transfer without having any intermediaries (like Banks, Government and financial institutions). On the other hand, these cryptocurrencies witnessed severe volatility resulting in a good use case for pattern analysis. This work focuses on identifying the intrinsic trends that may exist in the prevalent cryptocurrencies in the market. The exploration will be done for short-term and long-term patterns. This work will be helpful to explore the behavior of cryptocurrencies that may add significant value for DeFi and associated sectors.

■ MC-11

Monday, 12:30-14:00 - U7

MCDA methods 1

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *José Rui Figueira*
Chair: *Mladen Stamenković*

1 - Attribute Significance Index: A New Take on the Managerial Aspects of Dominance-Based Rough Set Approach

Mladen Stamenković, Dragan Stojkovic, Aleksa Dokić

The academic literature in retail is yet to provide a uniform, objective, and quantitative approach to classifying various multiple channel advents. In a fast-moving, always-changing multiple channel environment, retailers want a clear-cut take on a precise, measurable, and easily replicable framework for multiple channel strategy selection. In this paper, we address the issue of creating an objective, non-biased method for the quantitative classification of retailers according to their multiple-channel strategic modality. We use a dominance-based rough set approach (DRSA) to provide a set of decision rules to identify retailers' multiple channel strategy. Derived "if-then" decision rules help retail managers focus on channel aspects relevant for implementing a specific multiple channel strategy. To build a roadmap that will simplify the optimization process and provide a complete overview for an individual retailer on his position and where to go, we create a new DRSA-based metric named attribute significance index. It measures the frequency of appearances of an attribute in the set of decision rules for the union of classes. Using DRSA, combined with this metric, we provide a unique strategic pathway for a retailer towards the desired multiple channel strategy.

2 - A robust TOPSIS method for decision making problems with hierarchical and non-monotonic criteria

Salvatore Corrente, Menelaos Tasiou

This paper introduces an extension of a well-known Multiple Criteria Decision Aiding method, namely the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). Most of the TOPSIS applications assume that preferences are monotonic for each evaluation criterion and that qualitative scales are converted into quantitative ones before the method is applied. However, both assumptions imply a normalization step, issues in which have been subject of discussion and criticism in the literature. To this solution, this paper introduces a normalization technique based on simulations that permit taking into account non-monotonic preferences as well as qualitative criteria. An additional novelty lies in the integration of the Multiple Criteria Hierarchy Process, which extends the applicability of the method to problems in which criteria are hierarchically structured. To deal with robustness concerns, the Stochastic Multicriteria Acceptability Analysis will be used in the new proposal, giving information in statistical terms on the goodness of the considered alternatives. The new method has been applied to evaluate a set of banks listed in the LSE's FTSE350 Banks Index.

3 - Experimental comparison of outranking-based approaches for multiple criteria partially ordered clustering

Dariusz Grynia, Miłosz Kadziński

The problem of clustering aims at grouping similar objects together. It has been extensively studied in the context of Data Analysis (DA), not receiving a great deal of attention in Multiple Criteria Decision Analysis (MCDA). In turn, MCDA focuses on the similar problem of multiple criteria sorting, where alternatives are assigned into pre-defined and preference-ordered categories. However, sorting approaches cannot be applied when information regarding the preference structure between classes is not given a priori but is yet to be discovered. Hence, classical methods from DA are commonly used for clustering in the context of MCDA, albeit they are not well suited for this problem as they measure similarity in the original criteria space and do not exploit the additional preference information provided by the Decision Maker. This study aims to propose new methods utilizing an outranking-based preference model to solve the multiple criteria partially ordered clustering problem. Their performance is compared against a variety of well-known methods from DA and existing approaches that have been specifically designed for this problem. All algorithms are applied to several real-world MCDA problems. The obtained results are evaluated regarding the quality of the partitioning and the consistency of the clustering relations with respect to the relations between pairs of alternatives through objective quality measures.

4 - UTASTAR-T: a time-series-based approach for preference disaggregation in MCDA

Sarah Ben Amor, Betania Campello, Leonardo T. Duarte, Joao Romano

Multiple criteria decision aid (MCDA) aims to support decisions involving a set of alternatives and multiple criteria. The preference disaggregation approach in MCDA infers preferential information from examples of decisions provided by the decision maker (DM). Methods based on this approach generally use a linear programming formulation to determine piecewise linear marginal value functions. A typical problem with these methods is that each criterion is associated with a single value, which may be the average of the criterion performance in a given period of time or some other static data. However, several decisions are made considering the evolution of the criterion over time, its time-series, or some characteristics of these time-series (summary measures such as the average and tendency). For instance, to open a new country branch, the DM analyzes two criteria, gross domestic products and purchasing power parity. In this type of investment, the tendency of these criteria is as relevant as their average. We propose UTASTAR-T, an extension of UTASTAR, a well-known preference disaggregation MCDA method, to learn the DM's preferences in a context where the average and tendency of the time-series criteria are considered simultaneously. UTASTAR-T was tested and validated using actual data for the assessment of ten countries, using three criteria life expectancy at birth, education, and gross national income per capita, while considering the criteria's average and tendency

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■ MC-12

Monday, 12:30-14:00 - U9

Towards technical and economical feasibility of renewable-dominated power systems

Stream: OR in Energy
Invited session
Chair: Miguel Carrión

1 - A stakeholder engagement approach to map risk mitigation strategies for the promotion of energy efficiency investments in Europe
Aikaterini Papapostolou, Charikleia Karakosta, Filippos Dimitrios Mexis, Nikos Kleanthis, Alexandros Flamos

Stakeholder engagement is the process of involving stakeholders in dialogue in order to determine their views, concerns and experience about a specific problem, and to determine economic, social and environmental factors that can improve the decision making. Successful engagement necessitates researchers to begin engagement early in the research process by developing a strategy and defining the activities based on the target group needs, and to integrate feedback into research processes and outputs. The objective of the present study is to propose a stakeholder engagement approach that aims at closing the gap between project developers and financing bodies and promoting the successful financing and implementation of sustainable energy projects. The proposed methodology aims at identifying the most suitable stakeholder profiles, contact them through a variety of communication means and, finally, engage them through a targeted questionnaire. The questionnaire developed focused on identifying and categorising the main strategies that could mitigate the risks hinder the financing of sustainable energy projects. Apart from the energy sector, the proposed methodology could be also used as a basis for the development of stakeholder engagement plans in different sectors of activity.

2 - Planning future power systems considering Hydrogen-fired gas turbines
Miguel Carrión, Hernán Gómez-Villarreal, Miguel Cañas-Carretón, Rafael Zarate-Miñano

Planning decarbonized power systems is one of the most relevant problems that power system planners are facing nowadays. In this work we propose a generation capacity expansion that aims at designing an low-carbon power system considering the possibility of installing hydrogen-fired gas turbines. The problem is formulated as a two-stage stochastic programming problem. The proposed model considers the installation of electrolyzers, storage facilities and desalination plants. A realistic case study is solved to test the proposed formulation.

3 - Energy System Modelling to Support Managerial Decision-Making in the Energy Sector: Selected Insights and Pitfalls
Valentin Bertsch, Jonas Finke

Energy systems around the world are undergoing a process of fundamental change and transformation aimed at reducing greenhouse gas emissions and combating climate change mainly through investment in renewable energies. While energy systems models (ESMs) have been developed and used for several decades to support decision makers in governments and companies, these models typically take a central-planning approach. Moreover, a number of simplifications and assumptions are usually made, e.g. to keep the models computationally tractable. While simplifications and assumptions are obviously an inherent part of any modelling process, it is important to note that their effects can remain unseen when only considering ESM results at the macroscopic level. The attempt to use ESM output to support managerial decisions of energy companies, e.g. related to individual investment projects, reveals a number of such hidden effects raising general questions related to the usefulness and robustness of the ESM output - also at the macroscopic level. This paper will illustrate several such examples and discuss possible ways forward.

4 - A multidimensional approach for Benchmarking Energy Efficiency Projects
Charikleia Karakosta, Aikaterini Papapostolou, Filippos Dimitrios Mexis, Haris Doukas

Standardisation is an essential element in various sectors to avoid conflict, duplication of effort and establish a common language between key actors. Even though Energy Efficiency (EE) is a high priority for the European Union (EU), it lacks common standardisation procedures and methods among interested parties. EE investment ideas usually lack a common framework on which projects are considered profitable and merit attention by investors, while financing institutions mainly evaluate the creditability of the company that develops the project rather than the project itself. In this framework, the present study proposes a multidimensional benchmarking approach for the identification of bankable EE project ideas. The methodology aims to set the pace for EE project developers and investors to establish a consensus based on which EE investments are bankable. Unlike other approaches, the proposed methodology establishes an integrated approach, especially in terms of variety of investors and financing options, taking into consideration all possible benefits of EE investments, providing awareness concerning their compliance with the EU Taxonomy, deploying KPIs and thresholds broadly used by EE and financing sector, and providing a hub in which these projects could be financed. The benchmarking deploys outcomes that have emerged from lessons learnt, databases of already financed projects, and stakeholders' consultation to ensure that the evaluation is in line with market needs.

■ MC-13

Monday, 12:30-14:00 - U119

Applications in Discrete Optimization II

Stream: Discrete Optimization and Algorithms (contributed)
Contributed session
Chair: Felix Hennings

1 - Optimizing transient gas network control for challenging real-world instances using MIP-based heuristics
Felix Hennings, Kai Hoppmann-Baum

Optimizing the transient control of gas networks is a highly challenging task. The corresponding models feature the combinatorial complexity of determining the usage of the many active elements as well as the non-linear and non-convex nature of the physical and technical principles of gas transport. In this talk, we present the latest improvements of our ongoing work to solve this problem for real-world large-scale instances: By adjusting our model regarding the gas compression capabilities in the network, we are able to more accurately reflect the technical limits of the underlying machines while maintaining a similar overall model size. In addition, we introduce a new algorithmic approach that is based on splitting the complexity of the problem by first finding assignments for discrete variables and then determine a corresponding locally optimal non-linear solution for the continuous variables. For the first task, we apply well-established heuristic concepts for time-expanded problems that find solutions by solving a sequence of sub-problems on reduced time horizons. To demonstrate the competitiveness of our approach, we test our algorithm on particularly challenging historic demand scenarios. The results show that high quality solutions are obtained through reliably short solving times, making the algorithm well-suited to be used at the core of time-critical industry applications.

2 - Graph Theory and Cost-Benefit Analysis for Optimizing and Evaluating Networked-Infrastructures Transitions: A Case Study on Wastewater Infrastructure's Mergers in England
Yasmin Jaaron, David Saal

This research focuses on applying a hybrid methodology of mathematical optimisation and economic analysis, seeking to develop an optimisation and evaluation tool to be used in infrastructural transitions planning. In particular, the concepts of graph-theory and Cost-Benefit Analysis (CBA) have been applied on facilities mergers of wastewater infrastructure, to demonstrate a proof-of-concept of an effective decision-making tool. The study has involved modelling sewerage systems considering the main two components of collecting and transporting sewage (pipelines and pumping stations) and wastewater treatment facilities. Graph-theory principles are adopted to simulate and solve a whole-system optimization model representing sewage collection and treatment. Accordingly, a heuristic greedy algorithm is developed and applied to find optimum/optimal solutions for two specific mergers scenarios. These are spokes-and-hubs and cascading mergers; both aim at reducing the number of sewage treatment plants by merging treatment facilities looking for long-term savings. The optimization approach involves solving the two merger scenarios heuristically in two stages, to find and compare optimal solutions referring to optimal merger structures. Subsequently, results of the optimization models are complemented by CBA to evaluate their feasibility on a long-term period, by analyzing the Net Present Value (NPV) of suggested merger structures over a twenty-five-year timeline.

3 - Multi-stage Heuristic for Facility Management
Arezoo Vejdanparast, Andre Maravilha, Felipe Campelo, Aniko Ekart, Randa Herzallah

We consider a complex real-world Facility Management (FM) problem requiring generating and updating schedules for approximately 1,000 engineers to attend around 10,000 daily job sites executing maintenance tasks, under numerous constraints related to skills matching, job deadlines and geographical location. The problem is modelled as a Mixed Integer Programming (MIP) problem. We propose a multi-stage heuristic solution strategy, with (i) a pre-filtering stage to select valid engineer-task pairs; (ii) an allocation stage where tasks are attributed using a greedy shortest transit time rule; (iii) a route refinement stage for each engineer, modelled as multiple small-scale Travelling Salesperson Problems with Time Windows; and (iv) a final refinement using a general solution polishing strategy. The results of the proposed heuristic are compared to a time-limited Branch-and-Cut strategy using data provided by a partner FM industry. Preliminary results indicate that the proposed heuristic provides good solutions and scales well up to the required problem sizes, providing a feasible alternative for the problem considered.

4 - New research exploiting a local precomputed cost function for the nuclear outage planning problem
Rodolphe Griset, Saad Balbiyad, Luis Marques

The nuclear outage planning problem is challenging for the french electricity producer EDF. It combines a scheduling aspect with specific nuclear constraints and a production dispatching. Moreover, both the supply/demand structure and nuclear units' availabilities, are unknown. The reference two-stage model for this problem was the subject of the EURO/ROADEF challenge in 2010. In this model, outages dates are " here-and-now " decisions common to a set of scenarios modelling uncertainties on the supply/demand structure in which production and stocks are optimized.

In the literature, the most efficient MILP based approaches use extended formulation to handle nuclear specific constraints leading to an efficient resolution in the deterministic case [Griset et. al,2022]. In stochastic settings, however, even using Dantzig-Wolfe/Benders decompositions to handle the large scale of the problem is too slow for operational use where EDF resort to a local search heuristic.

We present a one-stage MIP formulation exploiting local cost indicators to link nuclear outage decisions to solution costs without the need for production dispatching in scenarios. We compare several compact and extended formulations for this new problem. This new problem is designed to be used in a local search scheme where the cost function is iteratively updated by a neural network tool. Moreover, robust cuts can be added iteratively to handle uncertainties impacting outages maximum fuel level constraints.

■ MC-14
Monday, 12:30-14:00 - U261

Decomposition methods for network optimization

Stream: Network Optimization
Invited session
Chair: Markus Sinnl
Chair: *Kübra Tanınmış*

1 - A Benders decomposition algorithm for blocking the spread of contagions in networks
Necati Aras, Evren Guney, Markus Sinnl, Kübra Tanınmış

The COVID-19 pandemic is a reminder of the danger of the spread of harmful contagions in networks. It has infected over 450 million people and caused the death of over 6 million people. In this work, we introduce the measure-based spread minimization problem, which can be utilized to model the optimal minimization of the spread of harmful contagions in networks. We are given a directed graph G=(V,A) representing a network, a stochastic diffusion model for spread in the network, and a set of initially infected nodes/people. Let K be a set of labels each of which representing a certain relationship (contact) type between two people. There can be multiple arcs between a pair of nodes and blocking a label means taking a measure that prevents the contact between every pair of nodes connected via an arc having that label. In other words, there is a measure associated with each label which causes the arcs with the relevant label to be removed from the network. In a disease spread context, possible measures could be closing of schools, closing of department stores, and the lock-down of a certain area. We present an integer program that is based on stochastic programming and live-arc graphs to model the diffusion process. We propose a Benders decomposition based solution algorithm enhanced with various components to allow for the solution of large-scale instances. A computational study is carried out to analyze the effectiveness of the algorithm and generate managerial insights.

2 - Solving the orienteering interdiction game with a decomposition method
Kübra Tanınmış, Eduardo Álvarez-Miranda, Markus Sinnl

The orienteering problem (OP) is a fundamental routing problem where the aim is to find a tour on a graph such that a given maximum tour length is not exceeded and the total prize collected from the visited nodes is maximized. This NP-hard problem has applications in several areas such as scheduling, logistics, and tourism. In this work, we introduce the orienteering interdiction game (OIG), which involves two players, leader and follower who act sequentially. The aim of the leader is to select a subset of the nodes to interdict such that the total prize earned by the follower, who solves an OP, is minimized because he or she cannot collect the prizes of the interdicted nodes. The OIG can model a competitive environment where an existing agent makes contracts with some of the locations so that the newcomer's profit is minimized. It can also be used to analyze the worst-case scenarios in case of attacks during military operations. We propose a single-level reformulation based on interdiction cuts in order to solve this challenging bilevel problem. Based on this reformulation, we develop a branch-and-cut algorithm and introduce various enhancements such as heuristic separation procedures and usage of solution and cut pools. We test our approach on instances created from a set of TSPLIB instances with several leader budget levels and prize generation schemes. The preliminary results show that the proposed enhancements improve the efficiency of the branch-and-cut significantly.

3 - A decomposition method for solving fortification games

Markus Sinnl, Markus Leitner, Ivana Ljubic, Michele Monaci, Kübra Tanınmış

Fortification games, also known as sequential defender-attacker-defender problems, are a class of trilevel optimization problems with many applications in areas such as survivable network design and facility protection. These problems are an extension of interdiction problems, i.e., attacker-defender problems, with an outer level which allows for defense against the attacker: In the outer level, the defender can select some assets to protect, in the middle level, the attacker can select some of the unprotected assets to attack, and in the inner level, the defender solves an optimization problem over the non-attacked assets. In this talk, we present a decomposition method to solve fortification games by introducing fortification cuts, which allow modeling the objective function of the fortification games in an outer-approximation-fashion. Based on these cuts, we develop an exact branch-and-cut algorithm for fortification games. We discuss lifting procedures for fortification cuts, as well as separation and implementation details. We also present a computational study on shortest-path fortification game instances from literature, including a comparison to a state-of-the-art algorithm for fortification games.

4 - A novel decomposition-based approach for the p-center problem

Elisabeth Gaar, Markus Sinnl

The p-center problem (PCP) is a fundamental problem in location science, where we are given customer demand points and possible facility locations, and we want to choose p of these locations to open a facility such that the maximum distance of any customer demand point to its closest open facility is minimized. The classical textbook integer programming (IP) formulation of PCP is usually dismissed due to its size and bad linear programming (LP)-relaxation bounds.

We present a novel solution approach that works on a new IP formulation that can be obtained by a projection from the classical formulation. The formulation is solved by means of branch-and-cut, where cuts for demand points are iteratively generated. Moreover, the formulation can be strengthened with combinatorial information to obtain a much tighter LP-relaxation. In particular, we present a novel way to use lower bound information to obtain stronger cuts. We show that the LP-relaxation bound of our strengthened formulation has the same strength as the best known bound in literature, which is based on a semi-relaxation.

Finally, we also present a computational study on instances from the literature with up to more than 700,000 customers and locations. Our solution algorithm is competitive with highly sophisticated set-cover-based solution algorithms, which depend on various components and parameters.

■ MC-15

Monday, 12:30-14:00 - U262

Decision Support in Routing, Scheduling and Planning

Stream: Decision support (contributed)
Contributed session
Chair: Liwen Zhang

1 - Decision support in the Technician Routing and Scheduling Problem

Mette Gamst, David Pisinger

The technician routing and scheduling problem (TRSP) consists of technicians serving tasks subject to qualifications, time constraints and routing costs. In the literature, the TRSP is solved either to provide actual technician plans or for performing what-if analyses on different TRSP scenarios. We present a method for building optimal TRSP scenarios, e.g., how many technicians to employ, which technician qualifications to upgrade, etc. The scenarios are built such that the combined TRSP costs (OPEX) and investment costs (CAPEX) are minimized.

The proposed method consists of a heuristic based on column generation. To reduce computational time, the routing costs of a technician are estimated instead of solved to optimality. The proposed method is evaluated on data from the literature and on real life data from a telecommunication company. Finally, future research directions are discussed.

2 - BL.Optim: a configurable optimizer towards decision-making support for various scheduling and routing problem

Liwen Zhang, Florent Mouysset, Mustapha Derras, Christophe Bortolaso

Nowadays, there is a wide demand from many organizations to regularly route and schedule staff and goods to satisfy specific objectives. Scheduling and routing issues often require consideration of various businesses constraints under different industrial contexts, thereby ensuring the optimal use of resources. Decision-makers need customizable optimizers to specify business-oriented constraints and define their target planning generation needs. In our work, we present "BL.Optim", an optimizer with two-stage model-based architecture, which aims at capturing routing and scheduling requirement for a wide category of Constraint Satisfaction Problems (CSP). We demonstrated our approach on Home Health Care Routing and Scheduling Problems (HHCRSP), Home Meal Delivery Problems and Preventive Maintenance Scheduling and Routing Problems. The captured requirements are customizable by activating the necessary constraints facing the different realistic use cases. A series of CSP-based activable soft constraints and non-violated hard constraints are embedded in BL.Optim. To meet industrial requirements in solving the real-world cases with significant dimension, we opted for the Ant Colony Optimization algorithm for solution generation. Solutions generated by BL.Optim for HHCRSP are competitive against the manual scheduling result, with less 28% less assigned caregivers to perform required 142 services per day by respecting all the specified constraints.

3 - Combined batch process and manpower scheduling to minimize workforce requirements

Saurabh Chandra, Debashish Jena

The malt beverage production follows a two-step process, the first one being a continuous flow process and the second stage being a batch production process. The batch production process comprises multiple baking ovens in parallel. The process has lumpy manpower requirements, as labor is needed only for the loading and unloading operation of each oven while baking, while the small infrequent manual inspection is needed while the baking process is going on. The firm uses a temporary workforce to meet the daily fluctuations in production demand. The biggest challenge here is to schedule the baking process with multiple ovens across multiple shifts in a day such that minimal manpower is required, with an objective to meet the production target. We present MILP and CP models for the problem along with a heuristic solution method comprising of a two-stage solution approach.

■ MC-16

Monday, 12:30-14:00 - U264

Commodities Related Real Options

Stream: Real Option Analysis
Invited session
Chair: Stein-Erik Fleten

1 - Subsidy termination risk, incremental investment and capacity growth
Roel L.G. Nagy, Stein-Erik Fleten, Lars Sendstad

Investments are frequently subsidized, but once a subsidy is close to reaching its goal or loses political support, it may be terminated. An important question for policy makers is how to minimize the negative impact of the risk of subsidy termination on the firm's investment.

We study a monopolist eligible for a subsidy faced with option to invest irreversibly in small increments. We assume the social planner sets a subsidy, and the firm decides on when to install the capacity increments. The social planner may have to withdraw the subsidy due to unexpected events outside of her control.

We contribute to the literature by analyzing how the subsidy retraction risk impacts optimal investment timing, the firm's total investment and total surplus. We find that the firm installs capacity increments sooner and, as a result, install a larger capacity than a firm without a subsidy. Furthermore, a subsidy can increase total surplus if set correctly. The social planner's optimal subsidy size increases with the firm's capacity, and decreases with subsidy withdrawal risk.

2 - Why wait? Modeling the timing of EV charger investments and the role of policy
Emil Dimanchev

Governments aim to encourage the deployment of charging stations for electric vehicles. However, private-sector decision makers face an incentive to delay irreversible investment decisions due to uncertainty in future demand. This incentive has not been captured by previous research, which evaluated charging station investments using Net Present Value methods. To address this gap in the literature, this paper models the problem of charging station investment as a Real Option. We introduce a numerical model to study the effects of different ways governments can design subsidies to de-risk investment decisions and thus accelerate charging station deployment. Our results further quantify the cost-efficiency of different subsidy designs.

3 - Risky vs Safe production mode: when to invest and when to switch?
Carlos Oliveira, Igor Kravchenko, Cláudia Nunes

In this paper we study the investment strategy of a firm that upon investment may produce in two alternative modes. These two modes differ in terms of the risk associated with the running payoff: one being more profitable when the market conditions are favourable but leading to larger losses in times of crisis (risky mode), whereas the other mode leads to smaller profits and losses (safe mode).

Once the investment takes place, the firm may still switch from one mode to another. Therefore the firm may adjust itself, in terms of production mode, to the conditions of the market. Moreover, we assume that the firm may decide to exit the market, and this decision is possible in both production modes.

We find that the investment strategy may be dichotomous. In this case we have an inaction region, for a range of prices in a certain bounded interval, where the firm does not invest and waits to have more information about the price evolution. Another interesting fact that we find is that under some conditions, the firm can operate with a negative instantaneous profit. This region - the hysteresis region - can only be reached under special conditions.

4 - Revenue and risk of variable renewable electricity investment: the cannibalization effect under high market penetration
Lina Reichenberg, Tommi Ekholm, Trine Krogh Boomsma

The observation that wind and solar power depress market prices at times when they produce the most has been termed the 'cannibalization effect'. This can have a substantial impact on the revenue of these technologies, the magnitude of which has already been established within the economic literature on current and future markets. Yet, the effect is neglected in the capital budgeting literature assessing green investments in the electricity sector (e.g. including methods such as portfolio- and real- options theory). In this paper, we present an analytical framework that explicitly models the correlation between VRE production and electricity price, as well as the impact on revenues of the surrounding capacity mix and cost to emit CO2. In particular, we derive closed-form expressions for the short-term and long-term expected revenue, the variance of the revenue and the timing of investments. The effect of including these system characteristics is illustrated with numerical examples, using a wind investment in the Polish electricity system as a test case. We find the cannibalization effect to have major influence on the revenues, making the projected profit of a project decrease from 33% to between 13% and −40% (i.e. a loss), depending on the assumption for the rate of future VRE capacity expansion. Using a real options framework, the investment threshold increases by between 13% and 67%, due to the inclusion of cannibalization.

■ MC-17

Monday, 12:30-14:00 - U356

Accounting 3

Stream: Operational research in financial and management accounting
Invited session
Chair: Sascha H. Moells

1 - Truthful Reporting of Auditors under Uncertainty - An option-based Approach
Tim Burger, Sascha H. Moells

"Audit quality" has for long - in particular following accounting scandals and spectacular bankruptcies - been an intensively discussed topic in public media as well as regulatory debates. While the core of this debate refers to various aspects of the 'independence' of auditors, from an analytical perspective it seems appropriate to give particular attention to the rationale and incentives of auditors when making the decision on (non-)truthful reporting of detected irregularities. Thus, the option to report truthfully - and possibly end any future ventures with the client - should be at the core of modelling the decision-making process of auditors under uncertainty. When additionally recognizing the aforementioned irreversibility of the decision made, the application of an option-based approach seems suitable. Such a perspective allows to explicitly analyze critical parameters affecting the reporting of auditors as well as to capture situations in which the auditor might purposefully withhold critical information - e.g. in a situation of "low balling" while discounting future benefits from the mandate - causing additional hold-ups. Characterizing the behavioral leeway of auditors and conceiving corresponding critical thresholds for truthful reporting, existing as well as prospective regulatory measures to assure the independence of auditors can be evaluated in a complex setting. The results shed light on mechanisms not explicitly captured in the debate yet.

2 - Dynamic effects of CO2 certificate costs in case of complex cost calculation production structures
Anna Uhrmeister

In recent years, the effects of climate change have received heightened attention in academic as well as public discourses. Equally, the impact of climate change on the global economy becomes increasingly visible in various forms. For example, european companies have to pay CO2 emission fees if their production generates CO2 emissions. The German emissions trading system started in 2021 with a politically determined price system, which foresaw a fixed price per ton of CO2. Companies must therefore purchase CO2 certificates to a fixed price if they emit CO2. Besides the common manufacturing costs as defined by IAS 16.15 environmental costs must be included in cost calculations on the basis of cost valuations according to IFRS. Starting from this, this research takes a closer look to investigate the impact of CO2 certificates on German companies. It is assumed that the effects are greatest in the production sectors in which CO2 emissions are also the highest. Taking it into account, this research will model and analyze an average company in the steel industry. Specifically, business processes are modeled to investigate complex circumstances such as joint processes. Particularly in the research field of joint processes, evaluation difficulties often arise. Furthermore to consider temporal effects such as fluctuating material prices, system dynamics are used as a modeling technique.

3 - SuCCESs - An Open-Source Integrated Assessment Model for long-term Climate Change-Scenario Foresight
Nadine-Cyra Freistetter, Tommi Ekholm

Achieving a climate-neutral and sustainable society requires extensive transition towards carbon neutral energy production, material use and protection of ecosystems. Informed foresight can help decision-makers and society to ensure the sustainability of their actions.

Integrated Assessment Models (IAMs) are the workhorse for providing foresight for long-term sustainability strategies, particularly towards mitigating climate change. However, most IAMs focus on the transformation of the energy system alone, and thereby overlook the negative or positive feedbacks the energy system has with other systems, like land-use and materials production.

We present the novel Integrated Assessment Model "SuCCESs" that fully couples the production and use of energy, materials, and land-use globally; and calculates the associated greenhouse gas emissions and sinks from these systems. SuCCESs is an open-source intertemporal optimization (cost minimization) model, solved through linear programming, that simulates efficient markets in long-term scenarios. The joint optimization of multiple systems allows for a more holistic exploration of the energy system transformation, substitution between renewable and non-renewable materials, and possibilities in land-use to mitigate climate change or provide renewable energy and materials. This will provide important foresight for a broad set of decision makers on the required transitions to achieve a climate-neutral and sustainable society.

■ MC-18

Monday, 12:30-14:00 - U358

Advances in Optimization under uncertainty 2

Stream: Stochastic and Robust Optimization
Invited session
Chair: *Markus Gabl*
Chair: *Francesca Maggioni*

1 - The Static versus Static-Dynamic Uncertainty Strategy for the Stochastic Lot Sizing Problem under Random Demand
Markus Mickein, Knut Haase

We propose two model formulations for the stochastic capacitated lot-sizing problem (SCLSP) under the static and static-dynamic uncertainty strategy. While the static strategy fixes the production plan at the beginning of the planning horizon, the static-dynamic strategy enables adjustments of the production quantities after demand realization. Therefore, we apply a lot size adaptation approach that determines adjustments depending on demand differences between the expected and realized demand. We apply a sample average approximation to model the demand uncertainty by several scenarios representing possible demand realizations. We introduce a general solution approach designed for scenario approximated problems to solve the stochastic program. This approach guarantees sufficient uncertainty approximation within reasonable computing time by iteratively extending the scenario sample. First, all variables are optimized under a small scenario sample. Next, a subset of variables is fixed and the remaining variables will be optimized again under a large scenario sample. We evaluate 7,776 test instances to identify problem and demand structures where the static or static-dynamic strategy dominates. The numerical results prove that the proposed solution approach fulfills the service level in each test instance. Furthermore, the management analysis demonstrates that the static-dynamic strategy achieves lower average costs (2.7%) and lower overshoots of target service levels (15.2%).

2 - Maximum Mean Discrepancy Distributionally Robust Nonlinear Chance-Constrained Program with Statistical Guarantee
Yassine Nemmour, Heiner Kremer, Jia-Jie Zhu

Motivated by the open questions in distribution- ally robust chance-constrained programs (DRCCP), we propose an approximate solution method using the maximum mean discrepancy (MMD) ambiguity sets, which we term MMD- DRCCP. Different from previous works using the Wasserstein distances, MMD-DRCCP can handle general nonlinear con- straints with proven finite-sample statistical guarantees. We further propose computational schemes for constructing the the MMD ambiguity sets in practice. Our algorithms are validated numerically on a portfolio optimization problem and a tube- based distributionally robust model predictive control problem.

3 - Robust Optimization with Continuous Decision-Dependent Uncertainty
Haoxiang Yang

We consider a robust optimization problem with continuous decision-dependent uncertainty (RO-CDDU). RO-CDDU has two main features that have not been addressed in the literature: an uncertainty set with linear dependence on continuous decision variables and a convex piecewise linear objective function. We prove that RO-CDDU is NP-hard in general. To address the computational challenges, we reformulate RO-CDDU to an equivalent mixed-integer nonlinear program with a decomposable structure without loss of generality. Such an MINLP model can be further transformed into a mixed-integer linear program (MILP) by enumerating the extreme points of the uncertainty set. We propose an alternating direction algorithm (ADA) and a column generation algorithm (CGA) to iteratively solve the MILP formulation of RO-CDDU. We compare the solutions of ADA and CGA with the lower bound generated by a piecewise McCormick relaxation. We conduct numerical studies of RO-CDDU on a demand response management problem in electricity markets. Our results demonstrate promising computational performance for our proposed algorithms and the impact of uncertainty on the solutions of the RO-CDDU model in the demand response management problem.

4 - Adaptive-cut Method for Two-Stage Stochastic Programs
Eduardo Moreno, Ivana Ljubic, Cristian David Ramirez Pico

Decomposition methods, and in particular the Benders decomposition, have shown strong capabilities in the design and implementation of efficient solution algorithms for two-stage stochastic problems with a large number of scenarios. In recent years, improvements in Benders' methods have focused on the aggregation of scenarios, using different measures of distance between scenarios. On the other hand, the Adaptive Partition Method for two-stage stochastic problems has become a popular method for solving problems with a large number of scenarios, due to its ability to aggregate and disaggregate scenarios based on the information from the duals of each scenario. In this talk we discuss a generalization of the adaptive method and how to incorporate this generalization into the Benders decomposition method. The resulting algorithm can be seen as a middle ground between the so-called multi-cut and single-cut Benders methods. We present computational results on stochastic network flow problems, showing that the proposed method benefits from the advantages of both multi-cut and single-cut developments. Moreover, this technique follows the same structure of Benders decompositions, leaving open the possibility to apply the methodology to particular problems where acceleration techniques can increase the global efficiency of Benders decomposition.

■ MC-19

Monday, 12:30-14:00 - Y228a

OR in Sports 1

Stream: OR in Sports
Invited session
Chair: Frits Spieksma

1 - Generating a diverse and challenging set of sports timetabling problem instances
Dries Goossens, David Van Bulck, Morteza Davari, Jeroen Belien

The fifth International Timetabling Competition (ITC2021) was held to instigate further research on automated sports timetabling. Its artificial problem instances require constructing a compact double round-robin tournament with 16 to 20 teams while respecting various hard constraints and minimizing the penalties from violated soft constraints. We discuss how we generated a set of challenging, diverse, and realistic problem instances for this timetabling competition.

In particular, we present a set of features describing the structure of the problem instances, construct the so-called two-dimensional (2D) instance space of problem instances from the literature, and derive the region in instance space where all real-world-like instances are located. To generate a diverse and feasible set of problem instances, we propose the use of an instance generator whose parameters are set by an integer programming approach such that the resulting instance is projected at a specific spot in the 2D space.

Finally, we learn about strengths and weaknesses of the algorithms developed by the participants, by drawing their so-called footprints on the instance space.

2 - Integer programming models for round robin tournaments
Frits Spieksma, Jasper van Doornmalen, Christopher Hojny, Roel Lambers

Integer programming continues to be a very popular way to obtain a schedule for a round robin tournament. The ability to straightforwardly model the tournament scheduling problem, and next solving it using an integer programming solver, greatly facilitates practitioners, as it is usually possible to add all kinds of local, particular constraints to the formulation that help to address specific challenges. We intend to take a fresh look at the problem of formulating a round robin tournament as an integer program. Assuming a Single Round Robin format (where each pair of teams meet once), we propose, next to the well-studied, traditional formulation, two new formulations: the so-called matching formulation, and the so-called permutation formulation. These new formulations are not compact: they us an exponential number of variables. However, we show that their linear programming relaxations can be solved efficiently by showing that the corresponding pricing problem can be solved in polynomial time. When comparing the quality of the linear programming relaxations of the three models, we find that the matching formulation is stronger than the other two formulations when the number of teams exceeds 6. We show how these results can be extended to k-round robin tournaments, and we also look at how these formulations can be applied to the problem of minimizing the carry-over effect.

3 - Dynamic scheduling of e-sports tournaments
Celso Ribeiro, Zhilong Dong, Yujie Ma, Ailec Zamora, Fengmin Xu, Kui Jing

Electronic sports (e-sports) have seen a rapid growth as an emerging market with the development of the digital economy. The Asian Olympic Council announced that e-sports would be one of the 37 sports at the 2022 Asian Games in Hangzhou. AliSports, the sports arm of the multinational technology company, Alibaba Group, has partnered with the Olympic Council of Asia to bring e-sports to the Asian Games. The medal events are PUBG Mobile, DOTA 2, Hearthstone, League of Legends, FIFA, Street Fighter V, Arena of Valor, and Dream of the Three Kingdoms 2. Differently from traditional sports, optimization methods have been scarcely applied to e-sports scheduling. First, because most of the viewership follow the games online and pay for viewing each game. Second, teams do not move from one facility to another to play their games. Third, the number of teams may be much larger. We propose a dynamic integer programming approach for scheduling e-sports tournaments, based on a modification of the Swiss system. The schedule of each round considers the rankings of the teams at the end of the previous round, which are calculated using the Colley matrix. The goal consists in maximizing the attractiveness to the viewership of the games played in each round. Repetitions of the same game over a certain number of rounds should be avoided. The order of the games in each round enforces a fairness criterion. The approach was validated using data from e-sports tournaments of Arena of Valor and Dota 2.

4 - Backtracking in Sports Timetabling: a Traditional Benders' Decomposition Approach
David Van Bulck, Dries Goossens

In a round-robin sports timetable, each team meets every other team a fixed number of times. The simplicity of this tournament structure notwithstanding, constructing a timetable is challenging due to the large number and diversity of constraints that typically need to be considered. A common approach is therefore to decompose the problem with the first-break-then-schedule approach (FBTS), which first determines when teams play home or away after which it decides upon the specific opponents. Despite common use of FBTS to schedule real-life tournaments in practice, research on how to backtrack between the different phases of the algorithms is scarce. This talk shows how FBTS and a closely related decomposition approach known as first-day-off-then-schedule (FOTS), relates to classic Benders' decomposition with integer subproblems. Compared to the classic FBTS and FOTS approaches, traditional Benders' decomposition provably converges to an optimal solution and is able to cope with most real-life constraints or even situations where the objective is (partly) determined by the assignment of opponents. In this talk, we generate compact timetables that minimize the total number of travel trips and relaxed timetables that minimize rest time penalties and differences in rest time of opposing teams. Despite the fact that various algorithms have been proposed in the literature before, we find considerably better solutions for several instances of all three applications.

■ MC-20

Monday, 12:30-14:00 - Y228b

DEA methodological developments I

Stream: Data Envelopment Analysis and Performance Measurement
Invited session
Chair: Dimitris Despotis

1 - On the performance of the subsampling bootstrap in Network DEA
Maria Michali, Ali Emrouznejad, Akram Dehnokhalaji

Data Envelopment Analysis (DEA) provides an empirical estimation of the production frontier based on an observed sample of decision making units (DMUs), and sampling noise is not taken into account. However, alterations in the observed sample can affect the shape of the efficient frontier and therefore, the efficiency scores of DMUs. If the observed set of DMUs is considered as a random sample drawn independently and uniformly from an underlying population, then the true efficient frontier is unknown. In the multivariate setting, different bootstrapping techniques have been used to estimate the true frontier, under various assumptions. This study investigates the performance of the subsampling bootstrap in the estimation of the true efficiency scores of DMUs with two-stage series structures, through Monte Carlo experiments, for a range of sample and subsample sizes. The overall and stage efficiency scores are obtained through the additive decomposition approach. Coverage probabilities indicate a sensitivity to the sample and subsample sizes. The subsampling methodology is then illustrated on a dataset about European railways.

2 - A fair composition approach in Network Data Envelopment Analysis
Julia Nasiadka, Dimitrios-Georgios Sotiros, Gregory Koronakos, Dorota Kuchta, Dimitris Despotis

Network Data Envelopment Analysis (NDEA) is an extension of Data Envelopment Analysis (DEA) that takes into consideration the internal structure of Decision Making Units (DMUs) in the efficiency assessment. Notably, in NDEA, every DMU is conceived as a network of several sub-processes arranged into a series, parallel or mix of series and parallel structures. In this paper, we focus on two-stage series structures and develop a fair composition approach to derive the divisional and the overall efficiency scores. Our approach relies on Multi-Objective Programming (MOP) techniques, but unlike existing methods in the literature, we identify the divisional efficiency scores in a min-max and max-min sense simultaneously. Specifically, we identify a point on the Pareto Front of the objective functions space that is as close as possible to the highest divisional efficiency scores (Ideal point) and as a far as possible from the lowest divisional efficiencies (Nadir point). Selecting such a unique point that secures the fairness among the divisions is of crucial importance, as it will allow to set a common basis for comparison of the divisional scores of each DMU as well as to derive the overall efficiency. We compare the introduced method with other prominent methods in the literature, highlighting the differences and the advantages of our new method.

3 - A unified approach to non-radial models in data envelopment analysis
Maria Trnovska

Non-radial graph models represent an important class of data envelopment analysis models, whose efficiency measure aggregates all input excesses and all output shortfalls. The particular known models have usually been studied separately in the literature. In this contribution, we present a general scheme for non-radial graph models in the envelopment, as well as in the multiplier form. The proposed general scheme includes all known non-radial graph models as its special case. We analyse the behaviour of the models based upon several desirable properties of the optimal solution and the efficiency score. We also study the primal-dual relationship between the envelopment and the multiplier form of the models to reveal new features and useful insights.

4 - An alternative approach to Network Data Envelopment Analysis
Dimitris Despotis, Dimitrios-Georgios Sotiros, Gregory Koronakos

Network Data Envelopment Analysis (NDEA) has been introduced as an extension of standard DEA to assess Decision Making Units (DMUs) by considering their internal structure. The holistic approach to NDEA comprises methods, whose common characteristic is the joint assessment of the individual sub-units and the overall DMU. In this approach, the interdependency of the sub-units is considered in the efficiency analysis by means of the flow of intermediate measures. The observed inability of NDEA methods to identify efficient units in a number of real-world case studies motivated us to develop an alternative approach to address this issue. The common practice of merging, in a single model, production possibility sets from non-homogeneous technologies is the main reason for the deviation of NDEA from the fundamental principles of DEA. Developing our approach for basic two-stage processes shows that the failure of NDEA to locate efficient units is not a matter of complexity of the internal structure of the DMUs. The concept that our approach is based on allows us to employ conventional DEA without neglecting the interconnection of the sub-units and the role of the intermediate measures. Employing standard DEA models results in efficiency assessments within homogeneous environments, where the identification of efficient DMUs is secured. We use the case of twenty-two automotive manufactures as an example to illustrate our approach. Comparison with other NDEA methods is also provided.

■ MC-21

Monday, 12:30-14:00 - Y229a

AHP/ANP 3

Stream: AHP/ANP
Invited session
Chair: Josef Jablonský

1 - 4th Generation Product Management based on AHP and QFD - Designing and Testing Cyber-Physical Products
Thomas Fehlmann, Eberhard Kranich

The international series of standards ISO/IEC 14143, ISO/IEC 19761 und ISO 16355 define how to model and measure software, and the application of statistical and related methods to new technology and product development process. Key element of 4th generation cyber-physical products is the dominant impact of software on product features. Another characteristic of these products is its high complexity level as a system of systems. Today, manufacturers of highly complex systems, such as airplanes or trainsets, face problems both in designing and in testing their products. As a consequence, the many components have not been tested thoroughly, neither has design taken all the needs and user requirements into due consideration. The system components do not interact smoothly and flawlessly. Testing a system comprising millions of software functionality size units is hardly possible with today's methods. Good product design is even harder. At least for software, we have a clue to solve the problem. Software is measurable using ISO/IEC 14143 and ISO/IEC 19761. These measurements have been known in the past and used for estimating cost. But software measurements take equal role with physical measurements in mechanics for addressing issues of reliability, safety and delighting users. Based on these measurements, the methods explained in the series of standards ISO 16355 allow for successful design and extensive testing before putting into practical use.

2 - An aggregation AHP-based procedure for ranking of DMUs: A comparison with DEA models
Josef Jablonský

Ranking of decision making units (DMUs) is one of the desirable outputs in application of data envelopment analysis (DEA) models. Especially the DMUs that are identified as efficient by a DEA model cannot be ranked due to their identical efficiency scores. The study presents an original procedure for ranking of efficient DMUs (or all DMUs) that is based on the application of the analytic hierarchy process. The procedure considers, instead of the set of inputs and outputs, the set of partial efficiency measures that are defined as the ratios an output divided by an input. Considering the set of m inputs and r outputs, the procedure works with m.r efficiency measures. They generate the same number of partial rankings. The weights of partial efficiency measures are derived using standard pairwise comparisons. Then, an original aggregation procedure that is based on goal programming methodology is applied and the final ranking is derived by minimization of the sum of weighted deviations or by minimization of the maximum weighted deviation. The results are compared with traditional DEA ranking models.

■ MC-22

Monday, 12:30-14:00 - Y229c

Closed Loop Supply Chains

Stream: Sustainable Supply Chains
Invited session
Chair: Khakim Habibi

1 - Entering the Remanufacturing Business When There is Already One Actor Making Remanufacturing
Mehmet Alegoz

Remanufacturing has been receiving a growing attention in both academia and industry due to its economic and environmental benefits. Although remanufacturing is comprehensively addressed in the literature, studies basically assume that there is one remanufacturer in the system at a time. However, real-life examples show that different actors may consider entering the remanufacturing business simultaneously. Hence, economic and environmental effects of entrance of an actor to remanufacturing business when there is already one actor still needs the attention of the researchers. Motivating from this fact, in this study, we focus on three remanufacturing systems as only the manufacturer remanufactures (Case 1), only the retailer remanufactures (Case 2) and both the manufacturer and the retailer simultaneously remanufacture (Case 3) the used products under the carbon tax policy. Stackelberg Game models are proposed for each of these cases and the performances of the actors are compared. Computational results bring various managerial insights. Particularly, we observe that the manufacturer, in most of the instances, has no economic incentive to enter the remanufacturing business when the retailer already makes remanufacturing but this is not true for the retailer. Contrarily, in most of the instances, the retailer has a substantial economic incentive to enter the remanufacturing business when the manufacturer makes remanufacturing.

2 - Remanufacturing with Innovative Features: A Strategic Analysis
Can Barış Çetin, Georges Zaccour

In this study, we investigate the best remanufacturing strategy for the Original Equipment Manufacturer (OEM) and the Independent Remanufacturer (IR) in an innovative industry where the valuation of consumers for the products increases with the level of innovation and characterize how the best strategy changes with the identity of the remanufacturer. Our work differs from the existing articles which investigate the remanufacturing strategy in the presence of quality decisions by the need to actively include the innovative features in the remanufactured products as opposed to quality that is passively carried to the remanufactured products. We consider three remanufacturing strategies: (i) not remanufacturing, (ii) remanufacturing without adding innovative features, and (iii) remanufacturing with adding innovative features (upgrading). To analyze the problem, we create a single-period model where the OEM determines the level of innovation and new product quantity in both competitive settings and either OEM or IR determines the remanufacturing quantity depending on the competitive setting. We investigate how the environmental impact of the firms and the consumer surplus are affected by the competition and the remanufacturing strategy.

3 - Production-Routing Problem with Disassembly Equipment Consideration in Closed-Loop Supply Chain
Khakim Habibi

Production-Routing Problem (PRP) combines Lot-Sizing and Inventory-Routing Problems in forward supply chain context. Following the growth of environmental consciousness, we consider a PRP in a closed-loop supply chain by considering disassembly equipments. It determines (i) when and how much to produce, (ii) when and how much to remanufacture, (iii) when and how much to disassemble (iii) when and how much to stock at depot and retailer and the routes for the vehicles dispatched. Its objective function seeks to minimize the total cost of manufacturing, remanufacturing, disassembly, inventory, and routing by considering the equipment used to disassembly return products and the associated cost. It also considers the setting of multi-depot, multi-product, and multi-vehicle. To obtain high-quality solutions under a fast computational time, we implemented Relax-And-Fix Heuristic by embedding Stoer-Wagner algorithm for separating the subtour(s). The heuristic relaxes binary variables while keeps the integrality of the remaining ones in a rolling sub-interval of time horizon. The binary variables concerned are decisions on performing or not manufacturing, remanufacturing, and disassembly processes for each period. Following our preliminary test, the heuristic outperforms CPLEX by providing solutions with an average gap of 0.59 % by reducing up to 76.79 % of the CPU time.

■ MC-23

Monday, 12:30-14:00 - Y307

OR in Forestry II

Stream: Specific Applications of OR in Agriculture, Forestry and Fisheries
Invited session
Chair: Vasja Leban

1 - Integrating Wildfire Resistance And Environmental Concerns Into A More Sustainable Forest Ecosystem Management Approach
Liliana Ferreira, Alexandra Baptista, Susete Marques, Miguel Constantino, Isabel Martins, Jose Borges

This research aims at presenting landscape management planning methods to help stakeholders select forest ecosystem management plans that may address concerns related with wildfire risk and with a more sustainable management. Specifically, mixed integer programming models were developed in order to address spatial optimization. A wildfire resistance index as well as adjacency constraints are brought together into the models. The former is used to enforce a minimum level for wildfire forest resistance while the latter limits the size of contiguous clearcut areas, in each period of the planning horizon. Regularity of timber flows is another concern that is also taken into account. The models are used to provide decision spaces for further multicriteria analysis. This research is applied to the Zona de Intervenção Florestal (ZIF) de Castelo de Paiva and de Entre-Douro e Sousa (ZIF_VS) that is located in northwestern Portugal.

2 - Comparative analysis of forest ecosystem management with clearcut constraints
Alexandra Baptista, Liliana Ferreira, Miguel Constantino, Susete Marques, Isabel Martins, Jose Borges, Vladimir Bushenkov

Forest ecosystem management planning methods deal with many challenges. The problem is complex as it encompasses a multiple harvest context in a long planning horizon. Moreover, it requires collaborative approaches to provide forest ecosystem services while addressing wildfire risk (e.g., by including adjacency constraints on clearcut area).

This work sets out to make a comparative study between two different approaches to establish the set of contiguous areas that cannot be clearcut in the same period. The impact of these different perspectives in the solutions provided by the mixed integer programming models are measured and compared. Afterwards, Pareto frontiers are generated in a multicriteria framework in order to allow the stakeholders to analyze the trade-offs and to verify which approach provides the most advantageous option for choosing bundles of forest-based ecosystem products and services. This work was applied as a case study to a forest in Northwest Portugal, which comprises 1345 stands over two non-contiguous regions.

3 - Optimizing the transportation of timber from a large forest

Miguel Constantino, Marta Mesquita, Susete Marques, Jose Borges

One main challenge in forest management planning involves decisions such as the construction and maintenance of forest roads, the gathering of timber at loading sites in management units, and the transport out of the forest.

We consider a problem arising in a 7623 ha Portuguese forest. Harvested timber is gathered in the boundary of management units. It is then loaded and carried by trucks along forest roads, until a main road is reached. Forest roads must be built or main-tained. Timber extraction and transportation services are contracted externally, so their costs are proportional to the amount of timber harvested. Extraction costs also depend on the machinery used (forwarders, skidders or other tractor-based systems) and the location chosen to gather and load the timber.

We consider two standard Mixed Integer Linear Programming formulations, with bina-ry variables for road building and maintaining, and flow or multiflow variables for timber transportation. Unfortunately, the presence of big-M constraints in one formu-lation and the huge number of variables in the other, prevents the problem to be solved with a commercial MILP solver.

We exploit some features of the real-world problem to improve the values of the big-M and substantially reduce the number of variables. This allows to eventually solve the problem to optimality in a reasonable amount time. We present computational ex-perience and discuss the applicability and extensions of the approach taken.

4 - Investigating Driving Factors of Ecosystem Service Supply Efficiency on a Landscape Level

Vasja Leban, Lidija Zadnik Stirn, Špela Pezdevšek Malovrh

One of society's greatest challenges to sustainable resource management is balancing the multiple demands for and uncertain supply of ecosystem services (ESs). This study is an attempt to explore the supply side of ESs using efficiency measures and to investigate the underlying driving factors through a case study in southwestern Slovenia. As a first step, we modelled the potential supply of 17 relevant ESs on a square grid. Then we applied Data Envelopment Analysis to investigate the efficiency of landscape units, using the modelled ESs as outputs and the calculated expenditure per land use as input. In the third step, we regressed the obtained efficiency results against ten potential factors using Tobit regression. The average efficiency obtained was 0.299, thirteen units were efficient, and 36.6% of the units achieved above average efficiency. Efficient units are more likely to be located in areas with land uses other than forests, particularly in areas with more agricultural land and pasture. These units are also more likely to be located on flatter terrain, in more densely populated areas with smaller parcel sizes, near cultural heritage sites, and with a variety of land uses. In summary, improving the supply of ESs in underperforming units has been shown to require a threefold consideration: maintaining projects to keep rural areas vibrant and viable, improving infrastructure investments, and heterogenizing predominantly forested areas.

■ MC-24

Monday, 12:30-14:00 - Y307a

Innovative Models for Retail Operations

Stream: Demand and Supply in Consumer Goods and Retail

Invited session

Chair: *Alexander Hübner*

1 - Estimating Customer Attraction Parameters for Competitive Retail Location Selection using Inverse Optimization

Tobias Crönert, Layla Martin, Stefan Minner, Christopher Tang

Customer's store choice behavior is a key factor for competing retailers to determine their store locations. Customers may have a preference of one retail chain over the other, they may value accessibility, or the convenience of combining shopping with other errands. For incumbent retailers, ample historical data at a point of sales level permits approximating these customer attraction parameters using estimation approaches. Their competitive location decision under known choice parameters can be modeled as an integer programming game (IPG). New entrants lack this detailed information but can observe the resulting location structure of incumbents. Assuming the observed location structure is (near-)optimal for all incumbent retailers, information on the customer choice behavior can be extracted. For this purpose, we propose a novel inverse optimization approach for IPGs able to identify parameters that lead to the observed equilibrium solutions. This inverse IPG corresponds to a bilevel problem which we solve using a cutting plane approach. Our approach extends prior methods for inverse optimization of integer programs to a competitive setting with (approximate) Nash equilibria. We find that new entrants who base their location decision on inversely estimated parameters can improve their profits by up to 9%, compared with new entrants who rely on statistical averages for customer attraction parameters when making their location decision.

2 - From Return to Exchange: The Value of an Omnichannel Journey

Somayeh Torkaman, Sarah Gelper, Nevin Mutlu, Tom van Woensel

This study examines how retailers can convert returns into exchanges by exploiting their omnichannel capabilities. We do so in the context of a fast-fashion retailer that runs a traditional store channel alongside an online channel with pick-up-in-store and return-to-store options. Using a quasi-experimental approach, we quantify the value of omnichannel interactions – store interactions for online purchases, and online interactions for store purchases. Specifically, we study whether omnichannel interactions make consumers more likely to exchange a returned product (and keep it), thus generating revenue for the retailer. We find that a store visit in the return journey of an online purchase has a positive effect on the exchange probability, keep probability, and revenue. This effect is particularly strong for return-to-store interactions compared to pick-up-in-store interactions. Notably, we do not find similar effects of online channel interactions in the return journey of store purchases, providing evidence of asymmetric channel effects. Our findings thus underscore the importance of the return-to-store omnichannel capability for online shoppers to find the right product and, consequently, for retailers to turn returns into exchanges.

3 - Cross-border retail co-opetition

Faranak Khooban, Nevin Mutlu, Ton de Kok

Recent widespread adoption of Internet shopping, especially during and after the COVID-19 pandemic encouraged many retailers to open or extend their online businesses and offer their products to geographically distant consumers in other countries; however, delivery and return are still the most significant challenges for cross-border e-retailers. This paper investigates a win-win collaboration contracting mechanism between two competing online retailers in a cross-border e-commerce setting. A domestic retailer provides logistics service for the foreign retailer for an agreed service fee. Yet, both retailers will compete to sell a substitutable product in the same market. We formulate the model as an oligopoly price game with an MNL demand function and show that there is always a unique Nash equilibrium pair of prices in a co-opetition setting. In addition, we investigate the impact of the service fee on the market outcomes. The paper results shed light on retailers' strategic decisions on co-opetition and provide implications to public policymakers.

4 - Towards a customer-centricity framework for retail operations based on OR/OM Research

Anna Del Zotti, Susana Relvas

Retailers, as actors located at the last leg of the supply chain, cover a fundamental role for having direct contact with a huge variety of customers. Extrapolating the right information from customers has never been as arduous as today due to the digital disruption's effect in the retail sector, caused by the integration of e-commerce and the switch to an omnichannel strategy. Thus, retailers must accept that traditional retailing is not enough to survive nowadays challenges and must reinforce it, by improving the experience of customer journey and/or reducing friction during the purchasing process. According to the literature, the latter are actions that outline the customer-centric approach, although how to achieve/support it is not well addressed yet. Hence, we intend to fill this gap in the literature and to contribute to the dissemination of customer-centricity's concept in the interest of those retailers who still direct their business towards product-centricity. This work aims to provide a managerial framework for customer-centricity. To achieve this result, we developed a Systematic Literature Review of retail operations, by reviewing trends and directions in the use of OR/OM techniques in retail and how they incorporated customer-centricity. Finally, we identify several research gaps, and, by addressing the study's limitations, we make suggestions regarding the possibility of incorporating further inputs into OR/OM models towards the goal of customer-centricity.

■ MC-25

Monday, 12:30-14:00 - Y308

Location Analysis III

Stream: Location Analysis

Invited session

Chair: Nikolaos Ploskas

1 - Towards Unifying Scheduling and Location Problems: A Non-Stationary Hypercube Model

Regiane Maximo Siqueira, Caio Vitor Beojone

When developing location problems, we seek models that are capable of representing the pertinent geographic characteristics to the problem. On the other hand, when developing shift-scheduling problems, we seek models capable of capturing transient fluctuations in the components (such as demand, service times, available workforce, among others) of such a system. Therefore, in the search to improve the daily operations of systems, such as emergency service systems (ambulances, police, firefighters) using either of the two problems individually, it may lead to flawed conclusions. This paper aims to develop a non-stationary hypercube model capable of uniting the properties that models for both problems seek (location and shift-scheduling problems). We present the proposed model using a mixed discrete-continuous time Markov chain and compares it to a discrete-event simulation through an illustrative example. The method used in this paper is quantitative with a comparison between an approach of simulation and an exact model. The results show a high similarity between both models. However, the proposed model does not present noise in performance measures such as waiting times and travel times. The mentioned results suggest that the proposed model may become an option for applications uniting location and shift-scheduling problems.

2 - Integer programming formulations for the p-median problem with distance constraints

Nikolaos Ploskas, Kostas Stergiou

The p-median problem is a well-known and studied problem in the field of facility location. However, the p-median problem with distance constraints has received little attention within the vast literature on location problems in OR and related areas. In this work, we study a variant of the p-median problem where minimum distance constraints exist both between the facilities and between the facilities and the demand points. This problem can be used to model situations where the facilities to be located are semi-obnoxious, i.e., have both desirable and undesirable properties. We consider both the problem of locating homogeneous and the one of locating heterogeneous facilities on the plane so that the sum of distances between the demand points and their nearest facility is minimized. Various integer linear programming models are presented for the p-median problem with distance constraints, coupling classical formulations of the p-median problem with four formulations of the distance constraints. We utilize Gurobi Optimizer v9.0.3 in order to compare these integer linear programming models on a large dataset of problems.

3 - An adaptive evolutionary algorithm for congested edge-based p-median location problem

Mokhtar Essaid

In this study, a dimension-based adaptation strategy is proposed to control the mutation scale factor of the differential evolution algorithm. This novel strategy generates a mutation value for each dimension of every individual from the current population. Precisely, it stores successful parameters from the search history. Thereafter, using a weighted Lehmer mean formula, a location parameter is generated for each dimension and applied as a setting for Cauchy distribution to produce promising mutation values. This adaptive algorithm is proposed to tackle a congested edge-based p-median location problem with uniformly distributed demands along the network edges. It is assumed that customers need to wait in a queue to be served after arriving at facilities. The applied queuing system consists of a single server at each facility. The idea of distributed demands along with considering congested systems adds to the complexity of the given problem. Accordingly, the objective function minimizes the customers' aggregate traveling and waiting times. It is worth mentioning that a new mixed-integer non-linear programming model is developed. Besides, new instances are introduced to test the performance of the proposed adaptive algorithm. The problem is solved using the introduced adaptive algorithm and compared to a classic differential evolution algorithm. The empirical results reveal the superiority of the proposal over the static setting of differential evolution parameters.

■ MC-26

Monday, 12:30-14:00 - Y309b

Post disaster humanitarian and health care services

Stream: EWG HOpe, EURO working group on Humanitarian Operations

Invited session

Chair: Burcu Balcik

1 - Collaborative response for healthcare resilience improvement in disasters

Danuphon Tippong, Sanja Petrovic, Vahid Akbari

The study presents a simulation-based decision support tool for resilience improvement during disasters. We collaborate with the health authorities in Thailand who experienced the disasters to investigate real-world operations that take place in an emergency medical response. We develop a discrete event simulation model that simulates collaborative care according to the real-world operations of emergency medical response. In this study, there are three collaborative care strategies including non-collaborative, semi-collaborative, and collaborative care. The model is validated and verified using common practices and performs well with respect to the available system outputs. We present an analytical view for resilience improvement using collaborative care strategies during Tsunami in Thailand in 2004. The generic resilience metric presented in the literature is adopted in the healthcare context. Our analysis yields the managerial insights into the emergency planning as follows. The collaborative care strategy has a considerably greater impact on improving the resilience and returns to the pre-disaster state of the healthcare network quicker than others in all defined scenarios. The semi- collaborative care strategy frequently provides the worst resilience in almost all the identified scenarios. However, it provides better resilience than the non-collaborative care strategy when the number of affected patients is relatively low.

2 - Drone Routing for Post-Disaster Damage Assessment Under Different Communication Settings
Ecem Yücesoy, Elvin Coban, Burcu Balcik

Drones are increasingly used to support post-disaster damage assessment operations and obtain information about the affected areas. Efficient planning of drone routes is important for emergency response decisions. Routing decisions for multiple drones are complex since several factors should be considered in a short period of time, such as the charging requirements and the possibility of damages in different areas. Moreover, after a disaster, the communication infrastructure may be damaged, which needs to be considered in making assessment plans. We aim to provide drone routing decisions for damage assessment under different communication settings. We address the differences between the online setting, where remote communication is possible and the assessment information can be shared upon the visit, and the offline setting, where the drones must return to the operation center to share the information. We present results that compare different planning approaches with respect to response time based performance metrics.

3 - Optimizing Drone Use in Early Infant Diagnosis of HIV Supply Chain in Less Developed Countries
Alborz Hassanzadeh, Laurent Alfandari

We analyze the application of drones to help tackle a devastating global health challenge in less fortunate countries, specifically the early infant diagnosis of the human immunodeficiency virus supply chain. In Sub-Saharan Africa, without treatment, over 35% of the infected infants die before their first birthday and more than half of them perish before they turn two. Yet such countries experience significant delays due throughout the testing process to a lack of reliable roads, environmental factors, high maintenance costs, and operational inefficiencies. Using drones together with proper modeling of this resource-limited supply chain enables us to tackle this problem and create new opportunities. We first develop a mixed-integer nonlinear program to optimize the use of drones in such a supply chain, and convert it into a mixed-integer linear program.

The problem involves selecting each clinic as a point-of-care with dedicated testing equipment or assigning it to one of the labs with better detection performance, and sizing issues about the fleet of drones to carry the samples from clinics to labs. We also develop a novel objective function that considers both the equity and the effectiveness of the operations in such a network. We use queuing theory and state-of-the-art approximations to measure the total waiting time at labs, clinics, and the turnaround time. Sensitivity analysis is also conducted on drone budget and dispense of this budget in the network.

4 - Routing multiple work teams to minimize latency in post-disaster road network restoration
Vahid Akbari, Meraj Ajam, Sibel Salman

After a disaster, often roads are damaged and blocked, hindering accessibility for relief efforts. It is essential to dispatch work teams to restore the blocked roads by clearance or repair operations. With the goal of enabling access between critical locations and providing relief items in the disaster area in shortest time, we propose algorithms that determine the schedule and routes of multiple work teams. We minimize the total latency of reaching the critical locations, where the latency of a location is defined as the time it takes from the start of the operation until its first visit by one of the work teams. Coordination among the teams is needed since some blocked edges might be opened by a certain team and utilized by other teams later. First, we develop an exact mathematical model that handles the coordination requirement. After observing the intractability of this formulation, we introduce two heuristic methods and a lower bounding procedure. In the first method, we develop a mathematical model based on a multi-level network representation that yields solutions with disjoint paths. Given that this model does not coordinate the teams, we present a matheuristic based on a cluster-first-route-second approach embedded into a local search algorithm together with a coordination step to obtain alternative solutions with higher quality and in a shorter time. We test our heuristics on data sets coming from a real network from the literature and randomly generated ones.

■ MC-27

Monday, 12:30-14:00 - Y313

Regularity and Optimality Conditions

Stream: Splitting and ADMM Methods
Invited session
Chair: *Dimitri Papadimitriou*

1 - Optimal correction of an infeasible system with its application in intensity-modulated radiation therapy
Hossein Moosaei, Milan Hladik

A system is infeasible if no solution exists that satisfies all of its equalities and inequalities. As an application of an infeasible system, we can consider intensity-modulated radiation therapy (IMRT), which gives rise to systems of linear inequalities, representing the effects of radiation on the irradiated body. These systems are often infeasible. One of the frequently encountered issues in applied science is how to deal with infeasible systems. We could argue numerous reasons for the infeasibility of a system, including errors in data, errors in modelling, and many other situations. As remodelling, a problem and finding the errors of a system might take a remarkable amount of time and expense, and we might eventually get an infeasible system again, we do not do so. We, therefore, focus on an optimal correction of the given system. We want to reach the feasible systems with the least changes in data. This paper discusses a set of linear inequalities that emerge from IMRT to be inconsistent. Correcting this infeasible system to a feasible system by minimal changes in its data will attempt.

2 - On Exact and Inexact Convex Relaxations of Nonconvex Quadratic Programs
E. Alper Yildirim

A nonconvex quadratic program is an optimization problem in which one is concerned with minimizing a nonconvex quadratic function over a polyhedron. Despite the fact that it is an NP-hard problem, quadratic programs admit various convex relaxations, each of which provides a lower bound on the optimal value. We propose a unifying framework on convex relaxations, which allows us to study an implicit convex underestimator corresponding to each convex relaxation. We identify several classes of quadratic programs that admit exact convex relaxations. We also provide several necessary and sufficient conditions for an exact convex relaxation.

■ MC-28

Monday, 12:30-14:00 - Y405

Data Science and Analytics Applications 1

Stream: Data science and Analytics (contributed)
Contributed session
Chair: Lukáš Veverka

1 - Econometric Analysis of the Impact of TV Advertising on Organic Webpage Traffic

Lukáš Veverka, Vladimír Holý

Nowadays, when people are surrounded by multiple screens, it is common that they look for information immediately even when they watch the TV. This analysis examines whether TV can drive immediate responses and evaluates the factors influencing their size. Firstly, we estimate the diurnal as well as the seasonal pattern of the organic webpage visits with the kernel smoothing method. Then, we utilise the maximum likelihood method to estimate the increase in website visits after an ad is aired. Finally, it is possible to evaluate factors affecting its size. Because of the highly non-linear and unknown dependencies, we use the random forest method. The results confirm that people interact with TV and therefore it can boost an immediate interest.

2 - Eliciting sentiment on information security policies using deep learning affective computing

Tiny Du Toit, Hennie Kruger, Lynette Drevin

Information security behaviour is integrated into business and has emerged as a major subject in several research studies. Information security policies (ISPs) are among the most critical tools for influencing information security behaviour. These policies are formalised rules and regulations that govern the protection of information assets. Even though several ISP and related research exist, many studies identify ISP non-compliance as a major factor leading to undesired information security behaviour. It is worth noting that these studies typically do not concentrate on users' or employees' perceptions of the contents of the ISPs to which they are required to comply. The usual method of obtaining user or employee feedback is conducting a survey and soliciting their feedback. However, surveys provide particular difficulties in fake responses and respondent bias, often rendering results unreliable and worthless. This study presents a deep learning approach to affective computing for sentiment analysis on facial expressions. The study aims to address the issue of response bias that might arise during an opinion survey and provide decision-makers with a tool and methodology for evaluating the quality of their ISPs. The suggested affective computing methodology generated positive results in an experimental case study. Based on the sentiment provided by facial expressions, the deep learning model effectively classified positive, negative, and neutral opinions.

3 - Optimal Soccer Squad Selection

Shubhabrata Das, Soudeep Deb

The success of a soccer team depends on various individual skills and performance of the selected players as well as how cohesively they perform. This work proposes a two-stage process for selecting optimal playing squad of a soccer team from its pool of available players. In the first stage, a logistic regression model for the probability of favourable outcome for the reference team is derived based on different factors that takes into account performance of players of the team as well as those of the opponent, home game or not, and also effects of individual players as well as player combinations beyond the recorded performance of these players. In the second stage, a GRASP-type meta-heuristic is proposed and implemented for the team selection which maximises the probability of favourable outcome for the team. The work is illustrated with English Premiere League data from 2007–2015.

■ MC-29

Monday, 12:30-14:00 - M1

Manufacturing I

Stream: Industrial Production, Planning and Inventory Management
Invited session
Chair: Manuel Gonzalez-De-la-Rosa

1 - ANN Meta-model based on Simulation for Estimating Production Rate in an Assembly Manufacturing System

Dug Hee Moon, Ye Rin Seo, Dong Ok Kim, Yang Woo Shin, Chang Seong Ko

The estimation of performance measures such as production rate or lead time are the major concern in the phase of manufacturing system design, because they are required for solving the optimal design problems. Generally, two traditional approaches have been used, and they are mathematical models using stochastic processes, and simulation. However, both methods have the difficulties in developing models for complex systems and the optimization procedures, respectively. Therefore, meta-modeling based on simulation results has become as an alternative. The regression models and the artificial intelligence models have been studied as the meta-models. In this study, we introduce an approach for developing artificial neural networks (ANN) models using supervised learning, which can be applied to the manufacturing system design problems, especially to the assembly lines. We developed ANN models for reliable serial lines, unreliable serial lines and assembly lines with unreliable serial sub-lines successively. In the process of developing ANN models, various activation functions such as ELU, ReLU, and Sigmoid are compared, and C_Expo which means the c.d.f of exponential distribution is suggested. In the case of reliable serial lines, ReLU was better than C_Expo, but C_Expo was better than other activation functions in unreliable serial line and unreliable assembly lines. The ANN models with C_Expo is reasonably accurate, and they can be used for the optimization problem.

2 - Design of Reconfigurable Cellular Manufacturing Systems with Alternative Routing

Mehmet Uzunosmanoglu, Veronique Limère, Birger Raa

Cellular Manufacturing Systems (CMSs) have become one of the most studied topics in the literature and successfully adopted by the industry. These systems allow reduction of production time, set-up efforts, work-in-process, and an increase in productivity by grouping machines and products into cells and families, respectively. However, these systems are struggling to adapt to recent market trends, which have fluctuating demands and volumes and frequent product introductions. As a response, a new manufacturing paradigm, Reconfigurable Manufacturing, has been proposed. Reconfigurable Manufacturing Systems (RMSs) can adjust their capacity and functionality by reconfiguring the system and its components on hardware and software levels. The key components of these RMSs are so-called Reconfigurable Machine Tools (RMTs) which have a modular structure that provides machine scalability and convertibility, i.e., they combine different basic and auxiliary modules providing a variety of functionalities. Merging CMSs and RMSs results in the concept of Reconfigurable Cellular Manufacturing Systems (RCMSs). In our work, we propose an ILP model to solve a multi-period RCMS design problem under consideration of alternative part routings while minimizing inter-cellular transportation, processing, and (re)configuration costs. The problem consists of allocating RMTs and their modules to the cells, deciding part routings, and planning reconfiguration of the RMTs, concurrently.

3 - Minimum-Cost Selective Assembly

Thomas Weber

We consider the minimization of cost for a selective assembly system for a production output, given two random inputs and a finite number of matching classes. We determine optimality conditions for the optimal input portfolio, first using a normal approximation of the multinomial classification distributions, and second using a tight concave envelope instead of the exact output objective. The latter yields closed-form expressions for the optimal factor demands and total costs. A numerical study tests the practicality of the envelope solution, both as seed for a numerical solution and as a closed-form approximate solution, which allows for an analysis of structural properties.

4 - Sustainable inventory policy for items with backlogging and a power demand pattern considering a harmful gases emission tax

Manuel Gonzalez-De-la-Rosa, Luis A. San-José-Nieto, Joaquin Sicilia-Rodriguez, Leopoldo Cárdenas-Barrón

This paper studies a sustainable inventory model for items whose demands follow a time-dependent pattern. The inventory system allows backordered shortages. In this model sources of harmful gases emissions are considered related to transporting items and stock holding. The objective is to obtain the best sustainable inventory policy. For that, we have to maximize the profit per unit time obtained as the difference between the revenue due to sales and the costs associated with inventory management and gases emissions. The optimal inventory cycle, the sustainable economic ordering quantity, the optimal initial inventory, and the maximum profit per unit time are deduced. Numerical examples are introduced to illustrate the theoretical results proposed.

■ MC-30

Monday, 12:30-14:00 - M237

Extensions of Project Scheduling

Stream: Project Management and Scheduling

Invited session

Chair: *Tom Servranckx*

1 - Analytical analysis of the impact of different corrective actions on the distribution of the project completion time

Forough Vaseghi, Annelies Martens, Mario Vanhoucke

Taking corrective actions after evaluating the actual progress of the project to get the project back on track is one of the most important aspects of project control. Hence, selecting the most important activities and most effective actions in the corrective action-taking process is crucial. In addition, the importance of finding an efficient way to assess the impact of the corrective actions on the activities is inevitable. Traditionally, two approaches are described in the literature to select the right activities to take corrective actions on. The first approach uses CPM to determine the critical activities during project execution and the second approach uses MC simulation to determine and select the activities with the highest sensitivity values. In this study, an alternative approach for the corrective action taken process will be investigated. Corrective actions are modelled based on the changes in the original activity duration distribution. Further, an analytical approach to evaluate the impact of these corrective actions on the project duration distribution is proposed. This approach allows us to assess the expected impact of corrective actions on the final project outcome without requiring MC simulation, such that the activities and actions with the highest expected impact on the final project outcome can be selected for corrective actions. Moreover, the impact of network topology and type of the activity duration distribution on the outcome is evaluated.

2 - Extensions of the resource-constrained project scheduling problem with alternative subgraphs

Tom Servranckx, José Coelho, Mario Vanhoucke

The resource-constrained project scheduling problem with alternative subgraphs (RCPSP-AS) is a well-known problem to include project flexibility during the scheduling phase. In this problem formulation, alternative execution modes exist for work packages that consist of a subset of interconnected activities. As a result, the scheduling problem is subdivided in a selection and scheduling subproblem that should be solved in an integrated way. In the basic RCPSP-AS, the number, position and relations of the alternative subgraphs is modelled by means of a set of flexibility parameters. In this research, we extend the RCPSP-AS in two ways. First, more complex variants of the alternative project structure are considered such as the selection of multiple alternatives that are split in different groups as well as caused and closed choices. Secondly, we consider non-renewable resources with a limited availability over the complete project horizon such that certain combinations of alternatives are incompatible. These extensions improve the practical applicability of the RCPSP-AS in various business settings and industry contexts. In order to measure the impact of the extensions, we conduct computational experiments on a large set of artificial project instances as well as some case studies. We observe that combinations of the extensions result in complex alternative project structures and, consequently, an increased computational complexity and high numbers of infeasible solutions.

3 - Solution approaches for the Resource-Constrained Project Scheduling Problem with Alternative subgraphs

Rojin Nekoueian, Tom Servranckx, Mario Vanhoucke

This paper investigates solution approaches for the resource-constrained project scheduling problem with alternative subgraphs (RCPSP-AS). The RCPSP-AS is an extension of the resource-constrained project scheduling problem (RCPSP). From an empirical point of view, projects become larger and use more sophisticated technologies. Due to the ever-increasing complexity of projects, the assumption of deterministic project structures in the RCPSP has been rendered obsolete. The RCPSP-AS is the problem of scheduling activities in work packages that can be executed in different ways. This problem consists of two subproblems: a selection and a scheduling subproblem. In the selection subproblem, one alternative amongst a set of possible alternatives should be selected for each work package in the project. In the scheduling subproblem, activities of the selected work packages should be scheduled considering precedence and resource relations. In this paper, we examine different methodologies to generate high-quality solutions for a large dataset of complex RCPSP-AS instances and then compare the solutions. Due to the complexity of the RCPSP-AS, we propose priority rules, constructive heuristics and a genetic algorithm that integrate the selection and scheduling subproblem. The comparison of the different approaches can be used to stimulate the search for best-found solutions and improved solution approaches in future research.

4 - Multi-skilled workforce formation problems with minimised workers or skills: definition and complexity

Jakob Snauwaert, Rob Van Eynde, Mario Vanhoucke

This research focuses on multi-skilled workforce formation problems in which the objective is to assemble a set of multi-skilled workers that can execute the skill requirements of a set of predefined jobs. The skill requirements define a demand for workers per skill type that needs to be fulfilled by distinct workers that master these skills. Since the skills of workers have been a recent focal point in the workforce formation and the scheduling literature, we set out several multi-skill workforce formation problems that analyse efficient workforces. In this research, we start off by defining two problems that search for a feasible multi-skilled workforce with either minimised workers or minimised skills (i.e. the sum of the skills that the workers master). Furthermore, we define extensions of these problems in which the workforces are characterised by specific resource or skill restrictions. A set of dedicated multi-skilled workforce problems tries to find a minimised workforce that is constrained with a fixed number of available skills per skill type or a fixed number of mastered skills per resource. A set of restricted multi-skilled workforce problems restrict the total number of resources or mastered skills in the workforce. Finally, we prove the complexity of these problems and show their practical and theoretical relevance.

■ MC-31

Monday, 12:30-14:00 - M240

Lot-sizing: heuristic solution approaches

Stream: Lot Sizing, Lot Scheduling and Production Planning
Invited session
Chair: Christian Almeder

1 - A machine learning approach for identifying the best solution heuristic for a large scaled NP-hard problem
Jens Kärcher, Herbert Meyr

For some NP-hard problems, many different solution heuristics exist, but they have different solution qualities and computation times depending on the characteristics of the problem instance. The computation times of the individual solution heuristics increase significantly with the problem size, so that trying out all available solution heuristics for very large problem instances requires extensive time. Therefore, it is necessary to develop a method that allows a prediction of the best solution heuristic for the respective problem instance without testing all available solution heuristics. The Capacitated Lotsizing Problem (CLSP) is chosen as the problem to be solved, since it is well researched and several different solution heuristics exist for it. The CLSP addresses the problem of determining lotsizes on a production line given limited capacity, product-dependent setup costs, and deterministic, dynamic demand for multiple products. The objective is to minimize setup and inventory costs. A two-layer neural network is developed to select the best solution heuristic. It is trained on small problem instances, which can be solved very fast with the considered solution heuristics. Nevertheless, the neural network is able to identify the best solution heuristic even for very large problem instances.

2 - An adaptive MIP-based heuristic for the multi-stage lot-sizing and supplier selection problem with perishable inventory
Caio Tomazella, Maristela Santos, Douglas Alem, Raf Jans

This article addresses the multi-stage lot-sizing problem in which the raw materials needed for production are purchased in the form of a supplier selection problem. Moreover, inventory is perishable, which increases the importance of integrating production and purchasing decisions. This problem is found in several types of industries, and, given the complexity of this problem's model, the application of heuristic methods are essential for finding cost-efficient solutions. Computational tests have shown that, for large-size instances, deterministic MIP-based heuristics, such as relax-and-fix and fix-and-optimize, rarely find better solutions than a commercial solver does within a given time limit. Therefore, we developed a MIP-based heuristic using the ALNS framework to better explore the problem's structure and improve our results. The main motivation behind choosing the ALNS as the basis of our heuristic was twofold: it allowed us to better explore the structure of the model using a large neighbourhood set; its main operators are used to avoid an early convergence of the method, which was an issue found using fix-and-optimize. The results showed that the proposed heuristic found better solutions than the solver, and that it benefited from the hybridization with the ALNS framework. We also present insights on how the heuristic was developed, such as neighbourhood definition and parametrization, and show details of the performance and inner workings of the method.

3 - A Two-Phase Method for Production Planning and Machine Speed Optimization Problem
Mustafa Kaan Topaloğlu, Banu Kabakulak

Textile industry is becoming a highly competitive area with the increase in demand for textile products which are used in various sectors. Since expanding the production capacity is not always feasible or very costly, optimizing the existing system is more practical and cost efficient. In particular, we consider a felt production system of a textile factory operating in Turkey in this study. We aim to minimize the production costs by optimizing machine operating speeds as well as building an efficient production lot sizing plan within the planning horizon. In this direction, we propose the Lot Sizing and Machine Speed (LSMS) nonlinear model to determine the optimal unit processing times and production quantities while minimizing the work-in-process and end item inventories by changing the machine operating speeds dynamically according to demands. Since LSMS nonlinear optimization problem is NP-hard, we design a Two-Phase heuristic which iteratively processes a linear programming model by utilizing a commercial solver at each phase. We intensively test our Two-Phase heuristic via randomly generated demand, planning horizon and machine-hour capacity scenarios. Our computational experiments show that the introduced Two-Phase heuristic can find the local-optimal results in acceptable amount of time.

4 - New construction heuristic for capacitated lot-sizing problems
Daryna Dziuba, Christian Almeder

We consider the classical capacitated lot-sizing problem, which is known to be NP-hard. Several construction heuristics have been proposed in the research literature, but none of them is convincing in terms of solution quality and generality - meaning that they can be applied to different variations of the problem. We propose a general 2-step construction heuristic (2-SCH), which sorts the customer orders in the first step and iteratively add them to a partial production plan in the second step. We apply 2-SCH to the single-level capacitated lot-sizing problem (CLSP) without setup times and with setup times. The average gap to best solutions found by a MIP-solver can be improved by more than 0.5% compared to the best available construction heuristic (ABC heuristic) and brought down to less than 2.5% for CLSP without setup times. For CLSP with setup times, 2-SCH improves by around 2% the results of Trigeiro's simple heuristic and provides an average gap of 7%. 2-SCH is a flexible heuristic that can be applied to various problems and provide competitive results with a short computational time and, therefore, can be easily integrated into practical production planning software.

■ MC-32

Monday, 12:30-14:00 - F101

Mathematical Models in Macro- and Microeconomics 3

Stream: Mathematical Models in Macro- and Microeconomics
Invited session
Chair: Gerhard-Wilhelm Weber
Chair: *Fausto Gozzi*

1 - Smart home insurance: collaboration and pricing
Debajyoti Biswas, Sara Rezaee Vessal

Insurers have started to incentivise customers for buying smart home security products along with home insurance to reduce household hazards. In this paper, we study the discounting decision of the insurer and pricing and quality decisions of the smart product manufacturer for offering "smart home insurance" to customers under no-contract, a Wholesale price contract and a Cost-sharing contract, considering equal market power (Nash) and a dominant SPM (Stackelberg) separately. We consider two different types of promotional offers given by the insurer to customers for purchasing a smart home product along with home insurance - discount on insurance only , discount on insurance along with a free smart product. We find that both players can benefit when the insurer offers a free smart product in the Nash setting whereas both are indifferent to the insurer offering a smart product or not in the Stackelberg setting. Comparing contracts, we find that a Wholesale price contract can be Pareto-efficient compared to no-contract and a Cost-sharing contract can be Pareto-efficient compared to a Wholesale-price contract.

2 - Dynamic Pricing and Strategic Retailers: A Multi-Leader-Follower Approach
Ann-Kathrin Wiertz, Giorgia Oggioni, Alexandra Schwartz, Gregor Zöttl

We consider strategic retail pricing in markets, where retailers buy commodities at fluctuating wholesale prices and resell them by applying a dynamic retail tariff, such as real-time pricing (RTP), to final consumers. These tariffs can reflect wholesale price fluctuations and might increase market efficiency and retailers' profits. This is of large relevance in the light of current efforts to implement dynamic retail pricing schemes in liberalized energy markets worldwide. We propose a multi-leader-follower problem to investigate the implications of strategic retail pricing and compare the impacts of fixed price tariffs and RTP tariffs on retailers and final consumers. Our analysis tackles different aspects: first, we formulate the model and provide theoretical results on its solution for both asymmetric and symmetric retailers. Second, we develop algorithms, which solve the multi-leader-follower problem and allow us to characterize the resulting market equilibria. Third, we conduct a numerical analysis based on illustrative academic examples as well as real energy market data from the German retail electricity market. As our results show, RTP on the one hand typically increases market efficiency, which confirms previous results obtained without explicit consideration of strategic behavior. On the other hand, dynamic RTP turns out to significantly reduce equilibrium profits in case of strategic firms, especially in environments with strongly fluctuating wholesale prices.

3 - Cornflow. A platform for the development, testing and operation of mathematical models
Guillermo González-Santander, Franco Peschiera

The development, study, validation and operation of mathematical models for the same problem can be a tedious and complicated task when the developer wants to try an evaluate a higher number of models. Cornflow is an open-source platform that deals with these complications by establishing a framework for the structure of the problem, allowing the efforts to be focused on the development of solving methods so they can be evaluated, validated and compared with each other with the as easily as possible, and allowing the deployment of new versions of models or the deployment of new models by pushing them into a repository. In this way, the models can be developed more efficiently and all models can be evaluated under the same conditions and against the same instances of testing and validation of results, allowing the researcher or developer to focus on the results and robustness of their solving methods, rather than on the process of deploying and running the models. Cornflow consists on a set of python packages and a user interface that allows to exploit the models and the solutions provided by them. The python packages get divided in the main server logic, the client library to use from other python programs and a set of tools libraries that make developing an optimization model in the Cornflow framework as easy as possible.

4 - A Dynamic Theory of Spatial Externalities
Fausto Gozzi

We characterize the shape of spatial externalities in a continuous time-space differential game with transboundary pollution. We posit a realistic spatiotemporal law of motion for pollution (diffusion and advection), and tackle spatiotemporal non-cooperative (and cooperative) differential games. Precisely, we consider a circle partitioned into several states where a local authority decides autonomously about its investment, production and depollution strategies over time knowing that investment/production generates pollution, and pollution is transboundary. The time horizon is infinite. We allow for a rich set of geographic heterogeneities across states. We solve analytically the induced non-cooperative differential game and characterize its long-term spatial distributions. In particular, we prove that there exist a Perfect Markov Equilibrium, unique among the class of the affine feedbacks. We further provide with a full exploration of the free riding problem and the associated border effect. Based on a recent paper with Raouf Boucekkine, Giorgio Fabbri and Salvatore federico.

■ MC-33

Monday, 12:30-14:00 - F102

Game Theory and Operations Management 1

Stream: Game Theory and Operations Management
Invited session
Chair: Ana Meca

1 - An Analysis of Project Structure and its Impact on Project Completion Delays
Juan Carlos Gonçalves, Fernando Bernstein, Gregory Decroix

This paper considers a project consisting of multiple activities performed by independent players. Each player has control and discretion over the time required to complete the activity it is responsible for. Devoting a standard amount of resources to that activity would result in some base amount of time for completion. However, a player may divert some resources to outside projects in order to earn additional revenue leading to inexcusable delays in the activity under the player's control. Such delays may or may not cause delays in the overall project completion time. If an overall project delay results, the project manager incurs a penalty based on the terms of the contract established with the customer. We study the allocation of project-level penalties (arising from inexcusable delays) among project activities, and examine how this allocation impacts the players' decision making and the associated completion time of the project.

2 - Multi-objective Search Game : long-term vs short-term
Florian Delavernhe

In this work, we study a multi-objective formulation of the search allocation game. The search allocation game is the distribution of a search budget (player 1) over a searched area to detect an escaping target (player 2). An optimal search has to consider an optimal escape of the target. In the search theory literature, the classic objective function is the maximization of the detection probability at the end of the time horizon. In the present work, we extend this problem and propose a multi-objective formulation: seeking to produce a solution offering a long-term search and a short-term search. A long-term search is the classic maximization of the detection probability at the end of the time horizon whereas a short-term search means a high detection probability earlier in the time horizon (e.g. before half the time horizon) and it is actually represented by a set of objective functions. The two aspects were never considered together and therefore we carefully study two lexicographic solving processes to highlight the differences between these objectives. Afterwards, we propose an exact solution method, based on epsilon-constraint, and a matheuristic method based on a combination of lexicographic and epsilon-constraint. A set of experiments study the two main aspects of the results, namely computation time and quality (comparing exact and approached results).

3 - Frictions in International Operations: a Financial Approach
Haokun Du

International tradings involve selection of payment currency. Due to foreign capital regulation and insufficient foreign reserves of the government, companies may need to accept payment in less-traded currencies. These less-traded currencies have higher bid-ask spread in foreign exchange market. Additionally, lack of free access to the exchange market fuels into a larger de facto cost of currency conversion. We consider such frictions in the paper and seek to answer how to mitigate the effect. We consider two companies with opposite needs of currencies. Instead of resorting to centralized financial institution, we consider the possibility of decentralization, where they negotiate an exchange between themselves. Two negotiation schemes are considered. Forward contract is where negotiation happens prior to randomness resolution, while ad-hoc contract after. The forward contract has a larger potential in increasing companies' quantity decisions due to prior commitment. For the ad-hoc contract, quantity decision of the two companies is a non-cooperative game. The game has either a unique Nash equilibrium or a continuum of equilibria. A payoff dominance selection rule gives us a unique Nash equilibrium where both companies have the highest quantity decisions among all the equilibria. The results above are under general demand distribution. The comparison between the two negotiation schemes under uniform distribution for analytical tractability is also being discussed.

4 - Cooperative Purchasing with General Discount: Equal versus Different Price allocations
Ana Meca, Jose A. Garcia-martinez, Gerardo Alexander Vergara Mesa

Certain purchasing groups do not flourish. A supposed reason for this is a creeping dissatisfaction among various members of a group with the allocation of the cooperative costs. In this talk, we focus on cooperative purchasing cost models with general and continuous quantity discounts. Then, we compare the commonly used Equal Price (EP) method for allocating costs with a new method of Different Prices (DP). We show that the EP method, although unfair in many situations, works very well when discounts are linear. However, in situations with non-linear discounts, the EP method is not acceptable to some agents (mayor agents). For these situations, we propose a family of Different Price cost allocations with different prices that are efficient and acceptable to all agents.

■ MC-34

Monday, 12:30-14:00 - T003

Emerging vehicle routing applications

Stream: Smart Mobility and Logistics
Invited session
Chair: *Ninja Soeffker*

1 - Heatmap-based Repositioning for Crowdsourced Ride-Sharing Platforms
Jarmo Haferkamp, Marlin Wolf Ulmer, Jan Fabian Ehmke

Ride-sharing users submit trip requests online, are picked up a short time afterward, and are driven to their destination while possibly sharing part of their ride. In order to maximize the service availability and thus revenue, platform providers aim to balance the distribution of drivers in the city. Ensuring such distribution is particularly challenging in the case of a crowdsourced fleet, as drivers are free to decide where to reposition. Thus, providers look for ways to support drivers in making decentralized, yet well-informed, repositioning decisions.

We propose an intuitive means to support drivers repositioning: opportunity heatmaps. Creating reliable heatmaps is challenging as showing heatmaps changes the repositioning of drivers in the system, which in turn may lead again to imbalances. To address this issue, we propose an adaptive learning algorithm for designing our heatmaps. In every iteration, we simulate the system and generate heatmaps based on previously learned opportunities. We then update the opportunities based on the simulation's outcome and use the updated opportunities in the next iteration. Eventually, the expected opportunities and therefore the heatmap design policy converges.

We show in a comprehensive case study that carefully designed heatmaps improve service availability and thus platform revenue, reduce earnings volatility among drivers, and lead to a more balanced distribution of service availability across the city.

2 - Dispatching Electric Vehicles Using Reinforcement Learning
Giovanni Campuzano, Matteo Brunetti, Martijn Mes

The growth in freight transport greatly impacts intermodal logistics areas, which are at the core of international freight networks. A promising solution to increase throughput and reduce congestion, operational costs, greenhouse gas emissions, is the adoption of electric automated vehicles (EAVs). By implementing EAV systems, organizations aim to improve sustainability, flexibility and efficiency for the handling of goods. To reduce the costs of ownership and improve the utilization of EAVs, ports and business parks are now looking at EAV systems shared between multiple logistics companies. We define this new and challenging setting as the Internal Electric Fleet Dispatching Problem (IEFDP).

In the IEFDP, the transport of containers is carried out by EAVs while satisfying due date restrictions. When a job cannot be transported by an EAV on time, an alternative transport mode is used. The objective of the IEFDP is to minimize the use of the alternative transport mode through the decisions regarding the charging of AVs and the assignment of AVs to transport jobs, considering uncertainty in the arrival and characteristics of transport jobs. To solve the IEFDP, we introduce an MDP formulation and search for an optimal policy using a value-based RL approach. We compare our RL approach against three heuristics representing human decision-making. Results show that our approach outperforms the cost reductions between 5% and 16% compared to the benchmark heuristics.

3 - Optimizing Drone-Assisted Last-Mile Deliveries: The Vehicle Routing Problem with Flexible Drones
Ilke Bakir, Gizem Ozbaygin

We study a hybrid delivery system in which (multiple) trucks and (multiple) drones operate in tandem. In particular, we introduce the vehicle routing problem with flexible drones (VRPFD), which seeks to find a set of delivery routes for a fleet of trucks and drones operating in synchronization, with the goal of minimizing the makespan. We formulate the VRPFD as a mixed integer linear program on a time-space network, and present an efficient optimization algorithm based on a dynamic discretization discovery approach. We demonstrate the benefits of drone flexibility and the efficiency of the proposed solution approach through a detailed computational study performed on a newly generated set of benchmark instances. Our findings suggest that the flexible use of drones facilitates higher drone utilization and therefore results in makespan improvements. In clustered geographies, drone flexibility reduces the makespan by up to 12.12%, with an average of 5.39%. Our proposed solution approach is able to efficiently solve the VRPFD instances by making use of an intelligent lower bounding mechanism while keeping its subproblem small. Computational experiments reveal that it is able to reduce the solution time by up to a factor of 6.5 when compared to solving the VRPFD using a commercial solver.

4 - Multi-depot electric vehicle routing with single recharge
Ninja Soeffker, Magdalena E. Doerler, Jan Fabian Ehmke

Over the last years, the driving range of electric vehicles has been increasing, leading to more application areas. In addition to the use of electric vehicles in inner cities and for typical last-mile purposes, it is now also possible to apply electric vehicles for transportation purposes between cities. In this presentation, we consider a multi-depot vehicle routing problem with electric vehicles where each vehicle may recharge a single time at charging locations as multiple recharging is deemed unrealistic due to the associated time consumption. Further, overnight charging is possible at the depots. Different charging technologies are available at the charging locations that differ in the charging speed and the associated costs. The proposed MIP model makes decisions about the vehicle routes from depots to customers and potentially via charging stations. Further, decisions are made about the used charging technology and the charged energy. We solve instances inspired by the Austrian topology with an off-the-shelf solver. Further, we propose a heuristic that decomposes the customer set based on distances to the depots and then solves the resulting subproblems with a solver. We present results for both approaches using a time limit and analyze which approach provides better results in which cases.

■ MC-35

Monday, 12:30-14:00 - T004

Traffic flow

Stream: Transportation
Invited session
Chair: Eloisa Macedo

1 - Traffic congestion modelling: Convex quantile regression approach
Iaroslav Kriuchkov, Timo Kuosmanen

Traffic congestion causes severe negative effects on economic, environmental, and societal wellbeing in the cities around the world. The classic tool of traffic congestion modeling is the fundamental diagram, which maps the relationships between the speed, flow, and density of traffic. However, the empirical estimation of the fundamental diagram is conventionally based on rather restrictive parametric specifications such as parabolic or triangular functions. This study develops a new approach to estimate the fundamental diagram based on the convex quantile regression. The proposed method is fully nonparametric, which makes it highly flexible without prior functional form assumptions. The use of quantiles allows to introduce to the diagram the varying levels of efficiency, which depend on external factors. An empirical application to data from Finnish road network sensors demonstrates the benefits of the proposed approach.

2 - Differentiable Design of Mileage-based User Fees for Equitable Benefits
Venktesh Pandey

Mileage-based user fee (MBUF), also referred to as vehicle miles traveled tax, charges a traveler a fixed or a variable rate per mile traveled on the road. MBUFs are actively being considered as an alternative to fuel tax across several states in the US. Ongoing pilot programs and surveys have identified that MBUFs pose transportation fairness concerns. They are considered fair because all vehicles pay for their usage of highway infrastructure and the cost burdens on poor travelers is lower who pay more fuel taxes due to more fuel-inefficient vehicles. However, MBUFs are also claimed as unfair for travelers who drive long distances for work and for travelers with fuel-efficient vehicles who are doing their part to reduce greenhouse gas emissions. In this research, long-term equity impacts of MBUF rates are investigated accounting for travelers' route choices. Travelers are grouped using two criteria: type of vehicle ownership (fuel-efficient or inefficient vehicle) and the value of travel time (correlated with traveler's income level). A multicriteria static traffic equilibrium model is used to quantify the delay differences across different groups. Using the maximin fairness principle, the research optimizes the MBUF rates to obtain fair distributions of delays across groups as a function of driver behavior and vehicle parameters. The model is then extended to design differential MBUF rates to create fair delay distributions without compromising system optimality.

3 - Impact of traffic lights and speed control on noise optimization in urban networks
Facundo Storani, Roberta di Pace, Claudio Guarnaccia, Stefano de Luca

Reducing noise pollution exposure is a crucial issue in cities that impacts health and quality of life. Traffic noise alone is harmful to the health of almost every third person in the European Region, according to the World Health Organisation(WHO). As a result, the WHO introduces the Environmental Noise Guidelines for the European Region to support the policy-making process. It is necessary to develop mobility management policies that directly act on noise exposure. Some investigations are about the impacts of speed reduction, the dedicated bus lane, the green wave, the traffic signal optimisation, and demand management. The paper focuses on developing a framework for online traffic control that combines traffic performances and noise in a multi-objective optimisation approach. This approach must be integrated with a traffic flow model that captures the effects of a traffic control strategy on vehicle kinematics and provides the traffic control strategy with the input necessary for the traffic lights variables design. Accordingly, a hybrid traffic flow model (combining macro and microscopic traffic flow representation) has been developed. The whole framework has been applied to a toy network composed of interacting junctions under three optimisation scenarios that have been compared: a mono-criterion, a multi-criterion, and a combination between mono-criterion and speed optimisation. Results are encouraging and highlight the impact of multi-objective optimisation.

4 - Towards a deeper understanding of road safety and pollutant emission hotspots based on a driving behaviour assessment on a roundabout near a University Campus
Eloisa Macedo, Elisabete Ferreira, Paulo Fernandes, Margarida Coelho, Jorge Bandeira

As road transport is considered a major contributor to accidents and environmental pollution, possible emission mitigation and safety improvement strategies should be designed and implemented shortly. Driving behaviour plays a key role in these components and there is a lack of a comprehensive impacts assessment at intersection level. A deeper understanding of road safety and pollutant emission hotspots is crucial for efficient and sustainable road system planning and management. In this work, a first attempt is performed taking as a case study an urban two-lane roundabout near a University Campus in Centro Region, Portugal, with some congestion at peak hours due to pedestrian and cyclists crossings at roundabout's legs. An experimental monitoring with vehicles equipped with onboard diagnostic and GPS devices was conducted for typical weekdays. Variables under study include stopping and braking distances, driver's reaction time, speed, acceleration, vehicle-specific power (VSP), driving volatility-related variables, and consequent global and local emissions, estimated using the VSP methodology. The network was coded in PTV VISSIM microscopic traffic model, and the hotspot identification is based on the driver behaviour impacts assessment and identified for each roundabout segment, including downstream, upstream and circulating areas. The results can be valuable for policymakers to support operational and planning strategies to minimise negative side-effects in the area.

■ MC-36

Monday, 12:30-14:00 - U006

Workforce and Capacity Planning

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: Christos Vasilakis

1 - Robust annual scheduling of medical residents using prioritized multiple training schedules to combat operational uncertainty
Sebastian Kraul, Jens Brunner

Medical residents often have to pass through many departments, which place different requirements on them. They are informed about the upcoming departments by an annual schedule to keep the individual departments' service level as constant as possible. Due to poor planning and uncertain events, deviations in the schedule can occur. These deviations affect the service level in the departments as well as the satisfaction of the residents. This project analyzes the impact of priorities on residents' annual planning to overcome unknown departmental changes. We present a novel two-stage formulation that combines residents' tactical planning with daily and duty rostering's operational level. We determine an analytical bound for the problem that is significantly superior to the LP bound. Additionally, we approximate a bound based on the solution approach. In a computational study, we analyze the performance of various bounds, our solution approach, and the effects of additional priorities in residents' annual planning. We show that additional priorities can significantly reduce the number of unknown shifts to be worked. Finally, we derive a practical number of priorities from the results

2 - Practical Recommendations for Staff Rostering Justified by Real-World Optimization
Kimmo Nurmi

Staff rostering is a difficult and time-consuming problem that every company or institution that has employees working on shifts or on irregular working days must solve. The main goal is the performance of staff on financial efficiency. Other important goals include fairer workloads and employee satisfaction. Furthermore, the staff rostering optimization should address the health, safety, and well-being of the employees. The Finnish Institute of Occupational Health, which operates under the Ministry of Social Affairs and Health, published their latest recommendations for shift work in 2019. The recommended values for more than ten individual factors are well justified. However, problems arise when all these recommendations should be satisfied together in real-world staff rostering. We show the gap between the ideal recommendations, theoretical expectations and the everyday reality. We publish our five most important practical recommendations for shift work that researchers should consider when they implement staff rostering algorithms. The PEASTP metaheuristic is used for optimization test runs.

3 - Workload balancing in hospital wards through optimized patient admission scheduling
Pieter Smet, Greet Vanden Berghe

Ensuring sustainable working conditions for employees plays a crucial role in their overall engagement and performance. This is especially important in hospitals, where job performance directly affects the quality of care provided to patients. In this study we focus on one particular strategy for improving working conditions in hospitals: balancing workload. The goal is to balance hospital wards' workload both spatially (between different wards) and temporally (across different days). We propose an optimization-based approach which determines the admission date of patients and assigns them to suitable wards. In order to achieve this, we introduce new equity functions which are capable of taking into account the multi-period nature of patient admission schedules. Using real-world data, we then analyze the results of a series of experiments to gain new insights into (i) the effects of using different equity functions and (ii) the influence of problem properties such as ward specialization and ward transfers on workload balancing.

4 - Exploring the role of flexible use of bed capacity in acute stroke pathways: a computer modelling study
Christos Vasilakis, Richard Wood, Simon Moss, Ben Murch, Philip Clatworthy

Sound and evidence-based decision making on bed capacity options along patient pathways is essential to avoid pressure building in different parts of the healthcare system, and to help ensure best patient outcomes and financial sustainability. Yet, routine decision support methods typically use only average arrival rate and lengths of stay, which are well known to underestimate the number of beds required. This study investigates the extent to which averages-based estimates can be augmented by a robust assessment of additional 'flex capacity' requirements, to be used at times of peak demand. The setting is a major healthcare system in England, which has been working towards a centralised acute stroke pathway. Numerical experiments using an open-source pathway simulation tool recently developed by our team (PathSimR) showed that, to ensure delay for only 1% of presentations at the hyper-acute stroke unit, flex capacity would be needed at 45%, 45% and 36% of the allocated averages-based bed requirement for the hyper-acute, acute and rehabilitation units respectively. Some amount of flex capacity would be required 30%, 20% and 18% of the time. This study demonstrates the importance of appropriately capturing variability within capacity plans, and provides a practical and economical approach which can complement commonly-used averages-based methods. Results of this study have directly informed the healthcare system's new configuration of stroke services.

■ MC-37
Monday, 12:30-14:00 - V001

Time Dependent Vehicle Routing

Stream: Vehicle Routing and Logistics
Invited session
Chair: Tommaso Adamo

1 - Time-Dependent Vehicle Routing Problem with Time Windows on a Road Network
Maha Gmira, Michel Gendreau, Andrea Lodi, Jean-Yves Potvin

Travel times inside cities often vary quite a lot during a day and significantly impact the duration of commercial delivery routes. Several authors have suggested time-dependent variants of the most commonly encountered vehicle routing problems. In these papers, however, time-dependency is usually defined on customer-based graphs. Thus, one major impact of travel time variations is missed: in an urban environment, not only do travel times change, but also the paths used to travel from one customer to another. In fact, during a day, different paths may be used at different points in time. To address this issue, one possible approach is to work directly with the road network and consider travel time (or travel speed) variations on each road segment. We propose a solution approach for a time-dependent vehicle routing problem with time windows in which travel speeds are associated with road segments in the road network. This solution approach involves a tabu search heuristic that considers different shortest paths between any two customers at different times of the day. A major contribution of this work is the development of techniques to evaluate the feasibility and the approximate cost of a solution in constant time, which allows the solution approach to handle problem instances with up to 200 nodes and 580 arcs in very reasonable computing times. The performance of our algorithm is assessed by comparing it to an exact method on a set of benchmark instances.

2 - Time-dependent vehicle routing problem of waste collection on the real city network
Dušan Hrabec, Dominik Závada, Vlastimír Nevrlý

This work deals with the so-called time-dependent vehicle routing problem applied to the waste collection problem on a real traffic network. A homogeneous fleet of vehicles, where each vehicle can perform various trips, has to serve the collection points while considering one particular type of waste. The time of day is divided into several time intervals. The objective is to optimize waste collection routes when considering various time delays during various collection times (hours). The model is tested on a case study in Zlín (Czech Republic) with a collection network consisting of 23 containers for the selected waste type, electrical waste. The preliminary results demonstrate that waste collection with considering traffic flow information by the time of day can reduce route time (ca. by 15-24%) depending on the number of vehicles and the collection starting time. Minimizing total spend time by waste collection vehicle also reduces costs, emissions from vehicles, and city center traffic in congested hours.

3 - Stochastic time-dependent VRPs with a large number of random variables.
Stein W. Wallace, Zhaoxia Guo, Michal Kaut

The main focus of this work is to illustrate that it is feasible to solve stochastic time-dependent VRPs with tens of thousands of random variables, allowing for large networks and short time steps. We focus on the function evaluation for a given feasible solution (set of routes), so that any existing deterministic heuristic can be used to find the routes. We demonstrate, as an example, that for rather large problems, a stochastic evaluation takes about 15 times longer than a deterministic one. I.e., we need 15 scenarios for an accuracy of about 1% in a case of 28,000 dependent random variables.

4 - Learned Upper Bounds for the Time-Dependent Travelling Salesman Problem
Tommaso Adamo, Emanuela Guerriero, Gianpaolo Ghiani, Pierpaolo Greco

Given a graph whose arc traversal times vary over time, the Time-Dependent Travelling Salesman Problem consists in finding a Hamiltonian tour of least total duration covering the vertices of the graph. The main goal of this work is to define tight upper bounds for this problem by reusing the information gained when solving instances with similar features. This is customary in distribution management, where vehicle routes have to be generated over and over again with similar input data. To this aim, we devise an upper bounding technique based on the solution of a classical (and simpler) time-independent Asymmetric Travelling Salesman Problem, where the constant arc costs are suitably defined by the combined use of a Linear Program and a mix of unsupervised and supervised Machine Learning techniques. The effectiveness of this approach has been assessed through a computational campaign on the real travel time functions of two European cities: Paris and London. The overall average gap between our heuristic and the best-known solutions is about 0.001%. For 31 instances, new best solutions have been obtained.

■ MC-38

Monday, 12:30-14:00 - V002

Humanitarian Logistics: Transport and Inventory Management

Stream: Humanitarian and Healthcare applications (contributed)
Contributed session
Chair: Christine Currie

1 - Cost-Effective Evacuation Network Design under Travel Congestion
Halit Uster

We consider an evacuation network design problem under cost and travel congestion considerations while incorporating worst-case evacuation time for the evacuees. Employing a time-expanded network, we model for effective and controlled evacuation by determining active shelter locations and evacuee routes that can be implemented in the preparedness stage in response to foreseen extreme events, such as hurricanes and flooding. Specifically, we propose a mathematical model that prescribes evacuee routes through the road network to shelter locations under evacuation time constraints by making design decisions on shelter locations and capacities, contraflows, road segments utilized in evacuation and their capacities. To solve our model, we devise an efficient Benders Decomposition (BD) framework with convergence enhancements for solving large-scale instances while also taking advantage of specific characteristics of the problem. We design and implement an experimental study to test our BD technique using data from Central Texas.

2 - Optimising the budget allocation for food procurement in the response to natural disasters
Christine Currie, Stephan Onggo, Duc-Cuong Dang

In this talk, we describe a variant of the lot sizing problem that arises in the context of disaster management. Research to support disaster management often focuses on large disasters but in some regions, demand arises on a daily basis from small to medium scale disasters. For example, in Indonesia's West Java province, on average, there were more than 4 natural disasters per day between 2016 and 2020. These are typically described as routine emergencies in the literature; however, the agencies responsible for disaster management need to deploy the same types of resource as in disaster operations such as food and shelter. We consider the problem where a fixed budget has to be allocated efficiently over multiple time periods to procure large quantities of a staple food that will be stored and later delivered to people affected by disasters and where demand is unknown in advance. In the presentation, we will describe several approaches to solving the problem starting from the deterministic model where perfect information is provided, and moving on to include uncertainties using classical robust optimisation, risk-minimisation stochastic programming, and robust optimisation with affine rules. We will describe results of experiments conducted on the data of West Java, Indonesia, demonstrating how they can be used to determine whether an annual budget is fair and safe, or when storage peaks are likely to occur.

3 - Optimal Usage of Budget for Stocking Humanitarian Aid Materials in a Stochastic Dynamic Setting
Onur Kaya, Muge Acar

Governmental or non-governmental organizations (NGOs) purchase and stock humanitarian aid materials in appropriate quantities with a limited budget. The budget can either be used before the disaster for stocking decisions under uncertainty or it can be used after the disaster to satisfy the required demand at a higher cost when the uncertainty is resolved. In this study, we aim to decide how to allocate the budget for pre and post disaster usage. In this system, the budget of NGOs may also change over time through donations or other incomes. Dynamic stocking decisions of NGOs are analyzed using dynamic programming models under budget constraints. Infinite horizon stochastic dynamic programming models are presented and the results of the dynamic inventory models with and without budget considerations are compared via numerical analysis. The effects of different parameters on the system results are investigated. Detailed numerical studies and results of the sensitivity analysis show the significance of budget considerations in inventory decisions.

■ MC-39

Monday, 12:30-14:00 - U8

Theoretical developments in Problem Structuring Methods

Stream: Problem structuring and soft OR
Invited session
Chair: *Leroy White*
Chair: *Mike Yearworth*

1 - Shall we Dance? In search of Collective Intentions in GDSS facilitated decision making
Ashley Carreras

A persistent theme across many approaches to facilitated group decision making is that some aspect of collective agreement could be established as to current and future actions. This can be at the level of agreement on the overall objectives of a group or organisation, agreement on goals or it could be agreement on the best set of actions to achieve the desired collective goals. There is also the need for agreement on undertaking/participating in the facilitated decision making. Whilst some have pointed to these outputs/outcomes of as the some of the reasons why participants may gain value from their participation, the nature of these collective agreements remains underexplored. This paper seeks to delineate the different types of collective agreements that may be established using the concept of collective intentions. This will be done through the examination of workshops which the author has acted as a facilitator or co-facilitator using Causal Mapping in a GDSS environment.

2 - From problem formulation to problem structuring and back
Mike Yearworth

We have carried out an analysis of the OR literature on problem formulation and problem structuring with a view to understanding something of the breadth with which OR scholars approach problematisation. We have used Callon's notion of problematisation as the theoretical basis for our analysis precisely because it sits outside of OR and provides some insight into the "abundance of problematisations" facing any expert engaging with a real-world problem. The results suggest revisiting the motivations that led to the emergence of Soft OR/PSMs with a view to (re-)joining-up the thinking around problem formulation and problem structuring in OR generally.

Monday, 14:30-16:00

■ MD-01

Monday, 14:30-16:00 - A

Fran Ackermann

Stream: Keynotes
Keynote session
Chair: Rudolf Vetschera

1 - Managing Grand Challenges - Engaging Stakeholders through the lens of Problem Structuring Methods and Behaviour OR

Fran Ackermann

Addressing Grand challenges, such as navigating climate change or mental health, is increasingly gaining prominence across the globe. Those researching such challenges argue that progress requires collaborative, integrated, and coordinated responses from a wide range of stakeholders including organisations, governments, communities etc. Thus, to successfully navigate these challenges approaches need to be able to engage with stakeholders, both in terms of eliciting a comprehensive understanding of the challenge as viewed through the many lenses (managing the resultant complexity of data), as well attending to the myriad socio-political considerations. PSMs through their focus on managing messy, complex, problems are well situated to assist this endeavour, particularly when coupled with the growing body of work in the field of BOR. Through drawing on examples from practice, this keynote will reflect on how management scientists can provide valuable contributions to those seeking to address grand challenges.

■ MD-02

Monday, 14:30-16:00 - B

EJOR: policy, facts and highlights

Stream: OR Journals
Invited session
Chair: Roman Slowinski

1 - Deep learning in business analytics and operations research: Models, applications and managerial implications

Mathias Kraus, Stefan Feuerriegel, Asil Oztekin

Business analytics refers to methods and practices that create value through data for individuals, firms, and organizations. This field is currently experiencing a radical shift due to the advent of deep learning: deep neural networks promise improvements in prediction performance as compared to models from traditional machine learning. However, our research into the existing body of literature reveals a scarcity of research works utilizing deep learning in our discipline. Accordingly, the objectives of this overview article are as follows: (1) we review research on deep learning for business analytics from an operational point of view. (2) We motivate why researchers and practitioners from business analytics should utilize deep neural networks and review potential use cases, necessary requirements, and benefits. (3) We investigate the added value to operations research in different case studies with real data from entrepreneurial undertakings. All such cases demonstrate improvements in operational performance over traditional machine learning and thus direct value gains. (4) We provide guidelines and implications for researchers, managers and practitioners in operations research who want to advance their capabilities for business analytics with regard to deep learning. (5) Our computational experiments find that default, out-of-the-box architectures are often suboptimal and thus highlight the value of customized architectures by proposing a novel deep-embedded network.

2 - Mobile parcel lockers in last-mile distribution: Where to locate them and how to write about it?
Nils Boysen

The aims of this talk are twofold. First, we present our research on mobile parcel lockers and elaborate how operations research can support future parcel delivery via autonomous locker vehicles that reposition themselves in the neighborhoods of customers. Since mobile lockers are just one representative among manifold innovative concepts for future transportation, we furthermore present some thoughts what a good operations research paper on innovative applications should look like.

3 - Policy and facts about the European Journal of Operational Research (EJOR)
Roman Slowinski, Emanuele Borgonovo, José Fernando Oliveira, Steffen Rebennack, Ruud Teunter, Mike Yearworth

The session starts with two presentations done by authors of representative and highly cited papers published recently in EJOR. They represent two categories: Innovative Application of OR, and Theory & Methodology. Some further research developments and practical implications that followed these publications will be given by their authors. Then, the editors of EJOR will explain their editorial policy and will give some current characteristics of the journal. They will also describe their approach to evaluation and selection of articles and will point out topics of OR that recently raised the highest interest. In the last part of the session, the editors will answer some general questions from the audience.

■ MD-03

Monday, 14:30-16:00 - C

Dealing with Fairness in Machine Learning through Mathematical Optimization

Stream: Machine Learning and Mathematical Optimization
Invited session
Chair: *Kseniia Kurishchenko*

1 - Improving the fairness of Generalized Linear Models by feature shrinkage
Marcela Galvis Restrepo, Dolores Romero Morales, Emilio Carrizosa

In recent years, supervised classification has been used to support or even replace human decisions in high-stakes domains such as pre-trial risk assessment, police stop-and-frisk programs, credit scoring, insurance premiums, and healthcare access. The training of these algorithms uses historical data which might be biased against individuals with certain sensitive characteristics. The increasing concern over potential biases has motivated lawmakers to pass anti-discrimination laws which prohibit unfair treatment based on characteristics such as gender or race. In this paper, we propose a methodology that enhances the trade-off between accuracy and unfairness in classification. We use a numerical method that shrinks the possible values the predictors can take guided by a linear combination of the accuracy and the disparate mistreatment, our measure of unfairness, of the shrunk model. We illustrate the performance of our methodology in terms of accuracy and unfairness on a collection of real-world datasets.

2 - On a mathematical optimization formulation to trade off accuracy and fairness in LASSO regression
Thomas Halskov, Dolores Romero Morales, Emilio Carrizosa

The use of Machine Learning to aid Data Driven Decision Making is spreading rapidly and so are the concerns relating to the fairness of these algorithms. There are well-known examples of discrimination of sensitive groups, due to e.g. their race or their gender, in algorithmic decision making. This calls for controlling not only the accuracy but also the fairness of models. In the literature, this is done by either preprocessing the data, applying a post processing step to the predictions, or by constructing a machine learning model that trades offs accuracy and fairness. In this talk, we follow the latter approach. We propose to build a LASSO regression model that in addition to minimizing the loss function, has a direct control on the proportion of observations with a prediction above a threshold in both the sensitive as well as the non-sensitive groups. We provide a mathematical optimization formulation to describe the Pareto frontier of this problem, as well as some theoretical properties of it. We illustrate our approach on a number of datasets.

3 - An integer optimization-based approach to fair clustering
Philipp Baumann, Manuel Kammermann

Clustering algorithms are among the most widely-used machine learning techniques. With the usage of clustering algorithms in application areas with significant social implications such as college admission, recruitment, or credit approval, the issue of fairness has received considerable attention. Various notions of fairness have been formalized. We consider the problem of fair clustering as introduced by Chierichetti et al. (2017), where each object is associated with one of two colors. A clustering is considered fair if no color is over-represented in any cluster. We introduce a new center-based clustering approach that assigns, in each iteration, the objects to clusters by solving a binary linear optimization program. The fairness requirement is incorporated with constraints that ensure that the proportions of the colors in a cluster are within user-defined bounds. The user can choose between various clustering objectives such as k-center, k-means, k-medians, and k-medoids. For large instances, we propose a two-step scaling technique that first generates potentially unfair sub-clusters which are then combined to form fair clusters. We report results involving synthetic and real-world data sets that show that our approach either outperforms or is comparable with several state-of-the-art algorithms. An important advantage of our approach compared to existing algorithms is its flexibility to incorporate additional constraints into the binary linear optimization program.

4 - On fair random forests
Kseniia Kurishchenko, Emilio Carrizosa, Dolores Romero Morales

Ensemble methods are one of the most powerful methods in Machine Learning. In this paper, we investigate how to make ensemble methods more flexible to incorporate desirable properties such as fairness. We propose a mathematical formulation to build an ensemble of stump trees that can control for sparsity, cost-sensitivity, as well as fairness. We illustrate the proposed models on a variety of canonical datasets.

■ MD-04

Monday, 14:30-16:00 - D

Machine learning for optimizing business decision-making II

Stream: Machine Learning and Mathematical Optimization
Invited session
Chair: *Wouter Verbeke*
Chair: *Kristof Coussement*

1 - Investigating the beneficial impact of the logit leaf model for credit scoring
Khaoula Idbenjra, Kristof Coussement, Arno De Caigny

Credit scoring plays a vital role in financial risk management that has been investigated extensively in extant literature. However, most credit scoring studies rely solely one-fit-all classifiers with logistic regression (LR) the golden standard. Although the financial legislative requirements' need for interpretability, extant research largely focusses on the prediction performance as main evaluation criterion. In order to balance the trade-off between predictive performance and interpretability, we introduce the Logit Leaf Model (LLM) as a hybrid segmentation-based model in the credit scoring field. The LLM aims to improve the predictive power of the logistic regression, as well as to offer deeper insights into the customers' drivers. Based on an empirical credit scoring dataset with 65,536 active customers, experimental design benchmarks the LLM against the LR and other various state-of-the art classification techniques. Our results show that LLM is an encouraging solution for credit risk problems, i.e. being able to compete with best performing approaches while producing deep insights vital for managerial decisions.

2 - Predicting Day-Ahead Stock Returns using Search Engine Query Volumes

Christopher Bockel-Rickermann

Data on internet usage exhibits vast amounts of behavioral information. This paper aims to answer the question whether this information can be facilitated to predict future returns of stocks on financial capital markets. In an empirical analysis it implements gradient boosted decision trees to learn relationships between abnormal returns of stocks within the S&P 100 index and lagged predictors derived from historical financial data, as well as search term query volumes on the internet search engine Google. Models predict the occurrence of day-ahead stock returns in excess of the index median. On a time frame from 2005 to 2017, the data exhibits valuable information. Evaluated models have average areas under the receiver operating characteristic between 54.2% and 56.7%, indicating a classification better than random guessing. Implementing a simple statistical arbitrage strategy, models are used to create daily trading portfolios of ten stocks and result in annual performances of more than 57% before transaction costs. With ensembles of different data sets topping up the performance ranking, the results further question the weak form and semi-strong form efficiency of modern financial capital markets.

3 - Predicting Credit Rating Migrations Combining Textual, Financial, and Market Data

Manon Reusens, Kameswara Korangi, Seppe vanden Broucke, Christophe Mues, Cristian Bravo, Bart Baesens

In business, one can often benefit from estimating the creditworthiness of counterparties. Information on the creditworthiness of companies is contained in credit ratings, which are offered by credit agencies. Even though their objectivity is sometimes questioned, the ratings still entail a significant amount of information and are often used as an indicator of the default risk of the company. One disadvantage of credit ratings is that they are slow to react. Sources like news give a better indication of creditworthiness at a given point in time. With this study, we want to add to the existing literature by combining multiple sources of financial data and adding text data for predicting migrations in credit ratings. More specifically, we focus on the following aspects. How can unstructured text help with the prediction of the credit rating migration? And what is the added value of using these sources on top of the financial ones? In our research, we use deep learning models to predict migrations in credit rating over time. Currently, the models used for this kind of research are non-deep learning techniques. However because of the richness of data sources, and variety of data forms, we are convinced that deep learning might be advantageous to the traditional methods. As said, we combine data from various sources, mainly from the following three databases: COMPUSTAT, CRSP, and ProQuest. The collected data entails information on US mid-cap firms over 10 years (2012-2022).

■ MD-05

Monday, 14:30-16:00 - E

Deep Learning in Healthcare

Stream: Deep Learning and Applications
Invited session
Chair: *Melisa Caliskan-Demir*

1 - Prediction model for the spread of the COVID-19 outbreak in the global environment

Ron Hirschprung, Chen Hajaj

The worldwide COVID-19 pandemic has claimed the lives of over six million people (as of March 2022) and triggered economic recessions. Before vaccines were available, the main strategy for fighting spread of the virus was based on lockdowns, which had a significant negative impact on the economy. Lockdowns introduce an inherent tradeoff between the values of life and good economy. To help mitigate this tension, this study develops a prediction methodology for the spread of the COVID-19 pandemic. We exploit the fact that this is the first time in human history that a global pandemic has been accompanied by an extensive flow of data. Using Data Mining and Machine Learning tools, we trained a model to predict the spread of disease, expressed by the number of confirmed cases in a spatial-temporal space. The study introduces an innovative idea, the Center of Infection Mass (CoIM), inspired by the center of mass concept in physics. The methodology was evaluated empirically using real data from western European countries, and shows that the spread can be predicted with relatively high accuracy. Thus, decision-makers could use this prediction model to impose lockdowns in a more precise manner, thereby reducing financial setbacks and increasing social welfare. The CoIM is a promising concept for Data Mining and Machine Learning based prediction models for pandemics spread between people in close proximity and, with some modifications, might be adopted to other spread mechanisms.

2 - Repositioning Digital Therapeutics Products by Integrating Biological and Technological Networks

Eunji Jeon, So Young Sohn

Finding new target patients is crucial to increase the market for digital therapeutics (DTx) products. However, the discovery of new target disorders of existing DTx products has not been extensively investigated. Utilizing their features, we provide a DTx product repositioning framework on the basis of the multiplex network. It integrates technical information of DTx products along with genomic and chemical information of disorders. We predict potential links between disorders on the network to propose a novel target disorder with the highest potential for each product. For this multiplex link prediction, we compare the random walk-based graph embedding method to the deep learning method. The framework is applied to suggest new indications for existing five psychiatric DTx products. Our framework is expected to contribute to both the companies and patients related to DTx products.

3 - Toward a Novel Data-Driven Healthcare Decision-Making with Deep Learning

Lina Siltala-Li, Eeva Vilkkumaa

Massive volumes of constantly collected Electronic Health Records (EHR) have been used as one of the most important pieces of information for decision-making. Despite the exploding volume and informative data of EHR from the healthcare system, it remains challenging to apply it directly for clinical research because of its complicated and heterogeneous data. With the fast development of artificial intelligence, there have been studies to tackle the complexity of EHR with deep learning methods (Shickel et al., 2017; Xiao et al.,2018). Most existing methods only consider a single objective, such as the minimisation of cost or maximisation of health outcomes. In reality, however, healthcare decision-making problems must tackle with trade-offs between multiple objectives, whereby single-attribute methods may be limited in practical relevance. Moreover, many existing methods have not estimated uncertainties which are important factors for healthcare decision-maker. In this study, we propose a data-driven healthcare decision-making framework augmented with bayesian deep learning. This framework estimates clinical cost and mortality risk under three different scenarios at a time range of one month to three years after patients have been diagnosed. Therefore, it could help decision-maker to optimise treatment paths dynamically. We apply our healthcare decision-making framework in real sleep apnea EHR from Turku university hospital in Finland.

4 - Mining potential frauds in the health insurance industry - a case of East Africa
Sajid Siraj, Salome Khvistani

We demonstrate the practical use of data mining and unsupervised machine learning techniques to identify insurance-related frauds in the healthcare industry. We apply our models to the real data obtained from our industrial partner in East African Market. Anomaly detection algorithms are applied to the fraud cases related to over-charging, over-servicing and over-prescribing. After applying the data preparation techniques, the data were analysed using three different models: the inter-quartile method (as a baseline model), the isolation forest method and the local outlier factor algorithm. Results suggest that the local outlier factor algorithm performed better than the other two models. During this process, a set of attributes related to participants and healthcare providers were found critical in detecting outliers. The developed system is offered to our industrial partner as a decision support tool to help them identify potential frauds.

■ MD-06

Monday, 14:30-16:00 - U1

Combinatorial optimization problems in intermodal maritime logistics

Stream: Combinatorial Optimization
Invited session
Chair: Anna Sciomachen

1 - Operations-time-space network for solving train scheduling problems in real port systems
Veronica Asta, Luca Abatello

The Port Rail Shunting Scheduling Problem (PRSSP) is a problem arising in the rail-sea yard where the modal switch between maritime and rail transportation is performed. The focus is on the trains' transfer operations within the port area, between the maritime terminals, and the railway network [1]. The PRSSP consists in defining the schedule of all activities necessary for transferring trains from the railway network station to the terminals and vice versa, respecting the time limits imposed by the railway network schedule and by the ships one, and the limits due to the finite resources available in the port area. An operations-time-space network representing the rail station and the terminals (either the origin or the destination of the trains) and the operations that might be performed on the trains in each zone of the port is used for modeling the problem [2]. This work describes how it is possible to use this operations-time-space network to model port areas characterized by different infrastructures and different capacity constraints. Some focus on specificities of real port systems in Italy are shown. [1] D. Ambrosino, V. Asta, T.G. Crainic. Port Rail Shunting Scheduling Problem - submitted to Transportation Research Part E. Technical report CIRRELT 2022-02 [2] Ambrosino, D., Asta, V. (2021) An innovative operation-time-space network for solving different logistic problems with capacity and time constraints. Networks, 78 (3), pp. 350-367.

2 - A reduction technique for the k-Colour Shortest Path Problem
Davide Donato Russo, Carmine Cerrone

Over the years were defined many variants of the classic Shortest Path Problem. The k-Colour Shortest Path Problem (k-CSPP) is one of those variants. It consists of finding the shortest path on a weighted edge-coloured graph when the maximum number of colours used in a feasible solution is fixed apriori. This problem addresses several real-world applications; in particular, the k-CSPP can model problems related to network reliability or intermodal logistic. In this work, we propose an effective reduction technique, namely Graph Reduction Algorithm (GRA), that, starting from a heuristic solution, can remove more than 90% of the nodes and the edges from the input graph. It is also proposed the Colour-Constrained Dijkstra Algorithm (CCDA), a heuristic approach, used in conjunction with our reduction algorithm. Finally, an exact method, namely RILP, is described. It is based on the GRA combined with a MILP model. Several tests were performed to assess the effectiveness of the proposed approaches in terms of solution quality and computation times.

3 - The Generalized Close-Enough Traveling Salesman Problem
Carmine Cerrone, Claudia Archetti, Andrea Di Placido, Bruce Golden

This work studies the generalized close enough traveling salesman problem (GCETSP), a generalization of the close enough traveling salesman problem (CETSP). The canonical problem contains a set of targets, each associated with a generally circular area (neighborhood). In the GCETSP, each target is associated with a set of disks with different radii. Having multiple disks around each target allows researchers to model several real-world applications, in which a higher benefit is gained by more closely approaching the targets. A prize is assigned at each disk and is collected if the disk is traversed. For example, in the application of detecting containers with RFID tags in a port, prizes may represent the probability of successful RFID reading at a generic container's location. The goal is to determine the route that visits exactly one disk per target and the depot and maximizes the difference between the total collected prize and the route length or cost.We propose a metaheuristic algorithm, specifically, a genetic algorithm (GA), to solve this problem. The performance of the genetic algorithm is evaluated on instances that are generated from benchmark CETSP and TSP instances. We then compare GA solutions with CETSP solutions and with solutions obtained through a different approach based on preselecting intersection points with targets' disks. The results show that the proposed GA can produce high-quality solutions within a small amount of computing time.

■ MD-07

Monday, 14:30-16:00 - U3

Innovative Risk Management

Stream: Financial Risk Measurement and Management
Invited session
Chair: Rosella Castellano

1 - The relationship between UK government daily briefings and the stock market performance during the COVID-19 era
Valerio Ficcadenti, Thamila Madji, Gurjeet Dhesi

This paper investigates the link between the UK public mood and the UK FTSE indexes returns throughout the outbreak of COVID-19. We infer the UK public mood using sentiment scores attributed to 10 Downing Street Covid-19 daily briefings; the scores are studied jointly to the stock market outcomes of FTSE All-Share, FTSE 350, FTSE 250 and FTSE 100 indexes. The studied corpus contains 138 daily briefing statements transcripts delivered between 03 March 2020 and 23 June 2021. They have been collected through a web scraping procedure and analysed via natural language processing techniques. Namely, after the data processing phase, the daily polarity and subjectivity are calculated per each transcript. Furthermore, since multiple speakers have delivered the speeches during the period, e.g., UK ministers, the messages' features have been aggregated to have a view on speaker's profiles. Subsequently, a statistical analysis (e.g., correlations analysis, Granger causality tests) is used to investigate the relationship between the sentiment of each government briefing and the FTSE indices performances.

2 - Financial interbanking networks resilience under shocks propagation
Antonio Iovanella, Roy Cerqueti, Matteo Cinelli, Giovanna Ferraro

The concept of resilience i.e., the ability of a unified structure to absorb shocks, is of high relevance in the context of network modelling and analysis, mainly when referred to finance. This paper starts from this premise and deals with the resilience of a financial inter-banking system. At this aim, we firstly introduce a new measure of the resilience of a network, by taking into full consideration the influence of the topology of the network and the weights of its links in the propagation of the shocks; then, we build several financial weighted networks related to the inter-banking sector, whose weights are calibrated on high-quality empirical data; lastly, we compute the resilience measure of the considered networks. A discussion of the results is provided, by considering both finance and network theory perspectives.

3 - Volatility and Spillover effects between European Energy and Stock Markets: A Multivariate Approach
Claudiu Botoc, Sorin Gabriel Anton

This paper aims to analyze the multivariate volatility between energy, foreign exchange, and equities in the European markets. Furthermore, useful insights for other region (i.e. Asia) can be drawn from our results given the tide connections in the energy sector. The estimates for multivariate GARCH models highlight several remarks. First, for the Brent oil variable shocks to the conditional variance will be highly persistent, since the sum of the coefficients on the lagged squared error and lagged conditional variance is very close to unity. Second, the long-run persistence is rejected for the gas and coal variables and produces GARCH volatilities with a high vol-of-vol. Third, except for the coal and exchange rate, the asymmetric effect is significant for all remaining variables. Fourth, for most of the pairs, the correlation coefficients estimated under the CCC model are significantly positive and lower than the unconditional correlation. Finally, the log-likelihood value is slightly superior in DCC model than in the CCC model. Thus, the energy commodities and equities from Europe could not be considered simultaneously for portfolio diversification. Our findings are of interest to investors, policymakers, and academics alike.

4 - On the development of an Adaptative Health Index for a Hydropower Plant
Felipe Tetsuo Yamada, Flávia Barbosa, Luis Guimarães, Armando Leitão

This work studies how to optimize maintenance plans in Hydroelectric Power Plants (HPP) under integrating non-dispatchable Renewable Energy Sources. A unit health index could estimate the impact in the HPP condition of the selected operating points. Specific KPIs evaluate the degradation process and are included in the decision process to define the best maintenance policy and a risk analysis evaluation. An overall weighted health index, aggregating those KPIs, may indicate the equipment condition. In this work, we propose using Composite indicators (CIs) to create adaptative weights for aggregating the KPIs. CIs have increasingly been accepted as valuable tools for performance comparisons, benchmarking, and policy analysis. In the absence of reliable and consensual information about the weights to be used in the aggregation stage, it endogenously selects the weights that maximise the CI score for the unit under assessment. Thus, each unit can be assessed with its weights, emphasizing good performance indicators. This index will represent the health status of the entire system and lead to better system maintenance policies while having the maximum performance, safety, and the minimum possible costs.

■ MD-08
Monday, 14:30-16:00 - U4

Applied discrete optimization

Stream: Combinatorial Optimization
Invited session
Chair: *Dominique de Werra*
Chair: *Reinhardt Euler*

1 - New approach for a Maritime Inventory Routing Problem
Andréa Cynthia Santos, Quoc Khanh Dang, Sebastian Urrutia

In the Maritime Inventory Routing Problem, a set of ships must serve a set of ports transporting a product from the production ports to consumption ports. Production ports produce at a given rate and consumption ports consume at a given rate. The transportation service must guarantee that production ports do not exceed its inventory capacity and consumption ports do not run out of product on a time horizon. This kind of problems may be considered in a periodic way in which the obtained solution is repeated for the next time-period while the production/consumption operations continue. In a simplified setting with a single production port, a single ship, a constant consumption of the consumption ports, and considering that the cost of moving a ship is directly proportional to the load of the ship, we propose the strategy of reversing the route obtained after each visit to the production port. We show that the proposed approach is better than repeating the route, for very simple artificial instances and that is almost always better for realistic instances. Finally, we propose two mixed integer linear programming formulations optimizing the routes for each of the approaches. Computational results show that the proposed approach can have a big impact on the reduction of the transportation costs.

2 - On the completability problem for latin squares
Reinhardt Euler

The completability of incomplete latin squares can be studied along two lines: describing special cases that are always completable or caracterizing incomplete latin squares that are not completable and minimal with respect to this property. We survey and discuss recent results for both directions of research.

3 - Generalised 2-Circulant Inequalities for the Max-Cut Problem
Konstantinos Kaparis, Adam Letchford, Yiannis Mourtos

The max-cut problem is a fundamental combinatorial optimisation problem, with many applications. Poljak and Turzik found some facet-defining inequalities for the associated polytope, which we call 2-circulant inequalities. We present a more general family of facet-defining inequalities, an exact separation algorithm that runs in polynomial time, and some computational results.

4 - Exact methods for tardiness objectives in production scheduling
Georgios Zois, Ioannis Avgerinos, Yiannis Mourtos, Stavros Vatikiotis

Operating under tight deadlines, uncertain release dates and frequent disruptions in the supply chain is a major challenge for manufacturing. In this context, production schedules that minimise tardiness objectives appear far more important than the ones that minimise the makespan or the total flow time. This is further strengthened by current dominance of 'make-to-order' policies and mass customisation. Indeed, the related literature is growing substantially. We adopt a fresh look at the literature on exact approaches examining tardiness under unrelated machines, sequence-dependent setup times, precedence constraints, job-splitting (or malleability) and multiple resources constraining job setup or processing times. Then, we present a mathematical programming formulation encompassing most of the above features and an initial experimentation showing its limitations in terms of problem size(s) solvable to optimality. Specifically, the formulation includes sequence-dependent setup times, unrelated machines and setup resource constraints. We offer a Bender's approach that can be augmented with certain inequalities in order to represent additional problem features or to strengthen its relaxation. An experimental evaluation of our exact approach on quite large instances, along with a thorough literature review, shed light and offer motivation for challenging tardiness-related variants.

■ MD-09

Monday, 14:30-16:00 - U5

MILP approaches for location and routing problems

Stream: Mixed Integer Linear Programming
Invited session
Chair: *Lavinia Amorosi*

1 - A fast and effective time-space network model for a fully automated truck and drones delivery system
Lavinia Amorosi, Paolo Dell'Olmo

In this talk we present a novel multi-period mixed integer linear programming formulation based on a time-space network for a delivery problem with a fully automated mothership and a fleet of drones. The proposed formulation integrates the routing of the mothership and the scheduling of the drones embedding the charging cycles of drone batteries. The model is tested on a testbed of artificial instances, up to 100 customers, to assess model computational solvability. The model can be optimally solved, or it gets solutions very close to the optimum in a short time in most of the cases. In particular, the first feasible solution found by Cplex solver is always under 1% gap from the optimum with a computational time comparable with that of heuristic algorithms.

2 - Mathematical approach for Scheduling electric vertical take-off and landing vehicles at Vertiports
Julián Alberto Espejo-Díaz, Edgar Alfonso Lizarazo, Jairo R. Montoya-Torres

Recent advances in electric vertical take-off and landing (eVTOL) vehicles, part of the advanced air mobility (AAM) paradigm, suggest that these vehicles will soon become an option for passenger and cargo transportation. Currently, there are multiple initiatives to establish a market for AAM services. An essential part of the AAM services is their take-off and landing areas known as vertiports. They are comprised of a staging stand area, gates for loading and unloading passengers and cargo, touchdown and liftoff (TLOF) pads, and common ground taxi routes or taxiways that connect the previous components. We propose a Mixed Integer Linear Programming (MILP) model and a heuristic algorithm for scheduling eVTOL vehicles at the vertiport infrastructure components. Considering that a vertiport can have multiple gates or TLOF pads, we modeled the problem as a special case of the hybrid flow shop scheduling configuration. Apart from the traditional constraints of this scheduling environment, we included minimum separation rules between consecutive aircraft using the same TLOF pad to avoid aircraft being in the same vertical flight phase simultaneously. In addition, we considered blocking constraints and departing and landing time slots. Computational results show that the MILP model finds optimal solutions with instances of up to 18 aircraft. For larger instances, the heuristic algorithm provides good results in terms of solution quality and computational time.

3 - Location and Routing Models for Brazilian Police Collaboration
Carlos Lamas-Fernandez, Walton Pereira Coutinho, Suprasad Gavhane, Wei Yifu

Law enforcement in Brazil is divided into several departments, two of which are the state military and the state civil police. While the military police are often tasked with maintaining public order, the civil police are in charge of investigations, leading to the need to collaboration between them. For example, Brazilian authorities require that serious crimes are logged by a civil police team, in presence of the military team that attended the scene. However, while most towns have a military police team, the resources of the civil police are limited, and normally only present in larger cities or under restricted hours. This prompts the need of a police team (either military or civil) having to travel to meet their counterpart. In a system where resources are scarce, decisions regarding adequate location of teams and travel routes can have a strong impact in public safety (by keeping towns under police watch for longer periods), costs (by using better police time) and environmental implications (reducing the number of journeys across the state). In this talk we present mathematical models to describe this interaction and propose new forms of collaboration. We propose an Integer Programming Model (ILP) to optimise travel routes of police teams and a simulation optimisation framework that, making use of this ILP seeks to find suitable permanent positions for civil police stations considering uncertainty in crime occurrence and handling times.

4 - CFLG.jl: an algorithmic toolkit for continuous set covering on networks
Liding Xu, Mercedes Pelegrín

Covering problems are well-studied in the domain of Operations Research, and, in particular, Location Science. When the location space is a network, the most frequent assumption is to consider the candidate facility locations, the points to be covered, or both, to be discrete sets. In this talk, we study the set-covering location problem when both demand points and candidate locations are continuous sets on a network, and we propose several Mixed-Integer Linear Programming (MILP) Formulations. CFLG.jl is an open-source software written in the Julia programming language for the continuous set cover problem, and these MILP formulations are implemented in CFLG.jl. CFLG.jl can be extended to model other covering problems on networks, such as discrete cover problems. We conduct the numerical experiment of CFLG.jl on several benchmarks and compare the performance of different MILP formulations. The results show that our formulations are more scalable than the existing formulation.

■ MD-10

Monday, 14:30-16:00 - U6

Machine Learning and Complex Systems for Finance and Insurance

Stream: Financial Risk Measurement and Management
Invited session
Chair: *Zelda Marino*
Chair: *Stefania Corsaro*

1 - ESG rating and tail risk: the role of sustainability in financial networks
Francesca Grassetti, Davide Stocco

Sustainable Finance takes due account of environmental, social and governance (ESG) considerations when making investment decisions in the financial sector. Sustainable finance, however, is a complex and evolving topic. In this work, the ESG component of the financial market is investigated by means of network theory. The relation between financial tail risk and the ESG rating in the EU equity market is analysed to verify the existence of a relationship between ESG performances and the tail dependence in terms of conditional overlap probability.

2 - A machine learning model for lapse prediction in life insurance contracts
Daniele Marazzina

We use the Random Forest methodology to predict the lapse decision of life insurance contracts by policyholders. The methodology outperforms the logistic model, even if features interactions are considered. We use global and local interpretability tools to investigate how the model works. We show that non-economic features (the time passed from the incipit of the contract and the time to expiry, as well as the insurance company and its commercial approach) play a significant effect in determining the lapse decision while economic/financial features (except the disposable income growth rate) play a limited effect. The analysis shows that linear models, such as the logistic model, are not adequate to capture the heterogeneity of financial decisions.

3 - Quantile Mortality Modelling via Neural Network

Zelda Marino, Stefania Corsaro, Salvatore Scognamiglio

The development of multi-population mortality models is nowadays a central issue in the management of longevity risk. In last decades, in most developed countries there has been a significant improvement in mortality and is natural to think that these changes between different countries are correlated. For example, changes in mortality rates can be a consequence of epidemics and war which can easily cross national borders. In this context, it is mandatory to have accurate models to forecast multi-population mortality. The Lee-Carter (LC) mortality model has been widely used for making future projections of mortality rates. In [2] the author introduces a neural network approach for fitting the LC model on multiple populations. In [1] the author defines the LC quantile model for estimating the conditional quantiles of the mortality rate. In this work we develop some neural networks that replicate the structure of the individual LC quantile model and allow their joint fitting by analysing the mortality data of all the considered populations simultaneously. We perform our analysis based on data obtained from the Human Mortality Database. Numerical results confirm the effectiveness of our approach. [1] Santolino, M., The Lee-Carter quantile mortality model, Scandinavian Actuarial Journal, 2020:7, 2020 [2] Scognamiglio, S. Calibrating the Lee-Carter and the Poisson Lee-Carter Models Via Neural Networks (May 27, 2021). Available at SSRN: https://ssrn.com/abstract=3868303

4 - The choice between sustainable and unsustainable investment projects

Michi Nishihara

This paper develops a real options model regarding a firm's choice between sustainable and unsustainable investment projects. The sustainable project requires a high investment cost and yields cash flows perpetually, while the unsustainable project requires a low investment cost and yields cash flows till a random time that follows an exponential distribution. The optimal investment timing and values of sustainable and unsustainable projects are analytically derived. With higher growth rate and volatility of cash flows, as well as lower discount rate, the firm is more likely to choose the sustainable project. The solutions are also derived in the debt financing case. The optimal leverage is higher for the unsustainable project than for the sustainable project, and the access to debt financing increases the firm's incentive to choose the unsustainable project.

■ MD-11

Monday, 14:30-16:00 - U7

MCDA methods 2

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: Jacek Szybowski

1 - Consistent approximations of pairwise comparisons matrices

Jacek Szybowski

Multiplicative pairwise comparisons matrices can be transformed by a logarithmic mapping into a linear space and the set of consistent matrices into its subspace. The structure of a Hilbert space is obtained by using an inner product. Such a space is complete with respect to the norm corresponding to the inner product. In such a space, we may use orthogonal projections as a tool to produce a consistent approximation of a given pairwise comparison matrix. This procedure has been used by Crawford and Williams in 1985 in a case of the standard norm induced by the Frobenius inner product. The resulting matrix allows to obtain the priority vector, whose coordinates are geometric means of elements in each row. We generalize the Geometric Means Method for other inner products in the space of additive pairwise comparisons matrices and using the Gram-Schmidt orthogonalization process. This allows not only to obtain the priority vector but also to express the approximation matrix as a linear combination of a given basis in the space of pairwise comparisons matrices.

2 - A model for Expected Pareto Frontiers construction.

Nicolas Fayard, Alexis Tsoukias, David Rios Insua

Decision Problems can be affected by the presence of multiple values to be considered and multiple scenarios which could occur in the future. We consider the case where there is no preferential information enabling to construct importance parameters for the criteria, but we can get likelihoods about the different scenarios. From a decision support perspective a suitable tool would be to present a merge of the Pareto frontiers holding for each scenario considering their likelihoods. We present a procedure aiming at solving this problem satisfying a number of fundamental properties characterising the outcome.

3 - Group aggregation and consensus seeking in utility models incorporating veto related preference structures

Andrej Bregar

In the individual decision-making setting, multi-attribute utility and value models have been extended with veto related structures in order to allow for the principles of constructivism, incomparability and non-compensation of unsatisfactory preferences. The presented research aims to develop a procedure that further utilizes this kind of models in the group decision-making setting. It deals with both common decision-making problematics of ranking and sorting, where the ascending procedure is applied in the latter case to sort alternatives by comparing their global evaluations to thresholds that define the boundaries of adjacent categories. Two approaches are proposed to aggregate individual preferences into a collective decision. Firstly, the aggregation of veto and utility evaluations is performed in a direct compensatory manner. Secondly, a common consensual solution is approached iteratively by unifying different individual opinions with regard to the introduced proximity, agreement and robustness measures, which determine the direction towards which the group is heading. The procedure is evaluated with a simulation study. Convergence of opinions, ability of guidance and robustness are assessed. With regard to these factors, utility and value models incorporating discordance related information are compared to standard multi-criteria models that express utility/value only, in order to determine whether in some scenarios the characteristics may improve.

4 - Fixing Inconsistent Saaty's Matrix using Nonlinear Optimization Model

Robert Hlavatý, Helena Brozova

We revisit the famous Saaty's AHP method, where the data inconsistency issue is often present. Saaty's pairwise comparison matrix is considered inconsistent if the transitivity of preferences between criteria is not satisfied to an acceptable level. There are ways of measuring the level of matrix inconsistency. When the inconsistency reaches over the critical threshold, it is necessary to make adjustments to the original data. This may be impossible because: 1) the decision-maker is not available anymore for re-evaluation; 2) the decision-maker is not capable of doing so as it may be hard to recognize the cause of inconsistency, especially in larger matrices. There are various ways of fixing inconsistency in the literature. We propose our own approach, different from the existing one, based on a non-linear optimization model. We suggest changing the original data as little as possible to preserve most of the original information while reaching an acceptable inconsistency level. Our optimization problem is not tractable in the polynomial sense but is still easily solved because the issue is only considered for small size matrices due to practical reasons.

■ MD-12

Monday, 14:30-16:00 - U9

Planning problems in electric energy systems II

Stream: OR in Energy
Invited session
Chair: *Álvaro García-Cerezo*

1 - The importance of TSO-DSO coordination in the trade-off between flexibility contracting and distribution network investments
Ellen Beckstedde

Distribution System Operators (DSOs) increasingly use flexibility contracting to manage network peaks instead of expanding their network. Over the past years, several academics and DSOs examined the trade-off between flexibility contracting and network investments from the DSO perspective while neglecting the impact of this trade-off on Transmission System Operators (TSOs). However, the impact on the TSO is important to consider as flexible resources connected to the distribution network can be used for the TSO's congestion management and balancing services. Therefore, the aim of this paper is (i) to examine the optimal trade-off between flexibility contracting and distribution network investments from the DSO perspective, (ii) to explore how this trade-off evolves when the TSO's costs and social welfare are considered, and (iii) to analyze the sensitivity of these findings to different power systems and cost parameters. A bi-level model is constructed to capture this behavior. The DSO in the upper level decides on the optimal distribution grid to minimize its network investment and congestion management costs. The market sequence in the lower level consists of a zonal wholesale market followed by a separate DSO flexibility and TSO balancing market. In this way, policy recommendations on the optimal trade-off between flexibility contracting and distribution network investments can be given from the perspective of DSOs, TSOs, and TSO-DSO coordination.

2 - A bilevel formulation for an electricity network expansion planning problem with a reliability constraint
Xavier Blanchot, François Clautiaux, Aurélien Froger, Manuel Ruiz

We present in this work a formulation taking into account a reliability constraint used in long term network expansion studies performed by the french transmission system operator RTE. These studies aim at analyzing, over a 5 to 30 years horizon, the risk of imbalance on the transmission system, between demand and electricity production. Based on an integer stochastic linear program with a finite number of scenarios, the objective is to jointly minimize the network investment costs and the expected operational costs to maintain an adequate balance between supply and demand in each scenario. The main challenge is that the cost associated to an unsatisfied demand is not a big-M value, but rather an economic cost, given as input, estimating the maximum cost at which it is economically viable to satisfy a demand. This cost may not be high enough to drive some network investments, which may lead to a large number of unsatisfied demands in an optimal solution. To alleviate this issue, legislation imposes a reliability criterion which translates into a constraint limiting the expected number of nodes over the scenarios where an unsatisfied demand occurs. We propose a bilevel formulation of the problem. Solving with a MIP solver the single-level reformulation obtained after using the lower level's KKT conditions is only applicable to toy instances. For realistic instances, we introduce a heuristic based on Benders decomposition.

3 - From nuclear to PV and hydro storage. Should we go all the way?
Juan Esteban Martinez Jaramillo, Busra Gencer, Nina Walker

A growing number of governments are developing strategies to drastically increase green electricity generation, while phasing out nuclear facilities. However, the uncertainties around the economic consequences of introducing a high share of renewables in the system render the achievement of such transformation concerning. Renewable energy sources that are intermittent by nature could cause a significant hike in electricity prices, due to a mismatch of demand and supply that increases the need for storage capacity. In this paper, we analyze the impact of the phase-out of nuclear capacity and its replacement with photovoltaic (PV) technology on the electricity market equilibrium and on the function of pumped hydro storage (PHS) facilities. We develop a System Dynamics model to evaluate different end-states of the system and we test the impact of seasonality patterns on the electricity market equilibrium when PV is introduced. Our findings indicate that the PV generation leads to a substantial increase in consumer and market price. The price hike is due to an increased amount of electricity being stored by PHS and not consumed directly, as well as a higher sales price of PHS electricity, as the unsubsidized price of PV electricity is higher than the nuclear. In presence of seasonality, an increase in PV technology efficiency and lower capital cost are required to make this technology more attractive.

4 - Acceleration techniques for adaptive robust optimization transmission network expansion planning problems
Álvaro García-Cerezo, Raquel García-Bertrand, Luis Baringo

The computational burden of two-stage adaptive robust optimization transmission network expansion planning problems increases when accurately representing the operation of power systems, i.e., when intertemporal constraints, operational variabilities, and non-convex operational constraints are considered in the decision-making model. This motivates the use of acceleration techniques to avoid computationally intractable problems. In particular, the robust problem is solved using the nested column-and-constraint generation algorithm. We propose applying two novel acceleration techniques to this algorithm. On the one hand, some of the problems of the solution procedure are relaxed by only considering certain cutting planes and including more constraints if the evolution of the bounds of the algorithm is not appropriate. On the other hand, the uncertain variables are initialized to the solution obtained by using the alternating direction algorithm. Numerical results show that the use of the proposed acceleration techniques leads to significant reductions in the computational times.

■ MD-13

Monday, 14:30-16:00 - U119

Polyhedral Combinatorics

Stream: Discrete Optimization and Algorithms (contributed)
Contributed session
Chair: *Cécile Rottner*

1 - Polyhedral study of min-up/min-down polytope variants
Cécile Rottner

Consider a time horizon and a set of n possible states for a given system. The system must be in exactly one state at a time. We introduce generalized min-up/min-down constraints : if the system switches to state i at time t, then it must remain in state i for at least L time periods. These constraints generalize minimum up and down time constraints from the literature (Lee, Leung, Margot. 2004) (Rajan, Takriti. 2005), in the sense that the system has an arbitrary number n of possible states, instead of only two states (up and down). Generalized min-up/min-down constraints appear in practical Unit Commitment Problems, where nuclear and hydro production units have discrete production levels. We study the generalized min-up/min-down polytope P.

We also study a variant of P, where we relax min-up/min-down time constraints into so-called " no-spike " constraints. In this case, min-up/min-down constraints must be respected only when the system state decreases (resp. increases) after an increase (resp. a decrease). For both polytopes, we introduce new valid inequalities, and give complete linear descriptions.

2 - Hypergraph and Strong Valid Inequalities for Boolean Logical Pattern Generation
Dongwoo Kang, Hong Seo Ryoo

Logical Analysis of Data (henceforth, LAD) is a supervised learning methodology based on Boolean logic and combinatorial optimization. Pattern holds a key to successful data classification via LAD, and generating a LAD pattern for distinguishing different types of data has been shown to be equivalent to solving a 0-1 multilinear program (henceforth, PG). For efficient solution of PG, this paper exploits similarity among data through their combinatorial relation in a hypergraph. Namely, representing each 0-1 variable as a node in a graph, we first define a hyperedge for each observation as the set of n nodes such that the attribute values equal to 0. This results in an n-paritite hypergraph representation of data under analysis. Next, we examine properties among a set of hyperedges to discover methods for forging them into a stronger valid inequality for PG. A set of sufficient (and necessary) conditions for strong valid inequalities and facet defining inequalities for the 0-1 PG polytope are presented for a stronger LP relaxation of PG; thus, for more efficient LAD pattern generation in practice. We tested our new results in extensive numerical experiments with real-life classification data from the UCI machine learning repository. In summary, the new results exhibited superb performance in terms of the reduction in the root node relaxation gap, when compared to the standard, 'practically-and-efficacy-proven' McCormick relaxation method for 0-1 multilinear functions.

3 - Two Hard Problems In Box-Total Dual Integral Polyhedra
Francesco Pisanu

A rational linear system is totally dual integral (TDI) if for every integer linear function for which the optimum is finite the associated dual problem has an integer optimal solution. A TDI system is box-TDI if adding any rational bounds on the variables preserves its TDIness. Box-TDI systems are systems that yield strong min-max relations such as the one involved in the Max Flow-Min Cut Theorem of Ford and Fulkerson. A polyhedron is box-TDI if it can be described by a box-TDI system.

Box-total dual integral systems and polyhedra received a lot of attention from the combinatorial optimization community around the 80's. A renewed interest appeared in the last decade and since then many deep results appeared involving such systems.

In this talk, we study the complexity of some fundamental questions regarding box-TDI polyhedra. First, although box-TDI polyhedra have strong integrality properties, we prove that Integer Programming over box-TDI polyhedra is NP-complete, that is, finding an integer point maximizing a linear function over a box-TDI polyhedron is hard. Second, we complement the result of Ding, Tan, and Zang who proved that deciding whether a given system is box-TDI is co-NP-complete: we prove that recognizing whether a polyhedron is box-TDI is co-NP-complete. This is a joint work with Patrick Chervet, Roland Grappe, Mathieu Lacroix, and Roberto Wolfler Calvo.

4 - A new class of valid inequalities for the binary knapsack polytope
Guneshwar Anand, Sachin Jayaswal, Srirangacharyulu Brundavanam

We study the polyhedral structure of the binary knapsack polytope. We propose a new class of valid inequalities and the conditions, given in terms of analytical expressions, under which they are facet-defining. Further, we present separation problems to identify such violated inequalities/facets. Since the separation problems are NP-hard, we propose heuristic algorithms to solve them efficiently. Through computational experiments, we demonstrate the efficacy of our proposed valid inequalities.

■ MD-14

Monday, 14:30-16:00 - U261

Network Optimization

Stream: Network Optimization
Invited session
Chair: *Luís Gouveia*

1 - Online segment routing optimization considering polyhedral demand
Jérôme De Boeck, Bernard Fortz, Stefan Schmid

The Internet is composed of a set of interconnected routers in which requests are routed along paths defined by routing protocols. Most intra-domain protocols which route requests along paths defined by routing protocols rely on shortest path routing (SPR): traffic flowing from a given source to a given destination will always be routed along the shortest path. The shortest paths are computed using a link metric system, in which weights are assigned to links.

Even when metrics are optimized, SPR protocols suffer a number of draw-backs. In particular, restricting flows to shortest paths limits traffic engineering flexibilities. Furthermore, while a set of shortest paths may be efficient under certain demands, they may be suboptimal and lead to high congestion under other demands.

To provide more flexibility Segment Routing (SR) was recently introduced. In a segment routed network, an ingress node may prepend a header to requests that contain a list of segments with routing instructions that are executed on subsequent nodes in the network. The headers containing routing informations can be dynamically updated in case a variation in demand occurs.

We present stochastic and robust frameworks for online SR optimization considering a demand polyhedron. This polyhedron is defined by demands observed on the network. Our approach combines oblivious routing benefits with the flexibilities of SR. Numerical results compare our online procedure with existing oblivious SR.

2 - The Hamiltonian p-Median Problem: Polyhedral Results and Branch-and-Cut Algorithm
Luís Gouveia, Michele Barbato

The Hamiltonian p-median problem is to partition the n vertices of a graph G into p cycles of minimum total weight. We strengthen an MILP on edge variables withy two families of inequalities: i) the quasi-Hamiltonian cycle inequalities which are associated to cycles not spanning all nodes. ii) restricted cut constraints whose shores have specific cardinalities and are valid for the cases n=3p and n=3p+1 We give facet-defining conditions for subsets of the inequalities above. We develop a branch-and-cut algorithm also enhanced by cost-based inequalities. It compares well to existing algorithms for the HpMP and solves 3 benchmark instances previously unsolved and 16 new LaRGER instances with up to 400 vertices.

■ MD-15

Monday, 14:30-16:00 - U262

Decision Support in Supply Chain and Production

Stream: Decision support (contributed)
Contributed session
Chair: *Slawomir Pietrasz*

1 - Conceptualization of Human and Artificial Intelligence Interaction in Supply Chain Planning considering the Degree of Digitalization
Tim Lauer

Today, digitalization is often in focus. Companies apply novel technologies such as artificial intelligence, but leave out the human perception. The objective of this industrial study is the conceptualization of a framework that determine the appropriate human-AI-collaboration design considering the degree of digitalization, based on complementary strengths and weaknesses of humans and AI in the environment of uncertainty, ambiguity and complexity of supply chain planning. The framework draws on existing research and uses an exploratory case study for validation.

2 - Long Range Planning in Life Sciences Industry
Prateek Jain, Rishabh Agrawal

Loss of exclusivity(LOE) is a natural milestone in a drug's lifecycle. Focused & effective late lifecycle management can preserve meaningful value for the brand. Just as the planning for launch - LOE should be strategically planned for years in advance & carefully managed. Long range planning is required that covers purchase or production from RSM, API, Drug Products & Packaging through a value chain that includes in-house and external manufacturing sites. The drug making (small molecule or biologics) involves a very tightly controlled approval process that is defined by markets and adds to the dimensions that needs to be considered for taking optimum decision from thousands of scenarios. Non-optimal network decisions can lead to more expensive drugs for patients & might also cause unavailability in markets. A digital twin is developed using Mixed Integer Linear Programming to guide through the optimal supply plan in the decade long planning horizon by looking at end- to-end value chain with operational, financial and strategic constraints. The model provides insight into the supply strategy at different product stages for multiple markets, Capex & renewal decisions in contracts, qualifying new suppliers and Business continuity strategies while minimizing the total COGS under the domain area of approvals. These form an excellent decision support for pharmaceutical companies to reduce the cost of drug development & make drugs more affordable to patients around the world.

3 - Managing intramonthly operations of a liquified natural gas terminal
Slawomir Pietrasz, Estelle Barranger

Expert in liquified natural gas (LNG), Elengy owns and operates three terminals in France. To help Elengy handle intramonthly perturbation of terminal operations and offer flexibility to their customers, ENGIE Lab CRIGEN has developed a simulator. It analyses the feasibility of unscheduled carrier unloading defined by the unloading volume, unloading date and a gas emission profile. The software answers the question: would an additional gas shipment fit in the already established monthly programme? If the request is feasible, the shipper may subscribe this additional unloading. Otherwise, the optimization model determines a feasible solution closest to the customer's request for each characteristic of the shipment. The approach to this multiple criteria decision problem combines a multi-period linear mathematical programme with dichotomy. According to the selected strategy, the mathematical programme computes a feasible solution by relaxing either the shipment volume, the level of emissions or the operation date. The solution must satisfy minimum and maximum technical storage boundaries of the terminal, maximum emission values on GRTgaz transmission network, wharf availability. Physical emissions of the terminal comply with physical limits of the infrastructure. They can be anticipated but contractual emissions of other customers must remain undisturbed. Further developments shall consider the impact on emission profiles of reloading or cancellation of an operation.

■ MD-16

Monday, 14:30-16:00 - U264

Health Care Logistics

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: Daniel Santos

1 - Home healthcare routing and scheduling with teaming concerns, synchronization, dynamic time windows and continuity of care.
Ana Raquel de Aguiar, Tania Ramos, Maria Isabel Gomes

Demographic and social trends have been increasing the demand for home care services. To fulfill the demand, it is crucial for home care providing agencies to improve the efficiency of their operational plans. The home care is provided to patients requiring services that may need to be performed by one or by two caregivers. This work advances the literature by considering different teaming schemes, where caregivers are assigned to teams of either one or two caregivers. Additionally, teams of one caregiver are allowed to synchronize so that they can serve a patient whose tasks require two caregivers. To increase the possibility of patients being served through synchronization a dynamic time window is introduced, which allows the two single teams to arrive at the patient's home offset by at predefined amount of time. Daily continuity of care is also modelled given its relevance in home care settings and its impact on the team schemes. We solve a case-study based on the data provided by a partner home care provider. To do so we model the problem as a home healthcare routing and scheduling problem and propose a MIP formulation for a single-day planning horizon. The route plans obtained considering different scenarios are compared with the current situation. In all studied scenarios, all patients' tasks were performed with teams needing one less caregiver than in the current situation. Moreover, when considering synchronization the tasks can be done with less two caregivers.

2 - Determining optimal locations for blood distribution centers
Merel Wemelsfelder, Dick den Hertog, Onno Wisman, Mart P. Janssen

Blood products are both crucial in many lifesaving hospital interventions, and of a perishable nature. As a result, hospitals need to refill their stock regularly by ordering products from a blood bank. The blood bank's ability to deliver these orders both quickly and cost-effectively is dependent on the number and location of their distribution centers (DC).

We propose a mixed-integer linear programming approach to find optimal DC locations and allocate hospitals to one DC. The first objective is to maximize the 'reliability of delivery', which indicates the percentage of hospitals that can be reached within a given time limit. The second objective is to minimize transportation costs. Both objectives may also be turned into a constraint, ensuring that the reliability or transportation cost do not exceed some given value.

In the Netherlands, the blood product stock of 110 hospitals is supplied from the 7 DCs of Sanquin, the Dutch blood bank. When solving the model for this case study, we observe that the same reliability of delivery can be maintained when reducing the number of DCs to 6 or even to 5, but the transportation costs will increase. This increase should be compared to the decreasing facility exploitation costs being a result of less DCs, before implementing the result in practice. The model was also proven to be robust to changes in ordering data.

3 - Hospital Network Design: A bi-objective two-level hierarchical stochastic model
Maria Lopes, Daniel Santos, Ana Paula Barbosa-Póvoa

One of the most critical goals in NHS-based countries is ensuring the efficient provision of healthcare services while balancing costs and access. Planning an optimized hospital network is crucial for providing good quality healthcare since decisions related to the location of the hospital, demand allocation and installed capacity directly impact the daily activities of the hospitals and, consequently, the service level of healthcare provision. This study aims at developing and implementing an optimization model to aid in planning a hospital network within the scope of an NHS and considering relevant aspects of hospital networks. A bi-objective mixed-integer linear programming model is developed, minimizing two objective functions: the first relates to the travel time to reach hospitals weighted by demand - accessibility - and the second relates to the expected operational and investment costs - efficiency. Uncertainty in demand is incorporated through stochastic programming, and a hierarchical structure for the network based on medical services is supported. The model is applied to a case study, and its results are used to validate the model and assess its performance compared with the existing network. Results attained through the implementation of the epsilon-constraint method demonstrate that decentralizing care can improve geographical access and reinforce the need to make a compromise between equity in access to healthcare and costs.

4 - Ambulance planning under uncertainty in demand and service time: a two-stage stochastic optimization model
Paulo Abreu, Daniel Santos, Ana Paula Barbosa-Póvoa

Emergency Medical Services (EMS) play a vital role in society, delivering pre-hospital medical care and transport activities. In this context, the management of these services has become challenging due to the growth in demand and the increase in the aging rate. In addition, the planning of physical and human resources in EMS systems is under uncertainty in demand and service time, since demand forecasts are subject to a margin of error and interventions have different durations according to the type of vehicle dispatched and the type of occurrence. Recognizing this, an efficient strategic-level resource planning addressing these uncertainties is paramount to ensure that bases are located in the right location, and the right amount of each type of vehicle with the required crew is available at those bases. To this end, the Portuguese EMS case study is explored to develop a new bi-objective stochastic optimization model considering coverage and costs as objectives to be optimized and to propose a new data-driven scenario tree generation method. The stochastic model and its deterministic version are solved in a multi-objective context, analyzing the trade-off between coverage and cost. Additionally, the resource planning is analyzed and compared from three bases, deterministic planning, stochastic planning, and Portuguese EMS provider planning.

■ MD-17

Monday, 14:30-16:00 - U356

Software for LP/MIP

Stream: Software for Optimization
Invited session
Chair: *Timo Berthold*

1 - What's new in FICO Xpress Solver?
Timo Berthold

We will present the latest developments in the FICO Xpress Solver for mixed-integer linear and nonlinear problems.

2 - What's New in Gurobi 9.5
Michael Winkler

We will give an overview of recent enhancements, new feature and performance improvements in our Gurobi 9.5 release.

3 - Improving the Performance of Simplex-based Algorithms
Philipp Christophel

Simplex-based algorithms are used in many different contexts. On the one hand, they are an alternative to interior point methods for solving decision making or planning problems that are modeled as linear programming problems. On the other hand, they are often part of algorithms to solve other problem classes, such as in the case of mixed integer programming problems. In this talk, we investigate how to improve the performance of simplex-based algorithms in light of their many different use cases and demonstrate that rigorous performance evaluation requires taking these use cases into account.

4 - Recent advances in the Cardinal Optimizer
Gerald Gamrath

We summarize the developments in the Cardinal Optimizer (COPT) within the last year. The new features include solving capabilities for additional problem classes like SOCP and convex Q(C)P and support for the computation of IIS for infeasible problems. Additionally, we discuss some key techniques that contributed to the drastic performance improvements of our MIP solver and present performance numbers of the latest COPT 5.0 release for all problem classes.

■ MD-18

Monday, 14:30-16:00 - U358

Stochastic Programming in Transportation and Logistics

Stream: Stochastic and Robust Optimization
Invited session
Chair: *Francesca Maggioni*
Chair: *Francesca Vocaturo*
Chair: *Manuel Schlenkrich*

1 - An Empirical Risk Minimization Method for solving Inventory Problems
Johan Bjerre Bach Clausen, Moritz Fleischmann, Hongyan Jenny Li

Big data driven operations research has become one of the research frontiers in operations research. Data driven newsvendor models have been studied intensively and several ice-breaking studies have been published recently. However, how to solve constrained stochastic inventory problems with a feature set remains a challenging task and only a couple of papers are published. In this paper, we propose a direct Empirical Risk Minimization approach to solve a class of stochastic programming formulation of inventory problems with multiple features. We explicitly model how the decision variables are dependent on the feature set and discuss the methodology in the context of uncapacitated inventory problems. We introduce the methodology through a simple big data driven inventory problem and also provide big data driven formulations of two specific problems: the uncapacitated stochastic production planning problem and the uncapacitated two-stage production and distribution problem. In addition, we compare our method and the existing models in literature. The advantages and disadvantages of different methods are explored. Furthermore, we conduct experimental (numerical) studies to examine the performance of the proposed method and to discuss under what conditions a given methodology should be employed.

2 - A Quasi-extreme Reduction for Interval Transportation Problems
Elif Garajová, Miroslav Rada

Various approaches to modeling and solving transportation problems affected by different sources of uncertainty have been proposed in the literature. We adopt the approach of interval programming, leading to the model of an interval transportation problem, in which the available supply, the customer demand and the transportation costs can be uncertain and independently perturbed within some given lower and upper bounds.

We consider the task of computing the worst possible optimal value. The problem was recently proved to be NP-hard for interval transportation problems, in general. However, for interval problems immune against the "more-for-less" transportation paradox, it was shown that the worst optimal value can be found by considering only a specific subset of instances.

Our talk presents an analogous result that holds for general interval transportation problems. The result can be utilized to describe an exact method for finding the worst optimal value. We derive a reduction of the interval problem to the problem of computing optimal values over a set of quasi-extreme scenarios, in which almost all supplies and demands (except for one) are set to their respective lower or upper bounds.

3 - The impact of risk aversion and flexibility on stochastic and robust lot sizing decisions

Manuel Schlenkrich, Sophie Parragh

This paper presents a computational analysis of stochastic programming and robust optimization for solving the multi-item multi-echelon capacitated lot-sizing problem under uncertain demand. For decision makers facing an uncertain production environment the aspects of risk aversion and flexibility are highly relevant. Minimizing worst case overall costs usually comes at higher average case costs, but might be preferable to risk-averse decision makers. Being flexible in production by having a short response time to stochastic events might need additional planning effort, but can lead to significant cost savings during operation in many settings. We compare two-stage stochastic programming models representing different capabilities of flexibly adjusting production quantities with budget-uncertainty robust optimization models representing different levels of risk aversion. A Benders decomposition approach is tailored to the problem, in order to solve large stochastic models. We investigate the tradeoff between computational time, average- and worst-case performance on a set of out-of-sample scenarios and provide managerial insights by analyzing the structure of the different obtained solutions, such as holding- and backlog costs, number of setups and average lot size.

■ MD-19

Monday, 14:30-16:00 - Y228a

Routing, Scheduling and Policy Optimization for Queues

Stream: Performance Evaluation of Queues
Invited session
Chair: Benjamin Legros

1 - Agents' self-routing for blended operations to balance inbound and outbound services

Benjamin Legros

This study aims to evaluate the cost of agents' self-routing in a service system with inbound and outbound customers. We assume that inbound customers arrive over time depending on the waiting time offered, while outbound customers can be contacted at all times. Further, agents are in control of routing decisions and are aware of the state of the system. Accordingly, they decide whether to serve an inbound or outbound customer, or to idle. The system manager seeks to provide a suitable trade-off between agents' choice of serving inbound and outbound customers by incentivizing their actions through linear payouts. Hence, there arises a problem of determining the cost of agents' self-routing, which can be interpreted as a variant of the principal-agent problem where the agents' efforts are directed toward selecting their routing policy. Through a Markov decision process, we show that the agents' optimal policy is a reservation threshold policy for inbound customers, and express the compensation parameters that minimize staffing cost. We conclude that motivating idling decisions through linear payouts incurs high costs. This justifies the current practice of using automated routing in call centers. Moreover, paying for idling cannot reduce staffing cost. However, discriminating between delayed and non-delayed customers in the reward structure presents a high potential of reducing agents' pay.

2 - Analysis of Time-dependent Queues Using Machine Learning

Raik Stolletz, Seyed Mohammad Zenouzzadeh, Siamak Khayyati

Queueing systems are used for modeling many real world systems, including production systems and transportation networks. As many of them are time-dependent, there is a need for reliable and fast methods to estimate the first and second moments of their performance measures. We provide a performance evaluation framework for time-dependent $M_t/M/1$ queues where transient predictors are called iteratively.

In this work, we use machine learning as the transient behavior predictor of the $M_t/M/1$ queues. Black-box machine learning methods, such as deep neural networks, can generate prediction functions that have undesirable properties for the time-dependent behavior of queues. Therefore, we also propose a transient prediction model based on the "surrogate model" approach from the interpretable artificial intelligence field.

We iteratively connect the set of pretrained transient models to predict the time-dependent performance measures related to the queue length of the $M_t/M/1$ queues. These estimates together are used to estimate the distribution of the queue length which is then used for estimation of waiting times.

3 - Appointment-driven queueing systems with non-punctual customers

Oualid Jouini, Saif Benjaafar, Bingnan Lu, Siqiao Li, Benjamin Legros

We consider a single server queueing system where a finite number of customers arrive over time to receive service. Arrivals are driven by appointments, with a scheduled appointment time associated with each customer. However, customers are not necessarily punctual and may arrive either earlier or later than their scheduled appointment times or may not show up at all. Arrival times relative to scheduled appointments are random. Customers are not homogeneous in their punctuality and show up behavior. The time between consecutive appointments is allowed to vary from customer to customer. Moreover, service times are assumed to be random with a Gamma-Cox distribution, a class of phase-type distributions known to be dense in the field of positive distributions. We develop both exact and approximate approaches for characterizing the distribution of the number of customers seen by each arrival. We show how this can be used to obtain the distribution of waiting time for each customer. We prove that the approximation provides an upper bound for the expected customer waiting time when non-punctuality is uniformly-distributed. We also examine the impact of non-punctuality on system performance. In particular, we prove that non-punctuality deteriorates waiting time performance regardless of the distribution of non-punctuality. In addition, we illustrate how our approach can be used to support individualised appointment scheduling.

4 - Customer strategic behavior in a multi-server data center with setup time of servers

Hung Q. Nguyen, Tuan Phung-Duc

We study the model of a multi-server data center. Servers can be switched between ON/OFF states based on the number of customers present in the system. Furthermore, when a server is turned on, it takes some time in the setup mode. The system is modeled as a three-dimensional Markov chain. We recursively derive the expected waiting time of customers observing a particular system state upon arrival and study customer behavior in an observable system setting.

■ MD-20

Monday, 14:30-16:00 - Y228b

DEA methodological developments II

Stream: Data Envelopment Analysis and Performance Measurement
Invited session
Chair: Andreas Georgiou

1 - Robustness of efficiency scores in data envelopment analysis with interval scale data
Akram Dehnokhalaji, Nasim Nasrabadi, Pekka Korhonen, Banu Lokman, Jyrki Wallenius

In this research, we focus on a robustness analysis of efficiency scores in the context of Data Envelopment Analysis (DEA) assuming interval scale data, as defined in A. Dehnokhalaji, P. J. Korhonen, M. Köksalan, N. Nasrabadi and J. Wallenius, "Efficiency Analysis to incorporate interval scale data", European Journal of Operational Research 207 (2), 2010, pp. 1116-1121, where we developed a MILP model to evaluate the performance of Decision Making Units with inputs and outputs measured on an interval scale. We investigate our definition of the interval scale efficiency scores and show our proposed efficiency measure is well-defined according to Aparicio and Pastor (J. Aparicio and J. T. Pastor, "A well-defined efficiency measure for dealing with closest targets in DEA", Applied Mathematics and Computation 219 (17), 2013, pp. 9142-9154.). Next, we characterize how robust the interval scale efficiency scores are with respect to improvements and deteriorations of inputs and outputs. We illustrate our analysis with numerical examples.

2 - Procedures for large scale DEA applications
Gregory Koronakos, José Dula, Dimitris Despotis

Algorithms and computations are an important part of Data Envelopment Analysis (DEA). In 2011 J. Dulà introduced the algorithm "BuildHull" to accelerate computations in DEA for large-scale applications. Since then, competing with "BuildHull" has motivated new works. In this study, we analyze and compare BuildHull to a recent contender. Different implementations and measurements of their computational effort are discussed. We propose the use of machine-independent operations count for DEA computational studies which, in conjunction with the traditional running time comparisons, enhances understanding, analyzing, and comparing the procedures. Counting operations serves as an excellent analysis tool.

3 - Evaluating efficiencies for big datasets in data envelopment analysis
Terézia Fulová, Maria Trnovska

Many data science techniques for data processing find applications in other fields of science. In this contribution, we show that algorithms related to the problem of finding optimal experiment design can be used in large-scale data envelopment analysis (DEA). To evaluate the efficiencies of N decision-making units in DEA, one typically solves N optimization problems, where the variable dimension of each problem also depends on N. This approach is only suitable for small-sized datasets. Several methods have been proposed in the DEA literature to make the efficiency evaluation computationally effective for large N. The idea behind some of the algorithms is to detect the subset of efficient units since these generate the technology set. Evaluating efficiencies of the decision-making units with respect to this subset may significantly reduce the computational time. In this contribution, we study and compare several approaches for dealing with big datasets in DEA, and propose a new one based on finding the minimum volume enclosing ellipsoid.

4 - The introduction of Data Envelopment Analysis in Markovian settings. Hybrid models and extensions
Andreas Georgiou, Emmanuel Thanassoulis, George Tsaples, Eleni-Maria Vretta, Konstantinos Kaparis, Alexandra Papadopoulou

This presentation discusses the development of a modelling framework which includes Data Envelopment Analysis blended with Markov Chains. The Markov process is in fact related to a population structure that defines mobility through time and the ultimate goal baseline is to support attainability of a desirable future state. Various control variables can be used towards this aim, such as, recruitment policies, transition matrices or starting structures. Radial and additive models are developed and a slack based measure is introduced to aggregate the performance of alternative DMUs. In addition, an attempt to expand the initial model includes the investigation of alternative approaches with variants on the DMUs or on the time horizon (as in network DEA models). The paper concludes with a discussion about the advantages and limitations.

The research work was supported by the Hellenic Foundation for Research and Innovation (H.F.R.I.) under the "First Call for H.F.R.I. Research Projects to support Faculty members and Researchers and the procurement of high-cost research equipment grant" (Project Number: 3154).

■ MD-22

Monday, 14:30-16:00 - Y229c

AI and Blockchain in Sustainable Supply Chains

Stream: Sustainable Supply Chains
Invited session
Chair: Shu Guo

1 - The role of artificial intelligence in sustainable supply chains
Stefan Walter

In the context of smart supply chains, artificial intelligence (AI) increases quality, flexibility and agility. Thus, industry can adopt adaptive strategies, increase its competitiveness by responding quickly to changing customer demands, and make its processes more robust and resilient.

At the same time, digital technologies can be introduced in a way that brings together digital and green concepts, e.g., to meet climate or sustainability commitments. Here, AI can be used to automate according to the principles of resilience, sustainability and regeneration of diverse resources.

The EU knowlEdge project has developed an architecture to address the need for AI solutions in supply chains, combining several top technologies. These solutions are flexible, reusable, distributed, scalable, accountable, secure, standardised and collaborative, ensuring the management of distributed data and facilitating knowledge sharing. The architecture contributes to increasing resource and energy efficiency and transparency, incorporates circular economy principles and has a decisive impact on competitiveness.

Knowledge sharing and learning are central to the cognitive supply chain. Learning stands for evolution and the ability to adapt to changing conditions. Such an approach leads to greater decentralisation of decision-making and to empowerment and autonomy of people. This will impact both the understanding of management and the resilience and sustainability in the supply chain.

2 - Evaluation of the energy usage of Ethereum blockchain network
Ernestas Filatovas, Aleksandr Igumenov, Viktor Medvedev, Remigijus Paulavičius

Blockchain is one of the most breakthrough technologies which attracted significant attention from the industry, government, and academia. The largest blockchain networks, Bitcoin and Ethereum, currently utilize Proof-Of-Work (PoW) based consensus protocols in which miners solve computationally expensive and energy-intensive cryptographic puzzles. Thus, the high energy usage of PoW-based blockchains raises environmental and sustainable concerns. The development of energy consumption estimation methodologies is required to deal with various issues related to the planning and distribution of electricity and the environmental situation. Governments could track electricity consumption and respond dynamically by introducing laws or decisions to change the environment and overall situation. For example, on 14/03/2022 EU rejected a proposal limiting PoW-based cryptos; however, it set draft rules for sustainability. A wide range of approaches for the Bitcoin network has been proposed. However, despite the tendentiously growing Ethereum popularity, no approach is proposed to represent the actual energy consumption used for mining in this network. To address this drawback, we introduce a new methodology that more realistically reflects the energy usage utilized by mining in Ethereum network. We also validate the proposed methodology and compare it to the existing ones. This research has received funding from the Research Council of Lithuania (LMTLT), agreement No. S-MIP-21-53.

3 - Developing a blockchain-based information system for sustainable supply chain management
Majid JavidiAlsadi, Seyed Hossein Siadat, Saeed Eini

Distributed ledger technology (e.g. blockchain technology) has been recently introduced as the disruptive technology in many areas such as financial systems, internet of things and supply chain management (SCM). Smart contracts, as an influential tool in blockchain ecosystems, enables the implementation of innovative business logics. These logics provide incentive models for contributors in order to enhance the functionality of systems as well as to deal with worldwide challenges such as the environmental crisis. Energy efficiency and environmental damage are considered as the emerging challenges in SCM. Blockchain technology can address trustless, transparent, secure and efficient solution based on smart contracts to overcome such challenges associated with SCM. This paper introduces a conceptual architecture of blockchain based information system for the efficient decision-making and sustainability in SCM. For this purpose, a market mechanism solution is proposed for SCM systems including energy efficiency, environmental impact and social impact certificates. These certificates involve the measurement and commodification of energy saving, environmental protection and social responsibility activities. This platform provides the tools for trading these certificates using a smart contract between contributors. The performance of the proposed system is evaluated by simulating a case study in a public/private blockchain network.

4 - Applications of Blockchain Technology in Sustainable Fashion Supply Chains: Operational Transparency and Environmental Efforts
Shu Guo, Xuting Sun, Hugo Lam

Motivated by the industrial practices, we explore the information disclosure games over the environmental efforts in fashion supply chains. We consider the case when a fashion retailer is the Stackelberg leader and orders sustainable fashion products made from environmentally friendly materials from a manufacturer. To declare the environmental quality of the fashion product, the fashion retailer can either affix an eco-label for declaration or adopt the blockchain technology for tracking. Meanwhile, given that the environmental quality is unobservable to the fashion retailer and the consumers, the manufacturer with credibility concerns can have the actual environmental quality of the fashion product discounted. We discuss how the application of the blockchain technology influences the information disclosure games. Regarding the value of blockchain in improving the environmental performance of the sustainable fashion product, we find that close attention should be paid to the contracted manufacturer's credibility level when the consumer's willingness to pay for the blockchain advertisement level is relatively low. Besides, applying blockchain for information disclosure can be a better alternative when the fashion retailer and the manufacturer are more risk averse or when the market demand is with more uncertainties. These findings advance the understanding on the application of the blockchain technology in sustainable practices in fashion supply chains.

■ MD-23
Monday, 14:30-16:00 - Y307

Pricing and Revenue Management 1

Stream: Pricing and Revenue Management
Invited session
Chair: Jacques Cartuvyels

1 - A combinatorial auction mechanism to match supply and demand in manufacturing
Juan De Antón Heredero, David Poza, Félix Villafáñez, Adolfo López-Paredes

In this work we present a market-based allocation mechanism to address production allocation problems in distributed manufacturing systems. This problem involves two types of agents: customers (who request the production of a number of items) and manufacturers (whose production capacity is limited). Traditional production allocation systems present inefficiencies: customers need to devote resources to contacting different manufacturers to determine whether they have the capacity/possibility to manufacture the required parts and, if so, to negotiate a contract (including price and number of parts supplied). From a manufacturer's point of view, producing a combination of items for different customers may be more cost-effective than producing a very small number of parts for a single customer. We claim that these inefficiencies can be mitigated by establishing a coordinating mechanism that considers the characteristics of customers' requests and the production capabilities of manufacturers when determining which manufacturer(s) produce(s) the items requested by each customer. To this end, in this work we propose the design of a combinatorial auction, a market-based allocation mechanism that has already been successfully applied in other allocation problems (radio spectrum, airport slots, etc.). We show that the allocation resulting from the combinatorial auction drastically improves the overall utility of all the agents involved.

2 - Parametrization of Operating Reserve Demand Curves in a Scarcity Pricing Mechanism
Jacques Cartuvyels

The rapid integration of renewable generation in power systems has led to a tension in the electricity market. It has depressed the prices and exacerbated the "missing money" problem incurred by flexible generators. The introduction of scarcity pricing through operating reserve demand curves has been proposed to remedy this issue by supplementing the real-time energy prices with an adder based on the level of reserve in the system. Our work focuses on the calibration of the operating reserve demand curves, which is a key design parameter in the implementation of the mechanism. Our method anchors the calibration to a closed-loop simulation model and examines specific design criteria that emerge in a realistic implementation of the mechanism.

3 - Estimating Price Sensitivity via Machine Learning with Causal Inference
Darius Walczak, Ravi Kumar

To improve their pricing airlines (and other sellers) have been experimenting with dynamically adjusting prices of their products based on unique product features and other relevant information available at the time of request. Such functionality usually requires estimates of customers' price-sensitivity based historical sales transaction data. However, when sales channels are not fully controlled by the firm, access to good quality loss information is challenging. But, in the absence of loss information, one can still estimate the price-sensitivity by learning price-demand relationships (demand response modeling) with aggregated sales for a product in given time period e.g., daily sales. Such estimation of price-sensitivity parameters via demand response modeling lies in the realm of Causal Inference (and not prediction) and construction of estimators robust to confounders and model misspecifications remains a challenge. Modern machine learning (ML) despite its high predictive power, does not easily lend itself to constructing an interpretable framework for price elasticity estimation. In this talk we propose a hybrid framework that builds on the synergy between predictive power of modern Machine Learning (ML) approaches and interpretable semi-parametric models for robust price-sensitivity estimation. We show performance of our hybrid approach methods via simulation studies.

■ MD-24

Monday, 14:30-16:00 - Y307a

Innovations in Retail Operations

Stream: Demand and Supply in Consumer Goods and Retail

Invited session

Chair: *Defne İdil Eskiocak*

1 - Outsourcing Decision in the Presence of Supplier Copycatting

Shobeir Amirnequiee, Hubert Pun, Joe Naoum-Sawaya

Supplier copycatting occurs when a supplier copies the manufacturer's product and encroaches on the market with copied product. To address this problem, the manufacturers can change their suppliers; while copycatting suppliers run the risk of encountering repercussions (e.g., losing the manufacturer's future business) if they get caught. Previous research has not considered the impact of these realities. We propose a multi-period game-theoretic approach to supplier copycatting. We investigate a setting with an original manufacturer that outsources the production of its product in each period to its preferred supplier(s). The supplier pool is characterized by a supplier of high process quality with copycatting capabilities, and a supplier of low process quality without copycatting capabilities. Our results indicate that (a) an increase in the quality of the copied product can make the manufacturer switch from outsourcing to the non-copycatting supplier to outsourcing to the copycatting supplier and, at the same time, improve the manufacturer's profits, (b) upon an improvement in the quality of the non-copycatting supplier, the manufacturer may abandon the non-copycatting supplier and outsource to the copycatting supplier, and (c) both suppliers can be worse off from an improvement in process quality. Driven by the manufacturer's future outsourcing opportunities and the supplier's future repercussions, these results have strong implications for the manufacturing managers.

2 - Optimal Collection Policies for Returned Products

Nizar Zaarour, Emanuel Melachrinoudis

In 2021, retailers got back, on average, about 16.6% of the total merchandise that customers purchased, accounting for $761 billion U.S. dollars of lost sales, which is more than twice the amount of the 2019 pre-pandemic year. With a significant increase of online sales during pandemic and increasing customer service expectations, a growing number of firms are leveraging return policies to drive a strategic competitive advantage. This presentation focuses on the development and comparison of collection models that reduce the firm's inventory and transportation costs by leveraging economies of scale and optimizing the collection period across multiple initial collection points (ICP) before transshipping the returned products to a centralized return center (CRC). First, an optimal collection policy for the case of a single product and a single ICP is described, which is then extended to the case with multiple products and a single ICP. Then, determination of the optimal collection policies for the case of multiple ICPs and a single product is presented: 1) individual shipment policy, 2) combined shipment policy and 3) hybrid shipment policy. Mathematical models are developed that express the combined inventory and transportation costs of all policies in terms of collection periods, and an efficient optimization approach is designed to determine the optimal collection period(s). Finally, the results are presented with an experimental dataset.

3 - Smart Inventory Audit Recommendation for an FMCG Retailer

Defne İdil Eskiocak, Sinan Vatansever, Buse Mert, Birol Yüceoglu, Murat Dağhan, Karin Çakan, Işıl Öztürk, Furkan Oral, Ramiscan Yakar

In FMCG retailing, increasing inventory accuracy has a positive effect on increasing customer satisfaction and reducing inventory holding costs as well as shrinkage. Inventory auditing is the most important tool in determining the problems that can occur in inventory records. While auditing every product category in each store will improve inventory accuracy, this causes enormous effort and additional costs due to overtime. An alternative approach is selecting a subset of product categories for periodic (in this case monthly) auditing. In this study, we consider a machine learning based approach to determine risky product categories for each store and create store specific recommendations for inventory monthly auditing. For this purpose, we aim to identify store-product category pairs with a high risk of inventory inaccuracy, which corresponds to the difference between physical and recorded inventory. We build a classification model with and create various attributes related to shipments, sales, customer returns, and past inventory adjustments. The created features are tested using various machine learning algorithms and the algorithm with the best results is selected. We present our computational results as well as the results of the real life experiment.

4 - Store-Wide Space Planning Balancing Impulse and Convenience

Bacel Maddah, Fouad Ben Abdelaziz, Tulay Flamand

We develop a store-wide shelf space planning framework that balances impulse buying and shopping convenience via a bi-objective nonlinear integer program, similar in structure to a quadratic assignment. The model parameters are estimated based on real data collected from a large supermarket in the Normandy region, France. We propose a linearization scheme and utilize it to exploit the efficient frontier of Pareto-optimal solutions via the epsilon-constraint method. Our results indicate that the supermarket management can significantly increase their revenue from impulse buying, while not burdening the customer with the inconvenience of extensive walking and search. For example, one well-balanced layout increases impulse profit by 82% and decreases walking by 11% with respect to the current store layout.

■ MD-25

Monday, 14:30-16:00 - Y308

Specific Applications of Stochastic Modeling and Simulation

Stream: Emerging Research and Specific Applications of OR

Invited session

Chair: *Katsunori Ano*

Chair: *Christopher Kirkbride*

1 - Using Cross-Impact Statements to Estimate Scenario Probabilities

Juho Roponen, Ahti Salo

Cross-impact methods are widely employed to build scenarios that are defined as combinations of outcomes for several uncertainty factors. In all these methods, cross-impact statements indicate how a given outcome for one uncertainty factor affects the outcome of another factor. Yet they are different in terms of the scales that are employed to elicit the statements; the probabilistic interpretation of such statements; and the number of scenarios that are generated. We present a computationally efficient method that admits cross-impact statements and derives corresponding probabilities for all possible scenarios (i.e., combinations of outcomes for uncertainty factors). Specifically, our method

(i) admits many kinds of probability statements (incl. marginals, conditionals), (ii) guides the process of expert statement elicitation, and (iii) can be readily interfaced with other probabilistic methods. We also show how scenario probabilities can be used to construct graphical models such as Bayesian networks and influence diagrams. This makes it possible to benefit from cross-impact elicitation in many kinds of analyses. We also present a case study in which cross-impacts were used to characterize possible future impacts of 3D-printing on the spare part logistics of Finnish Defense Forces. The quantitative results include, among others, the scenarios and their probabilities as well as the Bayesian network which helps visualize cross-impacts and supports what-if analyses, too.

2 - A simulation framework for safe and efficient ice navigation
Ketki Kulkarni, Fang Li, Pentti Kujala, Mashrura Musharraf, Cong Liu

Navigation in ice-covered seas presents multiple challenges due to the uncertainty of ice formation and limited icebreaking capabilities of vessels. Icebreakers can assist when needed but they are a limited resource that need to be shared, while ensuring safety and efficiency. Decision-making involves monitoring several parameters at both operational and system level, including multiple stochastic parameters. This work presents an integration of ice characteristics, operational level details of ships, and system level details such as traffic flows and icebreaker scheduling through a simulation framework. At the core is a discrete-event simulation model that mimics winter traffic flows in varying ice conditions obtained through meteorological data. Icebreaker movement and coordination, along with convoys and towing arrangements are modelled in detail. These functionalities are parameterized, and users can vary convoy sizes, speed limits and ice conditions to study their impacts on system level traffic. Numerical simulation techniques together with analytical approaches are employed at operational level to describe ship performance under various operation scenarios. These estimates are validated by case studies involving the entire winter navigation system, comparing the tool performance with the real-world data. This work brings in the novel combination of using ship-level research as an input in deriving vessel speeds for modelling traffic flows for system-level optimization.

3 - Road traffic estimation and algorithmic routing in a spatially dependent network
Rens Kamphuis, Michel Mandjes, Paulo Serra

This work concerns optimizing routing in a road traffic network with spatial dependence. Many studies aim to a priori identify a route that optimizes the expected travel time or on-time arrival probability. That is, an optimal path is determined, and it is assumed that this exact route will be traversed. However, as a consequence of the spatial dependence, new information about the travel time distribution of the remainder of the route becomes available as a driver travels across the network toward their destination. By exploiting this information, an algorithm is able to sequentially adjust the recommended route in order to realize gains such as a shorter expected travel time or a higher on-time arrival probability. Another limitation of many studies, is that the joint distribution of travel times on the network is assumed to be known. In reality, however, this distribution has to be estimated. Any estimate contains uncertainty, and when this uncertainty can be quantified, one may also want to take the uncertainty of these estimates into account as a form of incorporating risk aversion into the cost/loss. We aim to resolve both issues by developing a consistent estimator for both the mean and the covariance of the travel times, and we use these estimates to create an algorithmic based routing policy. We conclude with numerical experiments that demonstrate the validity of this procedure.

4 - Approximate Dynamic Programming for Dynamic and Stochastic Resource Constrained Multi-Project Scheduling Problems
Christopher Kirkbride, Peter Jacko, Ugur Satic

We consider a dynamic and stochastic resource constrained multi-project scheduling problem, which allows for both random arrival of projects and stochastic task durations. Completion of projects generates rewards, which are reduced by a tardiness cost in the case of late completion. Multiple types of resources are available, and projects consume different amounts of these resources when under processing. The problem is modelled as an infinite-horizon discrete-time Markov decision process and seeks to maximise the expected discounted long-run profit. We introduce an approximate dynamic programming algorithm (ADP) with a linear approximation model. This model uses project elements that are easily accessible by a decision-maker with the model coefficients obtained offline via a combination of Monte Carlo simulation and least squares estimation method. Our numerical study examines the performance ADP approach in comparison to alternative approaches in the literature and highlights where its use can be beneficial to the scheduler.

■ MD-26

Monday, 14:30-16:00 - Y309b

At the intersection of disaster relief and sustainable development

Stream: EWG HOpe, EURO working group on Humanitarian Operations
Invited session
Chair: *Maria Besiou*
Chair: *Jonas Stumpf*

1 - Towards Universal Health Coverage: Strengthening healthcare supply chain resilience to mitigate the impact of infectious disease outbreaks
Caspar Hoeyng, Maria Besiou, Timna Eckschmidt

We investigate the resilience of public healthcare supply chains to infectious disease outbreaks, and explore the effectiveness of different preparedness strategies using a system dynamics approach. Goal 3 of the UN Sustainable Development Goals targets good health and well-being for all, encompassing Universal Health Coverage and preparedness for infectious disease outbreaks. During infectious disease outbreaks, health supply chains are oftentimes a bottleneck in the provision of healthcare; health supply chains are oftentimes not resilient to the stress induced by infectious disease outbreaks. Our model evaluates the resilience of health supply chains looking at two dimensions: the response capabilities towards the infectious disease outbreak and routine healthcare continuity throughout the outbreak. This approach allows comparing preparedness investments holistically, not only with the immediate disease outbreak, but also healthcare continuity in mind. First results show the benefits of using system dynamics as a decision-making tool for epidemic preparedness and response decisions.

2 - Preparedness in Humanitarian Supply Chains - Exploring the Benefits of Investments in Different Operational Settings
Tina Wakolbinger, Jonas Stumpf, Maria Besiou

Investing in supply chain preparedness is considered a powerful trigger to improve the operational performance of humanitarian actors. To build strong business cases and further enhance preparedness efforts, more evidence on the actual impact of investments in the humanitarian space is needed. Here, the operational realities of humanitarian actors in the form of different organizational settings should be taken into account. Using system dynamics methodology and building on five case studies, we model the humanitarian supply chain from the perspective of a centralized setting with strong capacities at global hubs, a decentralized setting with strong presence in the countries, and a hybrid setting with response capacities at global as well as country levels. We find that the decentralized setting is less costly for low-value items and generates more local social impact than the centralized and hybrid settings. With respect to response time in medium to large scale disasters, the centralized and hybrid settings perform better than the decentralized settings. Our results show that decentralized settings have the largest improvement potential across all performance metrics. However, the models also demonstrate that decentralized settings are most vulnerable to major shocks such as the COVID19 pandemic.

3 - Saving and improving lives in the short and long run
Jonas Stumpf, Maria Besiou, Tina Wakolbinger

Whilst logistics and supply chain management are increasingly considered as backbone and lifeline for humanitarian operations, there is little evidence on the actual share and structure of supply chain related expenses. Through an extensive cost analysis on 19 relief operations we find that almost three-fourth of total humanitarian response cost are in the supply chain. Based on these new insights we discuss the tremendous potential lying in the supply chain, in particular in the context of sourcing and procurement, to tackle the ever-growing funding gap. In the second step of our study, we investigate to what extent the humanitarian supply chain can impact operational excellence of relief programs as well as longer term development efforts. We conduct a literature review to identify research that connects both fields and to trigger a discussion on future research agendas, ultimately providing new, adequate and more impactful solutions for a rapidly changing sector.

■ MD-27

Monday, 14:30-16:00 - Y313

Emerging Applications

Stream: Splitting and ADMM Methods
Invited session
Chair: Marjan van den Akker

1 - New efficient ADMM algorithm for the Unit Commitment Problem
Rogier Wuijts, Marjan van den Akker, Machteld van den Broek

The unit commitment problem (UC) is an optimization problem about the operation of electrical generators. Many algorithms have been proposed for the UC and in recent years a more decentralized approach, by solving the UC with alternating direction method of multipliers (ADMM), has been successfully applied. For convex problems ADMM is guaranteed to find an optimal solution. However, because UC is non-convex additional steps need to be taken in order to ensure convergence to a feasible solution of high quality. We introduce a new and efficient way to heuristically solve the UC with ADMM. We relax the supply-demand balance constraint and solve the previously mentioned problem of non-convexity by iteratively increasing a penalty coefficient until we eventually force convergence and feasibility. Our algorithm has a low computation time due to our efficient algorithm for the single UC subproblem that we developed in earlier work and our newly created algorithm to solve the transmission subproblems. Computational experiments on a large set of UC instances demonstrated that our algorithm produces high-quality solutions. The computation time seems to grow almost linearly with the size of the time horizon. For the case with quadratic cost it is significantly faster than solving the problem by a state-of-the-art MIL(Q)P formulation. For linear cost, it is competitive and starts to outperform the MILP approach for long time horizons.

2 - Interior point methods applied to optimal power flow with uncertain demand
Aurelio Oliveira, Demacio Costa de Oliveira

The optimal power flow problem can be employed to economic dispatch, reliability analysis of power generation and transmission, safety analysis and short-term generation programming among other power systems models. The decisions made in the energy sector depend on uncertain parameters present in short and long-term planning. Thus, in order to investigate whether it is relevant to consider the uncertain demand in such problems, we develop an approximation for the distribution function and, consequently, approximations for the expected value of the second stage problem. In addition, we proposed a two-stage quadratic stochastic programming with fixed recourse model for the optimal power flow problem with uncertain demand. We apply a specially tailored path-following interior point method to solve the proposed model. The considered sources of active power generation are hydroelectric and thermal power plants. The numerical experiments are applied to IEEE30, IEEE118 and Brazilian regional and national systems. The results indicate that it would be worthwhile to consider the stochastic solution for this problem.

3 - Identification of benefical Expansion Measures in Coupled Power and Gas Transmission Systems
Raphaël Houben

Today's energy system is faced with the necessity for increased energy transport and storage capacities resulting from the integration of intermittent renewable energy sources. An expedient interconnection and customized expansion of the existing power and gas systems presents an economically and environmentally favorable approach to meet these requirements. This publication therefore aims to present a procedure to determine beneficial expansion measures in a coupled power and gas energy system. It is based on injection shift keys as well as duals and reduced costs being the result of an optimized dispatch of the existing power and gas system. Within the procedure, offshore connection locations, the installation of electricity or gas storages, the expansion of lines or transformers and the installation of new or the conversion of existing gas pipelines are degrees of freedom either in the power or in the gas system. Interconnecting elements in the form of gas-to-power - or power-to-gas plants can be added to the coupled system. The publication concludes with a benchmark of the presented approach to an integer optimization showing that the procedure allows to identify reasonable expansion measures.

4 - Accelerated Gradient-free Neural Network Training by Multi-convex Alternating Optimization
Junxiang Wang, Hongyi Li, Liang Zhao

In recent years, even though Stochastic Gradient Descent (SGD) and its variants are well-known for training neural networks, it suffers from limitations such as the lack of theoretical guarantees, vanishing gradients, and excessive sensitivity to input. To overcome these drawbacks, alternating minimization methods have attracted fast-increasing attention recently. As an emerging and open domain, however, several new challenges need to be addressed, including 1) Convergence properties are sensitive to penalty parameters, and 2) Slow theoretical convergence rate. We, therefore, propose a novel monotonous Deep Learning Alternating Minimization (mDLAM) algorithm to deal with these two challenges. Our innovative inequality-constrained formulation infinitely approximates the original problem with non-convex equality constraints, enabling our convergence proof of the proposed mDLAM algorithm regardless of the choice of hyperparameters. Our mDLAM algorithm is shown to achieve a fast linear convergence by the Nesterov acceleration technique. Extensive experiments on multiple benchmark datasets demonstrate the convergence, effectiveness, and efficiency of the proposed mDLAM algorithm.

■ MD-28

Monday, 14:30-16:00 - Y405

Data Science and Analytics Applications 2

Stream: Data science and Analytics (contributed)
Contributed session
Chair: Lotte van Hezewijk

1 - Multi-Echelon Inventory Optimization using Deep Reinforcement Learning
Lotte van Hezewijk, Kevin Geevers, Martijn Mes

We study the applicability of a deep reinforcement learning approach to three different multi-echelon inventory systems, with the objective of minimizing the holding and backorder costs. We conduct an extensive literature review to map the current applications of reinforcement learning in multi-echelon inventory systems. We apply our deep reinforcement learning method to three cases with different network structures (linear, divergent and general structures). The linear and divergent cases are derived from literature, while the general structure case is based on a real-life manufacturer. We apply the Proximal Policy Optimization (PPO) algorithm, with a continuous action space. We show that the PPO solution outperforms the benchmark solution with 16.4% for the linear case, 8.3% for the divergent case, and 17.5% for the general case. Nevertheless, for large problem instances in the general case, the PPO algorithm is not stable, and we explain the limitations and avenues for future research.

2 - Bayesian Learning in Maintenance Optimization for Multiple Single-Component Systems under Population Heterogeneity
Ipek Dursun, Alp Akcay, Geert-Jan van Houtum

We consider multiple single-component systems with a finite lifespan. The lifespan consists of multiple periods of equal length. Each component fails randomly. A component can be replaced preventively at the beginning of each period or correctively upon failure. We assume there are two types of populations for the components (i.e. weak and strong) and a component always comes from the same population. The type of population is unknown but an initial belief is available and it is updated in a Bayesian way with the data pooled from multiple machines. We build a partially observable Markov decision process model to find the optimal maintenance policy where the objective is to minimize the total cost throughout the total lifespan of the system. We study how the optimal expected total costs behave as a function of different input parameters. We generate insights on the effect of data pooling by comparing optimal policy with single system policies with and without data pooling.

3 - Prescriptive Supply Stability Optimization in Production Planning in a Case Study of the Semiconductor Industry
Tim Lauer

The semiconductor industry having experienced a strong growth in the last years owes the role as a key segment of the global manufacturing sector due to its wide product portfolio.. A common approach to tackle those challenges is to incorporate and update current information in the production plan by a rolling horizon planning approach. On the downside, plan instability occurs as the deviation between two consecutive plans. Besides traditional, model-based solutions to reduce plan instability, a recent machine learning approach exists to predict plan stability. However, the prediction does not give any advice to the decision-maker how to act for optimal stability values. Therefore, this paper takes a step forward and applies prescriptive analytics to plan stability. The technique supports data-driven decision-making by linking optimization to prediction and is the most advanced field in the three-stage model of business analytics. Moreover, it helps to overcome the challenge of decision-making under large amounts of data that humans cannot process. The concept enables the decision-maker to determine quantitative values for input features of the production planning, in order to achieve optimal stability values. Based on the manufacturer's data and planning systems, a detailed numerical analysis is conducted.

4 - On Peer Group Situations and Related Games under Fuzzy Uncertainty
İsmail Özcan, Sırma Zeynep Alparslan Gök, Gerhard-Wilhelm Weber

In many economic and Operations Research situations the social configuration of the organizations influences the potential possibilities of all groups of agents. An important group for an agent consists of the leader, the agent itself and all the intermediate agents that exist in the given hierarchy, which we call a peer group. In this study, peer group situations under fuzzy uncertainty are studied and related games are modeled. In the sequel some game theoretical solution concepts are given. Finally, an application related with an auction situation is studied.

■ MD-29

Monday, 14:30-16:00 - M1

Manufacturing II

Stream: Industrial Production, Planning and Inventory Management
Invited session
Chair: Dennis Prak

1 - Temperature-based trajectory planning for surfaces in Wire-Arc Additive Manufacturing
Johannes Schmidt, Armin Fügenschuh, Johannes Buhl

In the process of Wire-Arc Additive Manufacturing (WAAM), the desired workpiece is split up into slices and built up layer-by-layer. The welding head can move freely over the clamped substrate plate to deposit droplets of metal wire, molten by an electrical arc or a laser. Also, transfer moves without welding are possible. The main issue about this manufacturing technique is the temperature distribution within the workpiece since the large thermal gradients caused by the welding process can cause thermal stress, leading to strain or even cracks. Especially for filled surface structures consisting of many weld beads, this must be taken into account. Thus, careful planning of the welding trajectory is essential for high-quality workpieces. We consider the trajectory planning problem of finding an optimal welding trajectory for a given two-dimensional layer. It is formulated as a mixed-integer linear problem (MILP) searching the welding path with the most homogeneous temperature distribution during the manufacturing process. The heat conduction, the weld source, and the heat exchange with the environment are incorporated into the model using a two-dimensional finite element method. All MILP instances are solved to global optimality using a linear programming based branch-and-cut approach, offered by standard solvers such as Cplex. For several standard surface shapes, the computed optimal trajectory is compared to commonly used strategies like raster, zigzag or spiral paths.

2 - A novel decomposition-based method for solving general-product structure assemble-to-order systems
Mohsen Elhafsi, Jianxin Fang, Essia Hamouda

Assemble-to-order (ATO) strategies are common to many industries. Despite their popularity, ATO sys- tems remain challenging to analyze. We consider a general-product structure ATO problem modeled as an infinite horizon Markov decision process. As the optimal policy of such a system is computationally intractable, we develop a heuristic policy that is based on a decomposition of the original system, into a series of two-component ATO subsystems. We show that our decomposition heuristic policy (DHP) possesses many properties similar to those encountered in special-product structure ATO systems. Extensive numerical experiments show that the DHP is very efficient. In particular, we show that the DHP requires less than 0.00001 the time required to obtain the optimal policy, with an average percentage cost gap less than 4% for systems with up to 5 components and 6 products. We also show that the DHP outperforms the state aggregation heuristic of Nadar et al. (2018), in terms of cost and computational effort. We further develop an information relaxation-based lower bound on the performance of the optimal policy. We show that such a bound is very efficient with an average percentage gap not exceeding 0.5% for systems with up to 5 components and 6 products. Using this lower bound, we further show that the average suboptimality gap of the DHP is within 9% for two special-product structure ATO systems, with up to 9 components and 10 products.

3 - Timing intermittent demand with time-varying order-up-to levels
Dennis Prak, Patricia Rogetzer

Current intermittent demand inventory control models assume that the demand interval is memoryless: the probability of observing a positive demand does not depend on the time since the last demand occurred. Contrarily, several forecasting contributions suggest that demand intervals contain more distributional information. We find that the data of the M5 forecasting competition confirms this. Therefore, we propose an inventory control model that explicitly uses the full distributions of the demand sizes and intervals and thereby acknowledges that the probability of a demand occurrence may vary throughout the interval. To exploit this information, we also allow for time-varying order-up-to levels that flexibly adjust inventories according to the dynamic requirements. We derive the long-run average holding costs, non-stockout probability, order fill rate, and volume fill rate. Inspired by an analogy with multi-item inventory control models, we propose a greedy marginal-analysis heuristic to optimize the order-up-to levels, which we benchmark against the optimal solution on theoretical instances. In a simulation study on the M5 competition data we demonstrate this method's improved on-target service performance compared to that of traditional solutions. We furthermore show that target service levels can be achieved at significantly lower costs with time-varying than with fixed order-up-to levels.

4 - Real-time optimization for a Digital Twin of a robotic cell with human operators
Andrea Brocchi, Teresa Albini, Marco Pranzo, Gianluca Murgia

Digital Twins (DTs) can support the simulation and optimisation of operations, but the presence of human operators may hinder their adoption. Differently from machines, humans are characterized by nondeterministic behaviours, thus requiring that constant monitoring of the manufacturing system is accompanied by the development of real-time simulation and optimization algorithms. This paper presents the DT of a manufacturing cell for Printed Circuit Boards (PCBs). A human operator oversees the management of the defective PCBs and the replenishment of the necessary materials for the cell but may also carry out some tasks otherwise performed by a robotic arm. The cell is autonomously optimized by a real time optimization algorithm adapting to the behaviour of the human operator. This algorithm suggests, without enforcing, the desired next moves for the human operator. Specifically, we developed a simulation-optimization algorithm based on the Approximate Dynamic Programming framework, which evaluates the set of available moves by simulating the behaviour of two independent agents (i.e., the robotic arm and the human operator) and selects the most promising moves for both these agents. Through an extensive experimental campaign, we show how the productivity of the cell is scarcely affected by human behaviours. These results may enrich the literature on DTs with human operators and provide useful insights to firms interested in the implementation of robotic cells based on DTs.

■ MD-30

Monday, 14:30-16:00 - M237

Extensions of Machine Scheduling

Stream: Project Management and Scheduling
Invited session
Chair: *Stéphane Dauzere-Peres*

1 - Anarchy in the UJ
Dirk Briskorn, Stefan Waldherr

We consider the distributed scheduling problem on parallel machines with the central objective of maximizing the number of on-time jobs. Jobs are self-interested utility-maximizers that can choose the machines they are processed on in order to reduce their own completion time or tardiness. Each machine processes the jobs according to a local policy. We discuss Nash equilibria in the resulting schedules and perform a thorough analysis of the resulting (absolute) prices of anarchy for various parallel machine environments, utilities of the agents, and local policies of the machines. We show that local policies that are based on simple sorting-based procedures like SPT and EDD lead to big losses in welfare compared to the global optimum. However, when employing Moore-Hodgson's algorithm as a local policy, we can prove a price of anarchy of $(2m-1)/m$ for uniform machines and a price of anarchy of 2 for related and unrelated parallel machines. Moreover, we show how these results can be used to prove approximation ratios for greedy scheduling algorithms.

2 - Aggregation techniques for scheduling on parallel machines in semiconductor manufacturing
Jérémy Berthier, Stéphane Dauzere-Peres, Claude Yugma, Alexandre Lima

Semiconductor manufacturing includes the most complex manufacturing processes. Scheduling problems to be addressed at the operational level involve a rich set of constraints and criteria, in particular in complex production areas such as the photolithography one. The scheduling problem in this area consists in scheduling a set of jobs on a set of parallel photolithography machines. Each job requires an additional movable resource, called reticle. This problem is addressed through an ILP model using a time-indexed formulation, which turns out to be intractable for large instances.

To improve the resolution efficiency of the ILP by a standard solver, we propose to reduce the problem size using two aggregation methods motivated by the specificities of the problem : 1. A method that batches multiple jobs using the same reticle to create a single job ; 2. A method that increases the time granularity by considering longer time steps.

Numerical results on industrial instances are conducted using the ILP in order to compare the performances of the two aggregation methods. Promising results are obtained in terms of time saving and gap to the optimal solution. Those methods can be used to speed up the multi-objective aspect of the problem in a context of real-time optimization.

3 - Maximizing the service level for classical criteria in the flexible job-shop scheduling problem
Mario Flores Gomez, Stéphane Dauzere-Peres, Valeria Borodin

This presentation extends a first solution approach proposed to maximize the makespan service level in the flexible job-shop scheduling problem with stochastic processing times. The makespan service level is the probability that the completion date of all jobs is smaller than or equal to a given time threshold. The first approach relies on a Tabu Search procedure and a Monte-Carlo sampling approximation. In this talk, we investigate the design of a more efficient solution approach that considers both the generation and reduction of scenarios representing the random variables. Then, service levels on other classical scheduling criteria are discussed, in particular those related to the due dates of jobs. The results of computational experiments are also analyzed.

4 - Multi-resource balancing - a case of a German kitchen manufacturer
Sina Glaeser

We address a multi-resource balancing-problem at a German kitchen manufacturer who produces kitchen furniture at two production facilities. Both plants can produce the same products and are currently operating at almost full capacity. The customised cabinets of a kitchen are manufactured in parallel and aggregated just in sequence for loading into trucks immediately after production. A smooth flow of materials is essential to ensure on-time completion and loading of a whole kitchen. Nowadays, changing customer tastes drive customisation. No longer only cabinets in different colours but also, e.g. cabinets with and without handles or integrated recessed handles are manufactured. These individualisations have meant multiple individual production processes. Ensuring a smooth material flow is therefore becoming more challenging and an increased amount of capacity restrictions in the production processes have to be taken into account. The current planning method has reached its limits. We consider shifting of orders between the production plants or to later production periods to solve the resource balancing problem. An integer programming model with a multi-criteria objective function as well as a set of constraints are presented. We propose a software based solution approach for the required instance sizes. The results of our computational experiments on real-world data demonstrate that our approach provides significant benefits.

■ MD-31

Monday, 14:30-16:00 - M240

Splitting methods in convex optimization I

Stream: Variational analysis and optimization
Invited session
Chair: *Francisco Javier Aragón Artacho*

1 - Inertial Algorithms for Monotone Inclusions and Fixed-Point Problems
Juan Peypouquet

We present an overview of the dynamical aspects of old and new first-order methods used in optimization and variational analysis, and how inertial features and relaxation can help improve their performance. Special attention will be paid to inertial and overrelaxed primal-dual methods, as an illustration.

2 - A primal-dual splitting algorithm for composite monotone inclusions with minimal lifting
David Torregrosa-Belén, Francisco Javier Aragón Artacho, Radu Ioan Bot

In this talk, we present a new primal-dual splitting algorithm for finding a zero of the sum of maximally monotone operators composed with linear operators. We show that the proposed method reduces the dimension of the product space where the underlying fixed point operator is defined, in comparison to other algorithms, without requiring additional evaluations of the resolvent operators. In fact, our scheme is proved to be minimal in some sense.

3 - Iterative regularization for low complexity regularizers
Cesare Molinari

Iterative regularization exploits the implicit bias of an optimization algorithm to regularize ill-posed problems. Constructing algorithms with such built-in regularization mechanisms is a classic challenge in inverse problems but also in modern machine learning, where it provides both a new perspective on algorithms analysis, and significant speed-ups compared to explicit regularization. In this talk, we propose and study the first iterative regularization procedure able to handle biases described by non smooth and non strongly convex functionals, prominent in low-complexity regularization. Our approach is based on a primal-dual algorithm of which we analyze convergence and stability properties, even in the case where the original problem is unfeasible. The general results are illustrated considering the special case of sparse recovery with the $\ell 1$ penalty. Our theoretical results are complemented by experiments showing the computational benefits of our approach.

4 - Cyclic CQ scheme for handling multiple dose-volume constraints in inverse planning of Intensity-Modulated Photon or Proton Therapy
Aviv Gibali

In this talk we present a feasibility-seeking problem with percentage violation constraints. These are additional constraints, that are appended to an existing family of constraints, which single out certain subsets of the existing constraints and declare that up to a specified fraction of the number of constraints in each subset is allowed to be violated by up to a specified percentage of the existing bounds. Motivation for studying such problems comes from the field of radiation therapy treatment planning wherein the fully-discretized inverse planning problem is formulated as a split feasibility problem and the percentage violation constraints give rise to non-convex constraints. We develop a string-averaging CQ method that uses only projections onto the individual sets which are half-spaces represented by linear inequalities.

■ MD-32

Monday, 14:30-16:00 - F101

Green Technology

Stream: Sustainable Development and Green Technologies
Invited session
Chair: *Özgen Karaer*

1 - Competitive Industry's Response to Environmental Tax Incentives for Green Technology Adoption
Anton Ovchinnikov, Dmitry Krass

We consider market response to environmental taxes by firms producing a commodity good with a polluting by-product. The firms are asymmetric (heterogeneous) with respect to production efficiency and pollution control technology. Cournot (quantity) competition is assumed, and two demand functions are considered: iso-elastic and linear. In this setting, two kinds of responses are considered: market response, where firms choose production quantities given their technology choices, and technology response, where firms also choose among a discrete set of available pollution abatement technologies. We characterize the market and technological equilibria in these settings and examine the possibilities and limitations of using environmental taxes as a mechanism to incentivize "green" technology choice. We also show that the resultant equilibria and the impact of taxation may qualitatively differ depending on the demand function assumed.

2 - Policy Mix Dynamics of Manufacturers' R&D Investment and Government Regulations within a Socio-Technical System Case of Sustainable Transition to Alternative Fuel Vehicle
Wissam EL Hachem

Within the context of sustainability transitions, specifically the transition from internal combustion engine vehicles (ICEVs) to alternative fuel vehicles (AFVs), this paper investigates the interactions between government regulations and the research and development (R&D) investment of car manufacturers in a green-sensitive and heterogeneous market. Given that an unjust transition is not sustainable, the triple bottom line of the said regulations and manufacturers' policies is analyzed via a simulation model backed with government data. We focus on the socio-technical system in which these interactions occur and how it impacts the evolution of the policy mix. Moderate levels of government intervention and manufacturers' investment best ensured the sustainability of the transition. Furthermore, manufacturers' profits were not adversely affected by cannibalization in the long term, mainly due to an increase in consumer environmental awareness and the enforcement of government standards. When optimizing only the environmental or economic performance, penalties should be transferred by the manufacturers to ICEV consumers. Moreover, maximizing profits and/or minimizing emissions resulted in lower quality and higher prices than when social factors were considered simultaneously with them. This paper offers indicators to help manufacturers improve their strategic R&D decisions in line with regulatory frameworks, while ensuring just and sustainable transitions to AFVs.

3 - Contracting for technology improvement: The effect of asymmetric bargaining power and investment uncertainty
Sam Aflaki

While investment in technology improvement (TI) measures that reduce the consumption rate of input commodities (like energy) yields significant economic and sustainability benefits, evidence shows that the holdup problem leads to inefficient levels of investment in TI: The suppliers refrain from investing in TI because they fear that a buyer with greater bargaining power will use cost reductions to push prices down in the bargaining process and further reduce the supplier's profit margin. We study and rank various contracting arrangements used in industry, including the price commitment and shared investment contracts to remedy these investment inefficiencies.

4 - Servitization as an alternative business model and its implications on product durability, profitability & environmental impact
Özgen Karaer, Mehmet Ali Kanatlı

Servitization is the activity of selling the services provided by the product rather than the product itself. It is a business model that might be environmentally superior to conventional selling. Servitization promises accessibility to the product's functionality, pooling of consumer use, and potentially products of better design. However, it can also inflate consumption and result in a bigger environmental impact overall. In this paper, we compare servitization with traditional selling for a monopolist durable goods manufacturer from both an economic and environmental perspective. In this comparison, we define the durability of a product as the use capacity; that is, how many usages it can endure before reaching end of life. We study the firm's durability decision, followed by the price/fee decision, and the consequent usage in the market under each model. We find that servitization produces durability levels that are robust to customer heterogeneity, and higher than selling. Overall, environmental superiority of servitization hinges on product related costs, customer heterogeneity, and market composition. It is, however, robust to varying environmental factors in the use and manufacturing phases. When we compare environmental preferability with the economic incentives of the firm, we observe that they are not always aligned.

■ MD-33

Monday, 14:30-16:00 - F102

Game Theory and Operations Management 2

Stream: Game Theory and Operations Management
Invited session
Chair: Maria Gloria Fiestras-Janeiro

1 - Rejection-proof Kidney Exchange Mechanisms
Bart Smeulders, Danny Blom

In this talk, we discuss mechanisms for collaboration between kidney exchanges. We consider a situation where agents truthfully reveal their patient-donor pool, but retain the option of rejecting proposed solutions. They may reject any exchange involving their patients and donors, and can use these to construct new internal exchanges, only involving their own pool. Such rejection and re-optimization decreases the total number of transplants, and thus should be avoided. We propose two mechanisms which compute kidney exchange solutions with the property of rejection-proofness, i.e., no agent has incentive to reject any exchange in the solution. The main mechanism does so optimally, but computing the best solution satisfying rejection-proofness is computationally challenging, the problem is Sigma-2-p-hard. We discuss algorithmic work showing it is feasible in practice. A second mechanism is also proposed, which is computationally simpler, but comes at a cost in terms of the number of transplants. We show experimentally that rejection-proofness can be achieved at a limited cost in terms of the number of transplants. Finally, rejection-proof mechanisms also make withholding information much less useful, even though these mechanisms are not strategy-proof.

2 - Evaluating the influence of certain attributes on a classification problem: an application to COVID-19 patients
Laura Davila Pena, Ignacio García-Jurado, Balbina Casas-Méndez

In this work, machine learning techniques are used to address a subject of great relevance in classification problems: the evaluation of the influence of each of the attributes on the classification of individuals. In particular, a measure of such influence is introduced using the Shapley value, and an axiomatic characterization is provided based on the properties of efficiency and balanced contributions. Furthermore, some experiments have been designed to validate the appropriate performance of such a measure. Finally, the introduced methodology is applied to a sample of patients infected with COVID-19 to study the influence of certain demographic or risk factors on various events of interest related to the evolution of the disease, such as hospitalization, admission to the ICU, or eventual decease.

3 - A game-theoretic model for effort competition in online food delivery
Arvind Shroff, Bhavin Shah, Hasmukh Gajjar

The sustainability of the OFD depends upon the factors like food quality, hygiene level, payment facilities, proper packaging and other considerations to optimize the impact on the environment. These factors form the primary source of differentiation for the customers to compare and purchase the products posted on the online platforms. Indeed, the platform also indulges in introducing a cloud kitchen (CK) to create a secondary level of differentiation. The CK allows the platform to increase its sales by appealing to a more extensive array of consumers' preferences and improving the diversity in its offerings. Such tie-ups are institutionalized through revenue sharing contracts, wherein the platform charges commissions from restaurants opting to increase the reach of their offerings through the platform's subscribers' base. For instance, online platforms like Doordash, Meituan, Zomato and Swiggy charge approximately 15-23% of the average order value as commissions to form their core revenue stream. While the restaurant exerts only self-efforts, the platform, by its online environment, exercises its power to induce quality efforts on the CK and the restaurant, either directly or indirectly. These efforts can be characterized as the additional facilities, services, exposure and tools provided by the platform's environment, promoting the demand for online orders. We propose an analytical game-theoretic model to examine the effects of the efforts exerted by the players.

4 - Cooperation in Inventory Models with Exemptable Ordering Costs
Maria Gloria Fiestras-Janeiro, Ignacio García-Jurado, Ana Meca, Manuel Alfredo Mosquera-Rodríguez

In this paper we introduce and analyse several continuous review inventory models in which the buyer(s) are exempted from transportation costs if the price of their orders is greater than or equal to a certain quantity. We first consider a simple model with one agent and one item. Then we study a model with one agent and several items for which we obtain an optimal ordering policy and a procedure based on cooperative game theory to evaluate the impact of each item on the total cost. Finally, we deal with a multi-agent model for which we obtain an optimal ordering policy and a procedure based on cooperative game theory to allocate the total cost among the agents in a stable way.

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■ MD-34

Monday, 14:30-16:00 - T003

Strategic and Tactical Decision-Making in Smart Mobility and Logistics

Stream: Smart Mobility and Logistics
Invited session
Chair: Ilke Bakir

1 - Service Network Design for City Logistics
Albert Schrotenboer

City logistics in large cities is often organized around a network of small-sized city hubs, each only having a limited number of docks for loading and unloading vehicles. Because time, and thus customer service, is of the essence, it is crucial that the limited (un)loading capacity is considered jointly while planning the distribution of goods between the hubs. In this paper, we introduce a new and novel discrete-time network design problem for city logistics that jointly determines commodity flows from origin to destination within a network of city hubs and determines for each hub a schedule of loading and unloading operations. We formulate the problem on a so-called time-and-activity expanded network, where each node resembles a particular activity (e.g. loading) at a particular city hub at a particular time. Under mild assumptions, we show that only using a limited amount of vehicle and commodity paths through the network suffices to model each potential consolidation action. The resulting formulation can be solved remarkably effectively with standard commercial MIP solvers. Furthermore, we employ column generation and Benders decomposition strategies within a matheuristic to find solutions in a quick and reliable way. Computational results suggest that allowing for each potential consolidation action, compared to existing limited approaches, reduces cost by on average 7%.

2 - Strategic Global Supply Network Planning under Disruptions
Aybüke Ekşi, Zehra Melis Teksan

In global supply chain networks, disruption management is an essential part of strategic decision making due to the increasing number of world-wide disasters. Every component of the supply network, e.g., suppliers, production facilities, distribution centers and customers, are affected by the global disruptions in different ways such as failure or closure of the facilities, transportation disruptions, or high demand volatility. While reducing the damaging impacts of these disruptions, a typical goal of a supply chain network is to minimize the costs and to maximize the service level.

In the related literature, there are network models which consider only one type of disruptions which occurs only at one part of the network. For instance, transportation disruptions that can happen in between components of the network, suppliers' facility failures, or peak demand in emergency items for customers.

However, we see that a disruptive event has multiple causes of disruption in the supply chains. In this study, strategic disruption planning for a global supply chain network is considered, where the effects of multiple disruptions are analyzed.

We consider a finite planning horizon which is divided into discrete time periods where optimal purchasing, production, distribution, and demand satisfaction decisions are made. We model the problem as a MILP where we analyze the effects of different disruption scenarios on the optimal solutions.

3 - It's All in the Mix: Technology Choice between Driverless and Human-Driven Vehicles in Sharing Systems
Layla Martin, Stefan Minner, Marco Pavone, Maximilian Schiffer

Operators of vehicle sharing systems such as carsharing or ride-hailing might benefit from integrating autonomous vehicles into their fleet. Here, the impact of optimal fleet size and composition on an operator's profitability is not trivial due to the tradeoff between operational benefits and higher investment costs for driverless vehicles. We analyze a two-stage fleet sizing and composition problem. The strategic first-stage problem determines fleet size and composition decisions. The operational second stage is a rebalancing problem, formalized as a semi-Markov decision problem and approximated by a queueing network to devise a scalable linear programming solution approach resulting in a state-independent policy. We extend the queueing network with SMDPs per station to allow state-dependent rebalancing. A numerical study on artificial and real-world instances reveals a significant profit improvement potential of driverless and mixed fleets. Vehicle sharing systems can benefit from driverless vehicles, in real-world instances profit gains amount to up to 3.9%. Frequently, a mix of driverless and human-driven vehicles further improves profits. In mixed fleets, the number of human-driven vehicles exceeds that of driverless vehicles; on average 19.8% of all vehicles are driverless. Even if demand is only slightly imbalanced and contribution margins for both vehicle types are equal, operators can benefit from introducing driverless vehicles into their fleet.

4 - Smart Sampling for Traveler-Oriented Multi-Criteria Itineraries
Thomas Horstmannshoff, Jan Fabian Ehmke

Multimodal routing platforms are becoming increasingly popular as new obility services have increased the options to organize door-to-door travel. Travelers expect a diverse set of multimodal itineraries according to their individual preferences (e.g. travel time, price, and the number of transfers). A major challenge of recent multimodal multi-criteria routing algorithms is to determine all non-dominated itineraries in efficient runtime. Hence, we propose a smart solution space sampling framework to approximate a set of Pareto-optimal multimodal itineraries which scales well when multiple traveler preferences are considered simultaneously.

We examine the Pareto-optimal solutions and derive characteristics of potential interest for the traveler to make the search more transparent and explainable. Furthermore, we cluster the structure of Pareto-optimal sets in terms of their similarity and predict for new queries correspondingly similar structures based on available attributes. We analyze whether the consideration of these predicted structures about relationships between the respective preferences in the multi-criteria solution space can enhance the frameworks efficiency and contribute to the explainability of the solution set. The proposed framework is evaluated on real-world data of several mobility services analyzing long-distance trips between major cities in Germany.

■ MD-35

Monday, 14:30-16:00 - T004

Freight transportation and logistic I

Stream: Transportation
Invited session
Chair: Seyed Parsa Parvasi

1 - Weather-dependent vessel routing with speed optimization: A case from offshore logistics in the North Sea
Andreas Ormevik, Kjetil Fagerholt, Frank Meisel, Karl Petter Ulsrud, Anders Helgeland Vandvik

We consider a real planning problem arising in offshore supply logistics, when supplying oil and gas platforms with cargo from an onshore depot using specialized supply vessels. The objective is to minimize sailing costs by determining routes and schedules for the vessels departing the depot at a given day. Sailing costs mainly relates to fuel consumption, which vary greatly both with the selected sailing speed and the weather conditions at the given time. This results in a Time-Dependent Vessel Routing Problem with Speed Optimization (TDVRP-SO).

To solve the TDVRP-SO, a mixed integer programming (MIP) arc-flow model is defined over a time-space network. Furthermore, we propose an Adaptive Large Neighborhood Search (ALNS) heuristic, extended with a local search, to solve larger problem instances. A set partitioning model that recombines promising partial solutions from previous ALNS-iterations is also implemented.

Experiments conducted using realistically sized test instances illustrate the superiority of the ALNS heuristic and its extensions compared to the arc-flow model, which fails to solve the largest test instances within reasonable time. Furthermore, our results highlight the importance of considering the correct weather conditions when planning the vessel routes, as, otherwise, the true costs of conducting the planned voyages are substantially underestimated.

2 - An adaptive large neighborhood search for the multi-port continuous berth allocation problem with speed optimization
Bernardo Martin-Iradi, Dario Pacino, Stefan Ropke

More than 80% of the cargo is carried by sea, and the global demand is expected to continue increasing in the coming years. This is forcing shipping line carriers and terminal operators to explore new means of optimizing their operations. The berth planning of a terminal is categorized as one of the most critical sea-side operations due to the scarcity of berthing space, and it is modeled as the berth allocation problem (BAP). The aim of the BAP is to assign incoming ships to berthing positions on the terminal, and the continuous version of the problem assumes that ships can berth anywhere along the quay. We extend the continuous BAP to multiple ports, thereby exploiting the potential of a collaboration between carriers and terminal operators. We denominate this problem as the multiport continuous berth allocation problem (MCBAP) and formulate it as a mixed-integer problem. We present an adaptive large neighborhood search (ALNS) heuristic to solve the MCBAP and compare its performance to commercial solvers. ALNS achieves high-quality results within short computational times and presents greater scalability compared to commercial solvers, which makes the ALNS more attractive from an operational and planning perspective.

3 - Primal-Dual Value Function Approximation for Stochastic Dynamic Intermodal Transportation with Eco-labels
Arne Heinold, Frank Meisel, Marlin Wolf Ulmer

Eco-labels are a way to benchmark transportation shipments with respect to their environmental impact. In contrast to an eco-labeling of consumer products, emissions in transportation depend on several operational factors like the mode of transportation (e.g., train or truck) or a vehicle's current and potential future capacity utilization when new orders are added for consolidation. Thus, satisfying eco-labels and doing this cost-efficiently is a challenging task when dynamically routing orders in an intermodal network.

In this work, we model the problem as a multi-objective sequential decision process and propose a reinforcement learning method, value function approximation (VFA). For our problem, we face two additional challenges when applying a VFA, the multiple objectives and the "delayed" realization of eco-label satisfaction due to future consolidation. For the first, we propose different feature sets depending on the objective function's focus, costs, or eco-labels. For the latter, we propose enhancing the suboptimal decision making and observed pessimistic primal values within the VFA-trajectories with optimistic dual ex-post evaluation when all information of a trajectory is known. We show the advantages of both components in a comprehensive study for intermodal transport via train and trucks in the European TEN-T corridors.

4 - A New Mathematical Model for RoRo Ship Problem with Considering Draft Limits
Seyed Parsa Parvasi, Alastair Main, Dario Pacino

Nowadays, maritime transportation has been known as the backbone of global commerce, and it has benefitted from the contributions of many OR researchers. In recent years there has been an increasing focus on short-sea shipping, particularly on freight transported on Roll-On Roll-Off (RORO) vessels. One of these new research areas is stowage planning: cargo arrangement into the ship. Though RORO stowage resamples the well-researched container stowage planning problem, unique planning elements such as loading paths for wheeled cargo make this problem academically intriguing. Recent research has either focused on the planning challenges of multi-port planning or on tackling vessel stability constraints. This work integrates both these research paths by studying the RORO stowage planning problem with multiple ports, multiple decks, stability constraints, ballast tanks, and draft limitations. We propose a mathematical model that maximizes the profit of the voyage by reducing the cargo re-handling costs and maximizing shipped cargo. We also introduce the first set of public benchmark instances, including stability data for three different ship sizes (small, medium, and large). Preliminary results will be presented alongside the model and detailed benchmark information.

■ MD-36
Monday, 14:30-16:00 - U006

Emergency Response

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: *Derya Demirtas*

1 - The fine line between life and death: Strategic placement of Citizen Responder System defibrillators
Derya Demirtas, Robin Buter, Erwin W. Hans, Erik H.koffijberg@utwente.nl, Ruud Koster
Citizen Responder Systems aim to improve volunteer CPR and defibrillation of out-of-hospital cardiac arrests (OHCAs). Using mobile apps, nearby citizen volunteers are alerted and guided towards the location of the emergency. Some volunteers are also asked to retrieve a close by automated external defibrillator (AED). However, numerous AEDs are barely used due to poor location choices, while many areas may lack appropriate AED coverage. In this study, we develop a greedy randomized adaptive search procedure (GRASP) algorithm that dynamically creates candidate AED locations and chooses near-optimal locations for new AEDs. The strength of the algorithm is that large instances can easily be solved since locations are created dynamically, keeping the problem size manageable while being able to evaluate a very granular set of candidate AED locations. We apply this methodology to 29 municipalities in North Holland. The OHCA-to-existing AED ratio vary vastly among the municipalities, ranging between 1.2 and 50.0 (IQR 6.6 - 2.2). We show that the coverage of OHCAs can increase from 49% to 62% through optimizing the locations of existing AEDs. On a municipality level, relative improvements range from 1% to 122%. Adding 5, 10, 20 AEDs to each municipality, while keeping existing AEDs where they are, improved weighted average coverage to 56.6%, 60.4%, and 66.6%, respectively. An estimated total of 477 additional AEDs were required to match relocation performance in every municipality.

2 - Moving from theory to practice: Decision support for emergency medical services using hybrid simulation and analytics
Sven Watzinger, Stefan Nickel
Emergency Medical Services (EMS) provide first aid and, if necessary, transportation to a hospital for patients in the case of an out-of-hospital emergency. The performance of EMS systems therefore can have a direct impact on the health and well-being of patients. From a logistical perspective EMS are complex systems with stochastic influences and multiple interdependencies. As such, EMS present logistical challenges at the strategic, tactical and operational level that are well suited to be addressed by analytical models. To validate the model solutions and compare different approaches, simulation is an often-used tool. Due to the lack of available real-world data however, the models are often validated by a single case study from one specific EMS region. It is therefore unclear, whether differences in model performance can

be explained by the models themselves or are due to the characteristics of the specific EMS region. A current project, EVRALOG-BW, in our county of Baden-Wuerttemberg, Germany, provides us with access to real-world data from different EMS regions enabling us to compare models across EMS systems with different characteristics. We therefore investigated whether we can find indications, that the characteristics of EMS systems or model parameter choices have an impact on the comparative performance of analytical EMS models. In our talk we will present preliminary results of conducted studies and discuss further research directions.

3 - Assessment of exponential smoothing methods for spatio-temporal forecasting of EMS call volumes
Mostafa Rezaei, Armann Ingolfsson

Forecasting emergency medical service (EMS) call volumes is critical for resource allocation and planning. The development of many commercial and free software packages has made a variety of forecasting methods accessible. Practitioners, however, are left with little guidance on selecting the most appropriate method for their needs. Using 5 years of data from 3 cities in Alberta, we compute exponential smoothing forecasts for 8-hour periods for each ambulance station catchment area and with a forecast horizon of two weeks. The methods that we consider differ on two spectra: the number and type of time-series components and the way in which forecasts at a specific resolution are converted to forecasts at the resolution of interest. We find that it is important to include a weekly seasonal component when forecasting EMS demand. Multiplicative seasonality, however, shows no benefit over additive seasonality. Adding other time-series components (e.g., trend, ARMA errors, Box-Cox transformation) does not improve performance. Spatial resolutions of station catchment area and lower, and temporal resolution of 4-24 hours perform similarly. We adapt an existing hierarchical forecasting framework to a two-dimensional spatio-temporal hierarchy, but find that hierarchical reconciliation of forecasts does not improve performance at the forecast resolution of interest for tactical planning. We show that added complexity does not materially improve forecasting performance.

4 - A Multi-Modal Approach to Locating Defibrillator Drones
Melanie Reuter-Oppermann, Sara Ellenrieder

Drone technology has rapidly evolved over the last few years. Increased payload capabilities as well as high forward velocities of over 100 km/h often allow drones to deliver goods faster than traditional transport modalities such as vehicles. Therefore, drones offer a variety of benefits for delivering medical goods, especially for emergency medical services, which operate under intense time pressure. Out-of-Hospital Cardiac-Arrest (OHCA) is still one of the leading causes of death today and decreasing the response times to OHCAs by integrating drones into the existing emergency and pre-emergency logistics could significantly increase survival rates. In this talk, we present an approach to define optimal locations for drone base stations to deliver defibrillators to OHCA victims. We formulate a bi-criteria multi-modal and multi-period maximum coverage location model considering cost-efficiency, transport reliability and demand shifts as well as coverage. We solve several scenarios for the State of Hesse, Germany, and compare our results to a bi-criteria set covering problem, which ensures full coverage. Results show that 24 drones transferring between 33 stations that are primarily allocated to semi-urban areas, can increase the share of OHCA cases receiving a defibrillator in less than 5 minutes by 74.5% in a multi-model pre-EMS and EMS network.

■ MD-37

Monday, 14:30-16:00 - V001

Innovative Solutions for Last Mile Logistics

Stream: Vehicle Routing and Logistics
Invited session
Chair: *Stefan Ropke*

1 - Integrating Shift Planning and Pick-up and Delivery Problems under Limited Courier Availability
Pinar Ozyavas, Evrim Ursavas, Paul Buijs, Ruud Teunter

With the rise of e-commerce and the on-demand economy, increasing time pressure and the importance of customer satisfaction make it more important to plan and execute last-mile operations carefully. Additionally, working arrangements for couriers have become more flexible. While this increased flexibility is cost-effective from the perspective of the delivery companies, it complicates their planning processes because the couriers may have limited availability. To better manage couriers on a flexible basis, delivery companies offer multiple shifts so that the couriers can specify their availability per shift. Due to these developments, matching delivery requests with the couriers is becoming a challenging and an important logistics problem. In this study, we introduce a variant of pick-up and delivery problem with time windows with profits and shifts. The couriers are allocated to shifts based on their preferences and vehicle availability. To ensure on-time service and efficient use of capacity of the vehicles, the model also decides on the couriers' routes. The objective is to maximize the profit obtained from the customer requests served (on time) minus hiring costs of couriers. We provide a set partitioning formulation for our problem and solve it exactly by a branch-and-price algorithm. Finally, we provide computational results on practically relevant instances adapted from the literature.

2 - New Solution Approaches for a Last Mile Delivery Problem with Parcel Lockers
Roberto Zanotti, Valentina Bonomi, Renata Mansini

In recent months, e-commerce has experienced dramatic growth, mainly due to the COVID pandemic. As a consequence, traffic in city centers and main roads has increased. Among the solutions identified to reduce this negative impact, parcel lockers are receiving considerable attention. Instead of delivering parcels directly to a customer's home, a last-mile delivery company can leave them in secure parcel lockers where customers can pick them up later. This approach can be extremely beneficial for the company, given the expected reduction in traveled distances. However, an often-neglected impact is the environmental one. In this work, we focus on a location and routing problem that considers as objective function the minimization of the overall emissions due to both the delivery company and the customers that need to collect their parcels. A key aspect of the problem is the introduction of different customer profiles, that define the distance that a customer is willing to travel with or without using zero-emissions transportation means. We propose a mathematical formulation for the problem and a matheuristic algorithm based on the kernel search framework to solve it. The computational results, obtained on a comprehensive set of instances, provide interesting insights and emphasize how the role of customers is one of the main drivers for controlling the environmental impact.

3 - Modelling and optimization of crowd-shipping for last mile delivery
Walid Behiri, Sana Berraf, Nicola La Palombara, Pietro Folco

Nowadays, the freight transport in cities and particularly the delivery of parcels has a multidimensional negative impact (CO2 emissions, other pollutants, noise, traffic congestion...). In this work, we study an alternative way to deliver parcels based on the crowd-shipping which takes place in the last mile delivery. From an operational point of view, citizens who actively participate in this crowd-shipping service during their daily travels, pick up parcels from specific urban pick-up points and deliver them to the address of the referred customer, using the available space in their vehicles. The delivery take place between the origin and the final destination of the occasional drivers. It is important to note that the studied crowd-shipping service is designed to be combined with a normal shipping service, which is a fundamental variable for fulfilling delivery agreements with the customer. In addition, the real time changes like occasional drivers who can no longer deliver parcel or who have refused the assigned one, the arrival of new parcel transport demands ... must be considered to ensure the overall efficiency of the proposed service. The described problem has been formulated into a Mixed Integer Program and a rolling horizon approach is developed to take into account periodically the disturbances.

The studied problem being NP-hard, an original heuristic is developed to obtain feasible solutions quickly, particularly for large instances.

4 - The Mobile Production Vehicle Routing Problem: Using 3D Printing in Last Mile Distribution
Stefan Ropke, Simon Klint Bergh, Yu Wang, Min Wen

In this talk, we present a new variant of the vehicle routing problem where the production of goods takes place inside the delivery trucks while en route to customers. This is, for example, possible if the products to be delivered can be produced using 3D printers. Adding production capabilities to the trucks complicates solution methods since a production scheduling problem must be solved simultaneously with an ordinary vehicle routing problem. The main advantage of the production/delivery form is that it allows a very short lag between order time and product delivery.

We present an adaptive large neighborhood search algorithm for the problem and present results from static and dynamic cases. Results are compared to the case where the production takes place in a central warehouse and products are delivered using ordinary trucks.

■ MD-38

Monday, 14:30-16:00 - V002

Humanitarian Logistics: Scheduling, Location

Stream: Humanitarian and Healthcare applications (contributed)
Contributed session
Chair: Eren Özceylan

1 - Minimizing Emergency Assembly Points using Set Covering Analysis: A Case of Gaziantep University
Eren Özceylan

Emergency assembly points (EAPs) are safe areas where people can gather away from the dangerous area in order to prevent the panic that will take place until the temporary shelter centers are ready after disasters and emergencies. Determination of a suitable site for an EAP is crucial to decrease the negative impacts of disasters/emergency situations. The number and locations of EAPs must be at a required level to cover all potential victims. To solve this problem scientifically, the aforementioned conditions should be modeled as a set covering location (SCL) problem. In this paper, the EAPs in the Gaziantep University campus are discussed and evaluated. To do so, the 32 current points are considered as source nodes, and 65 buildings are considered as demand nodes. The number of EAPs is minimized under different travel distance limits to cover the population who are evacuated from buildings. An integer programming formulation is applied to evaluate the current EAPs and the suitability of existing point signs is discussed. As a result, the required number of EAPs is determined and minimized.

2 - A multi-period location-routing model for search and rescue teams in a disaster relief network
Kamran Sarmadi, Mehdi Amiri-Aref

Disasters including earthquakes, floods, and fires lead to serious casualties and immense economic damages. The severity of these losses is linked with the performance of search and rescue (SAR) teams. Once the location of the known or potential victims is identified, designing an efficient disaster relief network is inevitable. Such network provides solutions to the following challenges: the number and location of temporary base of operations (TBO) from which responding SAR teams are mobilised, the allocation of affected sites to the designated TBOs, the exact number of SAR teams, and the corresponding routing decisions to visit affected areas within the rescue operational periods. To tackle this problem, we propose a multi-period location-routing problem which is formulated as a mixed-integer programming model. In practice, one of the critical objectives in response to the affected sites is to rescue casualties within immediate operating periods, minimizing the number of fatalities. To address this important issue, we propose a loss function which guarantees that the number of un-served victims due to the lack teams and the assigned operating time, remains at minimal level. Additionally, the model ensures that any un-served victim in a period will be served in the very next period. The applicability of the proposed model is tested based on a hypothetical case with realistic data. Finally, useful managerial insights are presented through various computational analyses.

3 - On the analysis of an idealized model to manage gasoline supplies in a short-notice hurricane evacuation
Rajan Batta, Monir Sabbaghtorkan, Qing He

Gasoline shortages and long lines at the pump spread at stations is a well-known challenge during large-scale evacuations ahead of hurricanes. One of the reasons for this problem is that evacuees rush to fuel up in a panic. Therefore, they attempt to get as much gas as they can without considering their true need and without considering other evacuees. An idealized management of gasoline supply is one in which each evacuee that needs gasoline to successfully evacuate is assigned a specific gas station along an evacuation route where they would be permitted to fill gas. Each gas station is restricted to a specific amount of gasoline per vehicle. This paper develops a mathematical formulation for such an idealized framework. The objective of the formulation is to maximize the number of evacuees that successfully reach the safe zone. The model takes into account different initial fuel level of evacuees, different evacuation starting times, and dynamic flow demand volume for each path over time. The superiority of the idealized evacuation over a simulated uncontrolled evacuation, in different scenarios, is verified on a small example. The idealized evacuation model is also applied to a real-world hurricane evacuation scenario in the evacuation network of St. Johns County, Florida. The results show that the idealized evacuation model manages a high percentage of evacuees to successfully reach the safe zones, even with a short amount of gasoline supplies available.

■ MD-39

Monday, 14:30-16:00 - U8

MAI: New models and user interfaces, using SPINE

Stream: Making an Impact
Invited session
Chair: Juha Kiviluoma

1 - Rapid development of new models: an introduction to SPINE
Juha Kiviluoma, Toni Lastusilta, Manuel Marin

When building new models, a lot of time can be spent on developing user interfaces and on the management of data. EU project Spine has developed a set of open-source tools that provides the required interfaces so that the user can focus on building the actual model. This workshop will demonstrate how to use Spine tools for rapid development of new models, with an example from the energy systems. The session will start with Spine Toolbox, which is a software to manage data, scenarios and workflows for modelling and simulation. After that, SpineInterface.jl is used to access data directly from a Spine Toolbox database in order to build the example model in the Julia JuMP environment. For more information see .

Monday, 16:30-17:30

■ ME-01

Monday, 16:30-17:30 - A

Marja-Liisa Siikonen

Stream: Plenaries
Plenary session
Chair: *Antti Punkka*

1 - Future trends in vertical transportation
Marja-Liisa Siikonen

In the middle of the 19th century, the invention of a safety device that prevented elevators from falling enabled the construction of tall buildings and skyscrapers. At first, the elevators were made of electro-mechanical components. A challenge in tall buildings was that the elevator groups could occupy nearly 50 % of the rentable area of a building. In the 1970-80s, software-based control systems invaded elevator technology. Passenger service level was improved by applying mathematical methods such as Artificial Intelligence. In the 1990s as the old relay boards of the skyscrapers in New York were modernized by the software-based group controls, passenger waiting times dropped to less than a half. In the 21st century, the need to decrease elevator core space has further grown since a significant number of buildings already exceed 300 -800 meters. At the elevator planning stage, elevator core space can be decreased by zoning and by arranging sky lobbies in the higher part of the building. With the destination control systems, passenger journey times could be decreased. The latest trends include systems with several elevator cars running in the same shaft. Covid-19 sets its requirements for smaller cars. This article considers elevator planning with core space minimization and still meeting the required passenger service level. In the comparison of different solutions and technologies, people flow in a building is simulated with the KONE Building Traffic Simulator.

Monday, 17:30-19:00

■ MF-01

Monday, 17:30-19:00 - A

Roundtable with Forums

Stream: EURO Forums Plenary Session
Panel session
Chair: *Julia Bennell*

1 - Roundtable with Forums
Julia Bennell

This is a roundtable event of the three EURO forums: EUROYoung, the Practitioners' Forum and WISDOM. The roundtable aims to explore the opportunities and challenges of conducting OR research, focusing in particular on research funding. The panellists span academics, practionners, and policy makers. The speakers and moderator are:

Speaker: Prof Giovanni Felici, Director of the Institute for Computer and System Science of the Italian National Research Council.

Born in Rome in 1967, Giovanni Felici graduates in Statistics at University of Rome La Sapienza in 1989 and is awarded the title of Master of Science in Operations Research and Operations Management by the University of Lancaster, UK, in 1991. In 1995 he successfully defends his Ph.D. dissertation in Operations Research at the University of Rome La Sapienza. Since 1994 his research activity is based at the Italian National Research Council of Italy (CNR), where he covers different tenured positions in the Istituto di Analisi dei Sistemi ed Informatica "A. Ruberti" (CNR - IASI). He is appointed, in May 2022, Director of CNR - IASI. From November 2016 to April 2022, he is seconded from CNR to the European Research Council Executive Agency (ERCEA) in Bruxelles, where he acts as Scientific Project Adviser for Panel PE1 (Mathematics) and PE6 (Computer Science and Informatics). Since October 2020 he is in the working group of DG - RTD - Directorate - General for Research and Innovation of the European Commission - for the definition of skills of researchers within the Agenda for the new European Research Area and Pact for Skills. He is specialized in Operations Research, Mathematical Programming, Machine Learning, and Bioinformatics. He is active in basic and applied research on models and algorithms, optimization techniques, and knowledge transfer to private businesses. He is author of more than 120 papers on primary international scientific journals, referred special issues, conference proceedings, book chapters.

Speaker: Dr Juan Miguel Morales Gonzalez, Universidad de Málaga.

Juan M. Morales is currently the head of the research group OASYS (Optimization and Analytics for Sustainable Energy Systems, oasys.uma.es) at the University of Málaga in Spain, where he also holds a tenured associate professorship position in the Department of Applied Mathematics. Juan M. Morales received his M.Sc. degree in Industrial Engineering from the University of Málaga and his Ph.D. in Electrical Engineering from the University of Castilla - La Mancha, Spain, in 2006 and 2010, respectively. In 2011, he was awarded a Hans Christian Ørsted research fellowship by the Technical University of Denmark, where he was also an associate professor in Stochastic Optimization in Energy Systems within the Department of Applied Mathematics and Computer Science, until 2016. Juan M. Morales's expertise lies in the fields of Data Analytics and Optimization, with particular focus on their applications to Energy Engineering and Economics, to which he has contributed a number of technical publications, including two monographs on the challenges of a fossil-free energy sector. He is a recipient of a Starting Grant awarded by the European Research Council for his project "Advanced Analytics to Empower the Small Flexible Consumers of Electricity," a Senior Member of IEEE, and a current member of the editorial boards of IEEE Transactions on Power Systems and the Springer journal TOP (the official journal of the Spanish Society of Statistics and Operations Research). More information about Juan M. Morales' work can be found on his personal webpage https://sites.google.com/site/jnmmgo/.

Speaker: Dr Anne Pépin, Senior Policy Officer, Gender Sector, Unit Democracy and European values, DG Research and Innovation, European Commission.

Anne Pépin is currently senior policy officer in the Gender Sector of the European Commission's Directorate General for Research and Innovation (DG RTD), in charge of developing gender equality policies in European research and innovation. Previously, from 2012 to 2017, she was heading the 'Mission pour la place des femmes au CNRS', the strategic unit in charge of gender equality policy at the French National Centre for Scientific Research. Among other responsibilities, she coordinated EU-funded projects INTEGER (2011-2015, on implementing gender equality plans) and GENDER-NET (2013-2016, a trans-national network on gender equality in the European Research Area). Anne Pépin holds a BSc in physics from the Université de Montréal (Canada), an Engineering Degree from the École supérieure d'électricité (France) and a PhD in electronics from the Université Pierre-et-Marie-Curie (Paris, France). She was recruited by CNRS in 1996, and was awarded the CNRS Bronze Medal for young researchers in 2003 for her contribution to nanotechnology. Since June 2017, she has been on leave from her permanent CNRS research director position to join DG RTD.

Speaker: Ms Nidhi Sawhney, Principal Data Scientist with the Global Center of Excellence for Platform & Technology at SAP.

Nidhi Sawhney has more than twenty years of experience in computational science, software development, and modelling, developing and helping customers develop scalable software solutions which require Machine Learning & Optimization techniques. She has a Bachelors in Mathematics from Delhi University, MSc. In Applied Statistics & Informatics from Indian Institute of Technology, Mumbai, and went to complete her Masters in Operations Research & Industrial Engineering from Cornell University in 2000. Since then, she has been an active OR practitioner starting as Optimization Specialist at Carmen Systems in Sweden where she worked on Planning and Day of Operations topics for Airlines, followed by her work in building Revenue Management System for Car rental companies and subsequently joined SAP in 2010. Her expertise lies in building highly scalable productive decision support systems for industry which require mathematical and computational expertise. Through her work at SAP she has been working towards designing algorithms which leverage the optimal capabilities of the underlying technology stack like in-memory databases and native parallelization to ensure efficient end to end processes.

Moderator: Professor Julia Bennell, Vice President 2 of EURO, Leeds University.

Professor Julia Bennell is the Executive Dean of Leeds University Business School. She graduated in 1994 with a first class honours in mathematics and management science and received her PhD in management science in 1998 from the University of Swansea. She was promoted to Professor of Management Science at the University of Southampton Business School in 2010. At Southampton, she was the director of CORMSIS (Centre of Operational Research, Management Science and Information Systems), one of the top three OR/MS research groups in the UK from 2011 to 2014, Head of the Department of Decision Analytics and Risk Research from 2012 -2015 and Deputy Head of School from 2015 - 2018. In addition to her university roles including undertaking research and delivering teaching, she is a qualified executive coach and mentor.

Tuesday, 8:30-10:00

■ TA-01

Tuesday, 8:30-10:00 - A

Antonio Conejo

Stream: Keynotes
Keynote session
Chair: Antonio Alonso-Ayuso

1 - Solving Certain Types of Large-Scale Scheduling Problems via Hybrid Decomposition
Antonio Conejo

We discuss an efficient solution method for the stochastic unit commitment problem, an important large-scale scheduling problem. Using a Benders framework, the solution method decomposes the problem into a mixed-integer linear master problem, and linear and continuous subproblems. The master problem corresponds to the first-stage decisions and includes all the scheduling variables and their corresponding constraints. The subproblems correspond to the actual operation of the production units. Based on the success of column-and-constraint generation algorithms to solve robust optimization problems, we improve the generally ineffective communication between the master problem and the subproblems in the standard Benders algorithm by adding primal variables and constraints from the subproblems to the master problem, which provides a better approximation of the recourse function. Our computational experiments demonstrate the effectiveness of this hybrid decomposition method.

■ TA-03

Tuesday, 8:30-10:00 - C

Counterfactual Explanations and Adversarial Learning

Stream: Machine Learning and Mathematical Optimization
Invited session
Chair: Jasone Ramírez-Ayerbe

1 - Poisoning Hidden-Markov-Model Inferences on Batch Data
Jose Manuel Camacho Rodriguez, William Caballero, Tahir Ekin, Roi Naveiro

Time-series models typically assume unadulterated and legitimate streams of data. However, an adversary may benefit from poisoning these data streams in accordance with their own self interest. By doing so, a decision maker's inference can be affected per the attacker's desires. This research focuses on Hidden Markov Models, an understudied technique in the Adversarial Machine Learning literature. Specifically, we provision a suite of poisoning problems for filtering, smoothing, and decoding inferences leveraging an Adversarial Risk Analysis approach. A collection of general solution methods is developed, and the efficacy of each method is illustrated via extensive, empirical testing. This research highlights the weaknesses of Hidden Markov Models under adversarial activity, thereby motivating the need for robustification techniques to ensure their security.

2 - Scalable methods for solving games in Adversarial Machine Learning
Roi Naveiro

Game Theory is gaining importance in the last years due to the rise of Adversarial Machine Learning (AML). Within this context, a new paradigm must be faced: in classical game theory, intervening agents were humans whose decisions are generally discrete and low dimensional. In AML, decisions are made by algorithms and are usually continuous and high dimensional, e.g. choosing the weights of a neural network. Closed form solutions for games generally do not exist in this new setting. Thus it is mandatory to have efficient algorithms to search for numerical solutions. In this work, we propose two different procedures for solving sequential games using gradient methods. We study time and space scalability of both approaches and discuss in which situation it is more appropriate to use each of them. Finally, we illustrate their use through an adversarial prediction problem.

3 - Model Extraction based on Counterfactual Explanations
Veronica Piccialli, Cecilia Salvatore

Automated decision-making classification systems based on Machine Learning algorithms are often used in many real-life scenarios such as healthcare, credit, or criminal justice. There is thus increasing interest in making Machine Learning systems trustworthy: interpretability, robustness, and fairness are often essential requirements for the deployment of these systems. In particular, according to the European Union's General Data Protection Regulation (GDPR), automated decision-making systems should guarantee the "right to explanations", meaning that those affected by the decision may require an explanation. Counterfactual Explanations are becoming a de-facto standard for a post-hoc explanation. Given an instance of a classification problem, belonging to a class, its counterfactual explanation corresponds to small perturbations of that instance that allow changing the classification outcome. The objective of this work is to try and exploit the information revealed by a small set of examples with their counterfactual explanations to build a surrogate model of the classification system. The idea is to define an optimization problem that provides in output a Forest of Optimal Trees as close as possible to the original classification model, given the information derived from the counterfactual points. This tool can be used either to attack the original model or to improve it, depending on the application context. Preliminary results show the viability of this approach.

4 - Counterfactual Explanations via Mathematical Optimization with applications to functional data
Jasone Ramírez-Ayerbe, Emilio Carrizosa, Dolores Romero Morales

Due to the increasing use of complex machine learning models in high stakes decisions, it has become more and more important to be able to understand their behaviour. An effective class of post-hoc explanations are counterfactual explanations, minimal perturbations of the predictor variables to change the prediction for a specific instance. In this talk, we propose a novel Mathematical Optimization formulation for constructing counterfactual explanations. Although our methodology is applicable to any score-based classifier, we will focus on additive tree models. Most of the research on counterfactual explainability focuses on tabular and image data and much less on models dealing with functional data. Our approach can generate sparse and plausible counterfactual explanations when dealing with functional data and can identify the samples of the dataset from which the counterfactual explanation is made of. We illustrate our methodology using two different real-world datasets, one univariate and another multivariate.

■ TA-04

Tuesday, 8:30-10:00 - D

Machine learning for optimizing business decision-making IV

Stream: Machine Learning and Mathematical Optimization
Invited session
Chair: Wouter Verbeke

Chair: *Kristof Coussement*

1 - Failure prediction vs. maintenance prescription: optimizing maintenance interventions by learning individual treatment effects
Toon Vanderschueren, Robert Boute, Tim Verdonck, Bart Baesens, Wouter Verbeke

Machine maintenance is a challenging operational problem, where the goal is to apply sufficient, timely maintenance jobs to avoid machine downtime while maximizing its useful life. Data-driven methods can be used to optimize maintenance by considering the machine's characteristics. Several recent works aim to solve this in the framework of predictive maintenance, where maintenance is planned when the machine's predicted failure probability exceeds a certain threshold. This predictive approach, however, does not consider the effect of a maintenance intervention when planning maintenance. This work proposes a different, prescriptive approach that optimizes maintenance based on the estimated reduction in failure probability resulting from a maintenance intervention. The estimated maintenance effects allow the prescription of the optimal sequence of maintenance interventions and their type during a machine's lifetime. This way, the costs of preventive maintenance and unplanned downtime can be minimized. We empirically validate our proposed, prescriptive approach and compare it to a predictive approach using a real-life data set containing detailed information on more than 4,000 maintenance contracts of industrial equipment provided by an industrial partner.

2 - Uplift Modeling with High Class-Imbalance
Otto Nyberg

Uplift modeling is the art of modeling the causal effect of some treatment on an individual level. It has been used e.g. in social sciences to identify students that will benefit from some intervention to prevent dropping out in the future, and in marketing to separate individuals that will be positively and negatively affected by some marketing activity to optimize campaign performance. Many marketing tasks online, such as targeting ads and discounts, would be optimally targeted with uplift modeling. These problems generally suffer from high class-imbalance where a very small fraction, often below 2%, of the observations are positive. While there are lots of approaches for uplift modeling, all of these break down for problems with high class imbalance. This is a thoroughly studied problem in classification but the methods developed for classification cannot directly be applied to uplift modeling without specifically accounting for the requirements posed by uplift modeling. In this work, we introduce novel undersampling strategies and the underlying assumptions as well as some novel uplift calibration methods that correct for the bias introduced by the undersmapling strategies. In addition, we also present some empiric evidence to illustrate the performance of the novel methods as well as the shortcomings.

3 - How counterfactual explanations can be used to detect bias in a machine learning model
Sofie Goethals, David Martens

Machine learning is used more and more for decisions in high stakes domains of our life such as employment, finance or justice. This can be a threat to fairness as machine learning models can amplify bias present in the dataset and there is no consensus on a metric to detect this. The literature already confirmed the need for an increase in transparency in the fairness domain. We will provide this by using counterfactual explanations, a well-known technique in the Explainable AI (XAI) domain, that are defined as the smallest change to the instance so that it ends up with a different classification outcome. We show that they can be used to detect both explicit bias, when the model is directly using the sensitive attribute, and implicit bias, when the model does not use the sensitive attribute directly but other correlated attributes lead to a substantial disadvantage for the protected group. We call this metric PreCoF, or Predictive Counterfactual Fairness. Our results show that PreCoF succeeds in detecting patterns in the dataset by assessing which attributes are more present in the explanations of the protected group, compared to the unprotected group. These results have important implications as insights into the nature of the bias can help policymakers decide how they should tackle it.

4 - Gaining insights into major public concerns during a crisis based on Twitter data
Lisa Schetgen, Matthias Bogaert

This study investigates whether Twitter data can be used to identify and gain insights into the most important public concerns in times of crisis or disasters. Specifically, we focus on the COVID-19 pandemic as a valuable case study. We add to existing literature by proposing a two-step approach that combines supervised and unsupervised learning techniques. First, tweets consisting of concerns are identified by classification algorithms. Second, the main concerns are determined by inspecting the clusters of tweets resulting from the application of topic modeling techniques. The presented framework can be used by governments and public health organizations to gain insight into the concerns that are present among the population and, hence, enables appropriate and real-time response.

■ TA-05

Tuesday, 8:30-10:00 - E

Data Science and Optimization

Stream: Data Science Meets Optimization
Invited session
Chair: *Ender Özcan*
Chair: *Andrew J. Parkes*

1 - New hard 0-1 knapsack problem instances
Jorik Jooken, Pieter Leyman, Patrick De Causmaecker

In this abstract, we will discuss one of our recent publications in European Journal of Operational Research in which we propose a new class of hard problem instances for the 0-1 knapsack problem. This is a fundamental NP-hard optimization problem and has received a lot of attention for several decades, which resulted in extremely powerful algorithms that are able to solve most (large) problem instances from the literature to optimality in several seconds. This is remarkable, because the 0-1 knapsack problem is NP-hard and this motivated researchers to investigate where the hard problem instances are located.

In our current work, we propose noisy multi-group exponential problem instances. We give theoretical arguments that help us understand why these problem instances are hard and also show this empirically. A large-scale experiment (using approximately 810 CPU-hours) reveals that our problem instances take several orders of magnitude longer to solve than the previously hardest problem instances, despite being much smaller. We visually show the location of our problem instances in the problem instance space by projecting them to a two-dimensional space using the Instance Space Analysis methodology. This visualisation shows that our problem instances fill an important previously unfilled gap of the problem instance space where the hard problem instances are located.

Full article available at: https://doi.org/10.1016/j.ejor.2021.12.009

2 - Multiplicity in Signed Graph Partitioning
Rosa Figueiredo, Nejat Arinik, Vincent Labatut

In order to study real-world systems many works model them through signed graphs, i.e. graphs whose edges are labeled as either positive or negative. Such a graph is considered as structurally balanced when it can be partitioned into a number of modules, such that positive (negative) edges are located inside (in-between) the modules. When it is not the case, authors look for the closest partition to such balance, a problem called Correlation Clustering (CC). The standard approach used in the literature is to find a single partition and focus the rest of the analysis on it, as if it was sufficient to fully characterize the studied system. Yet, it may not reflect the structure of the network, and one may need to seek for other partitions to build a better picture.

We study the space of optimal solutions of the CC. We propose an efficient enumeration method allowing to retrieve the complete space of optimal solutions of the CC. It combines an exhaustive enumeration strategy with neighborhoods of varying sizes, to achieve computational effectiveness. By applying our method, we show empirically that under certain conditions, there can be many optimal partitions of a signed graph. Some of these are very different and thus provide distinct perspectives on the system, as illustrated on a small real-world network. This is an important result, as it implies that one may have to find several, if not all, optimal solutions of the CC, in order to properly study the considered system.

3 - Automated Algorithm Configuration for the Quadratic Unconstrained Binary Optimisation Problem
Daniel Karapetyan, Jack Warren, Ender Özcan, Andrew J. Parkes

Quadratic Unconstrained Binary Optimisation (QUBO) is a mathematical model that can conveniently represent many combinatorial optimisation problems such as number partitioning, max-cut problem, graph colouring, etc. It is of specific interest as it is the representation used within the "D-Wave Quantum System" for solving optimisation problems. Here, we use the Conditional Markov Chain Search (CMCS) metaheuristic framework to automatically build a metaheuristic combining several low-level heuristics (mutations and local search operators). CMCS is a highly-configurable framework that is flexible enough to model a range of standard and new metaheuristics, yet its behaviour is completely controlled by numerical parameters. We designed an algorithm configuration method to optimise the CMCS configuration. It is a hybrid metaheuristic built specifically for CMCS configuration. The CMCS configuration obtained by our algorithm configuration method performs well across benchmarks and achieves state-of-the-art results on the widely used random benchmark instances.

4 - Bi-objective Search for Acoustic Topology Optimisation and Noise Reduction
Andrew J. Parkes, Vivek T. Ramamoorthy, Ender Özcan

Structural/topology optimisation in acoustics is concerned with optimising the shapes and materials for noise reduction. The aim is to maximise the noise absorption whilst minimising the weight. For example, in designing a car we want a quiet interior but still maximise fuel economy. There is a trade-off between the two, and so an associated bi-objective optimisation problem. Furthermore, the problem is expensive optimisation as evaluating the sound absorption from a potential material design requires an finite-element computation, and averaging over a wide selection of frequencies. Often the maximisation of sound absorption has been done using the "solid-isotropic-material-with-penalisation" (SIMP) method. This is a gradient-based constructive method and was developed for the single objective of increasing sound absorption keeping a constraint on the weight. We have developed a modified SIMP method to create an initial set of solutions to populate an initial Pareto Front (PF). We hybridise this with a secondary black-box hill-climbing, HC, method to improve the PF. The secondary HC method is a single-objective optimisation and so an issue is what single objective function to use. We do this by adapting it to the initial PF, hence guiding in directions likely to improve the PF. The novelty is the hybridisation of constructive gradient based methods and single-point blackbox search. We will discuss the potential for data science methods to enhance this hybrid search.

■ TA-06

Tuesday, 8:30-10:00 - U1

Combinatorial Optimization for Social Good I

Stream: Combinatorial Optimization
Invited session
Chair: Helena Ramalhinho Lourenco

1 - Efficiency effects of public hospital closures under the effect of reorganization of public hospital services: a multistep efficiency analysis
Songul Cinaroglu, Jonas Schreyögg

The efficiency effects of public hospital closures needs to be clearly demonstrated under the redesign of health markets. This study aims to examine the efficiency of public hospital closures under the mediating effect of public hospital restructuring, which belongs to the Ministry of Health in Turkey. In this study, we seek to elucidate the relationship between public hospital closure and hospital efficiency by using administrative data from Public Hospital Statistical Yearbooks for the years between 2005-2007 and 2014-2017. Our analysis has three steps. First, we calculated the efficiency scores of hospitals nearby to closed hospitals using bootstrapped data envelopment analysis (DEA). Second, we used nearest neighbor matching to ensure that any difference could be attributable to having close proximity to closed hospitals and is not caused by the differences in the hospital and market area characteristics between the intervention and control groups. Third, we employed a difference-in-difference regression analysis to explore whether close proximity to closed hospitals has an impact on hospital efficiency. A multistep efficiency analysis was designed by incorporating DEA and propensity score matching techniques. DiD was used to explore the effect of public hospital union policy on public hospital efficiency results. Results show that hospital efficiency is high in public hospitals that have close proximity to closed hospitals under the public hospital union policy.

2 - A Biased Random-Key Genetic Algorithm to solve a multi-period home care routing and scheduling problem
Maria Isabel Gomes, Ana Raquel de Aguiar, Tania Ramos

Home social care assumes a crucial importance in supporting families when their elderlies are no longer autonomous, and informal caregivers have demanding working lives. Depending on their autonomy level, elders may request services to be fulfilled by one or two caregivers. In many organizations, social workers are responsible for designing the home visit plans for teams of one or two caregivers. They usually plan for an entire week at the end of the week before. Home care services are associated to highly dynamic environments in which home visits may be canceled or a caregiver may call in sick and be absent for extended periods of time. Therefore, decision support tools are needed to help social assistants in planning efficient weekly schedules in short amounts of time. In this work, we address a case-study of a partner provider, modeling the problem as a home healthcare routing and scheduling problem (HHCRSP). Regarding specific HHCRSP features, the model considers hard time-windows (TWs), caregiver synchronization at patients' homes, dynamic TWs, a variable number of each type of teams, and single and multi-period continuity of care. Due to the high computational complexity of the problem, we propose a Biased-Random-Key Genetic Algorithm for routes design in a multi-period planning horizon.

3 - Optimizing the composition of baskets in a social food pantry
Laia Ferrer-Martí, Marc Juanpera, Rafael Pastor, Bruno Rodés, Albert Soler-Noguera

Social food pantries are entities that distribute food products to beneficiaries (individuals and families) who suffer from food insecurity. It is often complex to ensure that the food baskets distributed are balanced in terms of the nutritional needs of each person. The aim of this work is to develop a mathematical model to optimize the composition of the baskets that are delivered to the beneficiaries of a social food pantry, considering the nutritional needs of beneficiaries according to their age (babies, children, adults, elderly), the stock of products available, the products' expiration date and other management criteria. Solutions are also constrained by the economic budget available and potential dietary restrictions due to allergies, cultural reasons or personal choices. The model is applied to the real case of El Rebost, a network of social food distribution entities with over 2000 beneficiaries in Terrassa (Barcelona-Spain).

4 - **Optimization for Social Good**
Helena Ramalhinho Lourenco

Analytics focuses on transforming data into insights by applying advanced analytical method, based on mathematics, statistics, operations research and artificial intelligent models and algorithms, with the objective to improve the performance of an organization. One of the main tools in Analytics is Optimization. In this talk, we present the optimization tools and methodologies applied to NonProfit Organizations (NPO). We will describe applications of Mathematical Programming Models and Metaheuristics Algorithms to Social Care, Healthcare, Humanitarian Logistics and Environmental organizations. Examples of applications of Optimization in these organizations are: home health care logistics and scheduling; location of the primary health care centers or schools; planning the humanitarian aid distribution; planning a sustainable transportation, etc. We will discuss also the main aspects of these models and algorithms, and the main differences to other more frequent applications, as in manufacturing and retailing industries.

■ TA-07

Tuesday, 8:30-10:00 - U3

Enterprise Risk management

Stream: Financial Risk Measurement and Management
Invited session
Chair: Rita D'Ecclesia

1 - **SMEs' leadership, managerial and financial performance: A mediated moderation model from product life cycle perspective**
Eduard Gabriel Ceptureanu, Sebastian Ion Ceptureanu

In recent decades, researchers have begun to investigate the influence of leadership on managerial and financial performance. Previous studies have neglected to explore the connections between leadership, managerial and financial performance from a product life cycle perspective. To investigate these connections, we conducted a survey on a sample of 264 small and medium enterprises (SMEs) in Romania. We concluded that there is a positive relationship between the product life cycle and the effects of leadership on managerial performance; and ultimately, financial performance improves.

2 - **Generalized Optimal Transport Problems in Finance and Economics**
David Saunders

Optimal transport problems have seen many applications to problems in finance and economics. In this work, we consider generalization of optimal transport problems, both in the case where the objective function is not an expectation, but is instead a spectral risk measure, as well as when the role of marginal distributions is replaced by Choquet capacities. Results on duality and stability, as well as applications to problems in finance and economics will be discussed.

3 - **Escaping paradise? governance indicators and international entrepreneurship of island based firms**
Guido Rojer, Anoop Rai, Rebeca de Juan Diaz, Karen Watkins

International Entrepreneurship (IE) can be driven by multiple factors, among which institutional environment in the home country plays a major role. Often overlooked are small island-based firms (IBFs), whose institutions bequeathed from former colonizers are constrained by a small domestic market. This study examines 163 firms located in eight islands, Barbados, Cyprus, Iceland, Fiji, Jamaica, Malta, Mauritius, and Trinidad/Tobago over the 2009-2018 period, to determine whether strong governance and institutions facilitate IE. Using the World Bank Governance Indicators, this study provides evidence that institutions can both foster and hinder IE. Specifically, strong voice and accountability, political stability, government efficiency, and control of corruption, foster IE. The negative impacts of weak regulatory quality and rule of law in discouraging IE cannot be mitigated by other governance indicators.

4 - **Machine Learning in Due Diligence evaluation to increase NPLs profitability transactions on secondary market**
Maria Carannante, Valeria D Amato

In this paper, we contribute to the topic of the NPLs business profitability on the secondary market by developing a due diligence artificial intelligence-based. In particular, due to the ability to model complex relationships between predictors and the outcome variable, we set up a random forest regressor algorithm for projecting the recovery rate of a portfolio of the secured NPLs. Indeed the profitability of the transactions under consideration depends on forecast models of the amount of net repayments expected from receivables and related collection times.

■ TA-08

Tuesday, 8:30-10:00 - U4

Novel Optimization Approaches in Two-Tier Logistics

Stream: Combinatorial Optimization
Invited session
Chair: Alena Otto
Chair: *Erwin Pesch*

1 - **Day-Ahead Planning in Heterogeneous Two-Tier City Logistics: An Iterative Filtering Algorithm**
Ramin Barzanji, Gerhard Hiermann, Pirmin Fontaine, Maximilian Schiffer

Nowadays, sustainable distribution structures are imperative to mitigate the negative externalities of city logistics, such as emissions and congestion. In this context, it remains an open question whether city freighters, e.g., cargo bikes or e-scooters, will contribute to more sustainable distribution, particularly in multi-echelon scenarios. To answer this question, we study a novel two-tier location-routing problem in which a logistics service provider (LSP) operates a two-tier city distribution system and can use two different types of vehicles. Besides conventional single-tier truck-based transportation, the LSP may use a two-tier delivery structure, where larger vehicles, e.g., trucks, transport parcels to micro-hubs and city freighters perform final delivery tours starting and ending at the micro-hubs. To solve the underlying day-ahead planning problem, we present a novel metaheuristic that combines iterative filtering techniques with variable neighborhood search and nested local search to find locally optimal solutions. We prove the efficiency of this algorithm by benchmarking it on the well-known capacitated location routing problem and show that our algorithm matches or improves the state-of-the-art for this problem class. We then focus on our two-tier problem setting and apply our algorithm to a case study for the city of Munich. Our results highlight the improvement potential of city freighters in two-tier city logistics networks.

2 - **Evaluating an integrated planning approach for a synchronized two-tier city logistics system**
Julia Lange, Teodor Gabriel Crainic, Timo Gschwind, Walter Rei

Due to limited transportation and storage resources in urban areas, future city logistics systems focus on multiple tiers of heterogeneous vehicles and freight handovers with minimal spatial requirements. Thus, exact synchronization of transportation services of different tiers is a main challenge. With regard to an efficient use of resources, the integration of inbound, outbound and inner-city commodity flows is of increasing importance together with the application of innovative digital transportation-as-a-service ideas. The presented mathematical formulation follows a two-tier service network design approach, where transportation services with routes, departure time windows and capacities are given. Heterogeneous waiting time policies at customer and handover locations constitute another key characteristic. The goal is to find a selection of operated services, an assignment of all transportation demands and a precise schedule for each service so that travel and waiting times are minimal. With a comprehensive computational study, the effects of different problem characteristics on its complicatedness and solvability by a general state-of-the-art mixed-integer-programming solver are examined and reported. Therein, an elaborate generation procedure and a wide set of new instances for two-tier city logistics service network design are proposed.

3 - Tactical Vehicle Fleet Planning for Parcel Delivery with Trucks and Aerial Drones
Alexander Rave, Pirmin Fontaine, Heinrich Kuhn

In the context of parcel delivery, aerial drones have great potential as they operate mostly faster than conventional delivery trucks particularly when certain obstacles, e.g., highways, rivers etc. must be overcome. However, drones have limited capacity, so combining them with trucks can take advantage of both types of vehicles. There are two delivery methods with trucks and drones: drones can either launch from trucks or drones and trucks serve customers independently of each other when drones launch from the central distribution center (CDC) or microdepots. The question arises which vehicle fleet and delivery method or mix of methods are cost-optimal for a logistics service provider within a tactical planning horizon. We develop a decision support model that decides on the best fleet mix with trucks and drones, and model the problem setting as mixed-integer linear program (MILP). We develop a specialized adaptive large neighborhood search to solve larger instances. We present a numerical setup for parcel delivery in rural areas where customers are residing in small villages. We can show that a fleet consisting of both trucks and aerial drones, if launched from trucks, microdepots, or the CDC, always leads to sufficient cost savings compared to a sole truck delivery taking both variable delivery and fixed investment costs into account. These cost savings can be increased by even another 5.5% on average, if the best delivery method or a mix of methods is chosen.

4 - A Very Large Scaled Neighborhood Search for the drone routing problem with mobile charging station
Alena Otto, Catherine Lorenz, Nicola Mimmo, Daniele Vigo

In the present work, we consider a drone routing problem with a ground vehicle that has the purely supportive role of a mobile charging station, enabling replenishment at specific rendezvous locations on a road network. The drone can visit as many destinations as its battery capacity allows before deviating from its main tour for those encounters. This setting has been only partially investigated in scientific literature so far, even though it is highly relevant for applications in hazardous environments or in areas with low infrastructure.

We first solve the problem to optimality with a two-phased dynamic programming approach. A novel local search heuristic is then developed, which efficiently reduces the two phases of the dynamic program to fit a very large scaled neighborhood structure which extends the Balas Simonetti neighborhood for the classical TSP. Extensive numerical tests conducted for different parameter settings and instance sizes demonstrate the effectiveness of our heuristic.

■ TA-09

Tuesday, 8:30-10:00 - U5

Advances in Discrete Robust Optimization

Stream: Mixed Integer Linear Programming
Invited session
Chair: Marc Goerigk

1 - Optimization problems in graphs with locational uncertainty
Michael Poss, Marin Bougeret, Jérémy Omer

Many discrete optimization problems amount to select a feasible subgraph of least weight. We consider in this paper the context of spatial graphs where the positions of the vertices are uncertain and belong to known uncertainty sets. The objective is to minimize the sum of the distances in the chosen subgraph for the worst positions of the vertices in their uncertainty sets. We first prove that these problems are NP-hard even when the feasible subgraphs consist either of all spanning trees or of all s−t paths. In view of this, we propose an exact solution algorithm combining integer programming formulations with a cutting plane algorithm, identifying the cases where the separation problem can be solved efficiently. We also propose two types of polynomial-time approximation algorithms. The first one relies on solving a nominal counterpart of the problem considering pairwise worst-case distances. We study in details the resulting approximation ratio, which depends on the structure of the metric space and of the feasible subgraphs. The second algorithm considers the special case of s−t paths and leads to a fully-polynomial time approximation scheme. Our algorithms are numerically illustrated on a subway network design problem and a facility location problem.

2 - Solving Multistage Robust Discrete Optimization Problems with Interdependent Domains
Michael Hartisch

In our multistage robust optimization setting, which we interpret as a game between a decision maker and an opponent, the variable domains of both players are allowed to be interdependent. For each player a separate linear constraint system is used to describe their allowed actions and the primary task for each player is to ensure that the respective constraint system is satisfied. In this very general framework, the decision maker even might be able to force a violation of the opponent's constraint system. Moreover, this setting allows robust discrete optimization problems with decision-dependent uncertainty sets, where such a violation is usually prohibited. We discuss how our general solver for multistage robust discrete linear optimization problems deals with decision-dependent uncertainty sets and the more general interdependent domains. We give an introduction into our modeling and solution framework, discuss problem formulations and showcase our solver.

3 - Improved Algorithms for Robust Combinatorial Optimization
Mohammad Khosravi, Marc Goerigk

Using observations of what constitutes hard problem instances for robust combinatorial optimization problems, we derive new solution algorithms. We focus on both heuristic and approximation algorithms, as well as new exact solution algorithms, taking into account a range of possibilities to approach problems from a new angle.

In the first case, we study robust optimization problems under discrete uncertainty sets. We use optimization-based data aggregation to construct a new uncertainty set that best represents the original set and also simplifies the problem. To this end, first we divide the uncertainty set into a desired number of clusters using various methods. Then, in each cluster we use different linear programming models to construct a single scenario as a representative of the given cluster.

In the second case, we consider a popular exact solution method in which constraints are generated iteratively. In this method, scenarios are added to a reduced master problem one by one until the optimal solution is found. Different techniques of stabilization are used to improve the method as well as to guarantee that the method leads to an optimal solution either using less iterations or shorter evaluation time.

■ TA-10

Tuesday, 8:30-10:00 - U6

Portfolios risk management I

Stream: Financial Risk Measurement and Management
Invited session
Chair: *Tomas Tichy*

1 - Portfolio Volatility Estimation Using Cross-sectional Intrinsic Entropy Model
Claudiu Vinte, Marcel Ausloos

Selecting stock portfolios and assessing their relative volatility risk compared to the market as a whole, market indices, or other portfolios is of great importance for professional fund managers and individual investors alike. Our research uses the cross-sectional intrinsic entropy (CSIE) model to estimate the cross-sectional volatility of stock groups considered together as portfolio constituents. The CSIE volatility estimate is based on daily traded prices, that is, open, high, low, and close prices (OHLC), along with the daily traded volume of symbols listed on the NYSE and NASDAQ stock exchanges. In our study, we benchmark portfolio volatility risks against the volatility of the entire market provided by the CSIE, and the volatility of market indices provided by the intrinsic entropy (IE) volatility estimate. Our study uses an approximate 6000-day reference point, starting January 1, 2001, until March 18, 2022, for both the NYSE and the NASDAQ. In the context of a structured multifactor portfolio risk model, we introduce CSIE-based betas to characterize portfolio relative volatility risk against the benchmarks provided by the beta of market indices. We algorithmically simulate a massive number of stock portfolios and use the novel perspective provided by the CSIE volatility estimate to hierarchically assess their relative volatility risk in the broader context of the entire stock market volatility.

2 - Reference dependence in behavioral portfolio selection
Martina Nardon, Diana Barro, Marco Corazza

In this contribution, we address the issue of reference dependence within a behavioral portfolio model defined under Cumulative Prospect Theory. In such a framework, an investor selects the portfolio weights in order to maximize her prospect value, where portfolio returns are measured as deviations from a certain reference point. The location of this reference point affects actual investment decisions. We consider alternative hypothesis and perform an application to the European equity market.

3 - Innovation ambidexterity effects on financial performance
Sebastian Ion Ceptureanu, Eduard Gabriel Ceptureanu

This study examines the impact of innovation ambidexterity on financial performance of companies. It provides empirical evidence indicating that industrial SMEs may improve their financial performance by enabling or improving their innovation capability by simultaneously developing exploratory and exploitative innovation capabilities.

4 - A relative robust approach on expected returns with bounded CVaR for portfolio selection
Stefano Benati, Eduardo Conde

A robust optimization model to find a stable investment portfolio is proposed under twofold uncertainty sources: the random nature of returns for a given economic scenario which is in itself unknown. Our model combines expected returns together with risk and regret measures in order to find a solution ensuring acceptable returns while the investor is protected from the market volatility. More formally, we formulate a model that minimizes the maximum regret on the expected returns while the conditional value-at-risk is upper bounded under different scenario settings. Several mathematical formulations are analyzed. Duality relations drive us to obtaining bounds on the optimal objective value of the problem in order to develop a cutting plane approach. We show experimentally that, despite the large number (hundreds of thousands) of constraints and variables of the resulting problem, an optimal portfolio can be found in a few seconds. . Finally, our model is tested in a financial decision making environment by simulating its application in different markets indexes and under different underlying economic conditions. It will be seen that using scenarios usually improves the realized portfolio returns

■ TA-11

Tuesday, 8:30-10:00 - U7

MCDA and Composite Indicators: Issues, advances and applications

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Menelaos Tasiou*

1 - Multidimensional Welfare comparisons: a multivariate dominance approach
Nikolaos Argyris, Lars Østerdal, M. Azhar Hussain
Recent times have seen an increased acceptance within Government circles that the measurement of social wellbeing must encompass more than material economic standards, and should include dimensions such as health, education, social relationships etc. At the heart of this problem is the question to compare population distributions over a multi-dimensional space. Here we introduce the theoretical framework for such multi-dimensional comparisons and apply this to a specific dataset. The basis of our framework is multivariate first- and second-order stochastic dominance. We introduce theoretical results that enable practical comparisons of multidimensional distributions using these concepts. Additionally, we consider how different type of "preference information" can be utilised to refine the determinable comparisons. We illustrate our approach with the results of an application to compare welfare across EU countries.

2 - Introduction of weights in poset-based composite indicators
Giulio Caperna
We propose an innovative way to introduce the information of weights in the construction of composite indicators using poset theory. The aggregation method and the indicators' weights are among the most crucial steps of constructing composite indicators. Most composite indicators are developed on a macro-level to compare large entities, such as countries. For this reason, the constituting variables are proportions or averages, and usually, quantitative. Consequently, the standard aggregation procedures are the arithmetic and geometric mean, and the weights are included in those means with simple formulas. Nowadays, the request for composite indicators built on data measured on the ordinal and dichotomous scale is increasing. It is so because the micro-level of analysis is receiving more attention, and mixed data is now part of the policymaking process also for countries. To deal with this need, we explored the theory of partially ordered sets (poset theory). This theory allows one to compare the elements of a group by their reciprocal order and compute a score representing the position of the element in respect to the others (average rank). However, one of the most significant limitations to using this approach for the construction of indicators is the absence of a coherent method to introduce the values of weights in the intuitive form of a vector of values. In this work, we propose a solution to this limitation and present an application to a real case.

3 - The Saari Triangle As A Fuzzy Number
Jaakko Hakula
The aim of the essay is to reinterpret some properties of the Saari triangle in voting theory as those of fuzzy numbers. The Saari triangle is a geometric profile representation.Applying the Saari triangle some essential differences of pairwise and positional voting rules up to three alternatives can be depicted. Procedure lines are straight lines which have the plurality and antiplurality outcomes as their endpoints, and all

other (infinitely many) positional outcomes are between the two. Procedure lines are imperative to understand the formation of positional voting paradoxes based on a fixed preference profile. Candidates and voters in voting methods in social choice theory can stand for alternatives and criteria in multi-criteria decision making, thus widening the scope of fuzzy set theory applied in this work.The concept of fuzzy numbers is based on the Zadehian theory of fuzzy sets. Several types of fuzzy numbers exist. In general, any equilateral triangle, e.g. the Saari triangle, can be named a triangular fuzzy number in relation to the membership function of a fuzzy set. The focus of the study is to apply procedure lines and (generalized) triangular fuzzy numbers in a novel context. The challenge of the essay is to present a solution that utilizes both theories - and might have also some practical relevance. In future works the Saari triangle as an example of a crisp, multi-criteria decision-making environment could be further fuzzified in a Zadehian spirit.

■ TA-12

Tuesday, 8:30-10:00 - U9

Storage and Electric Vehicles in Electric Energy Systems

Stream: OR in Energy
Invited session
Chair: Jose Ignacio Muñoz-Hernandez

1 - Wholesale electricity market with photovoltaic cells, batteries and natural gas technologies
Irena Milstein, Asher Tishler, C.k. Woo

The paper presents an analytical solution for a two-stage model of a Cournot wholesale electricity market. There are three generation/supply technologies: photovoltaic cells (PV), battery storage and combined cycle gas turbines (CCGTs) to meet time-varying demands. PV can be used to sell electricity to final customers and/or for charging batteries during the daytime hours when the sun is shining. For an installed PV capacity, solar irradiance's intraday profile dictates PV's effective (usable) capacity, is relatively low in the morning and late afternoon hours, relatively high in midday hours, and zero in nighttime hours. Hence, daytime generation comes from PV and CCGT. Nighttime electricity supply can come from CCGT and batteries that have been already charged by PV generation. Our model captures the complex interactions of output and investment decisions made by profit-maximizing PV and CCGT firms, yielding the market's long-run equilibrium of capacity mix and short-run equilibrium of generation and price levels. Using Israel as a case study, it shows that declining battery costs enable PV firms to displace CCGT firms, resulting in carbon-free electricity supply as a market-based outcome. The battery cost threshold for this outcome is 30% of a CCGT's capacity cost, implying that natural gas is a transitional fuel in Israel's pathway to deep decarbonization.

2 - A multi-criteria assessment framework for the experience at charging stations from a battery electric vehicle drivers' perspective in Germany
Paul Fabianek, Reinhard Madlener

Based on economic and user-relevant criteria this paper proposes an evaluation framework for the experience at electric vehicle charging stations in Germany, using the Analytic Hierarchy Process approach for a Multi-Criteria Decision Analysis. The framework allows for a transparent evaluation of the customer journey at charging stations from the battery electric vehicle drivers' perspective, without their direct involvement and reassessment. The relevant criteria for the evaluation were derived from 20 interviews with battery electric vehicle drivers and confirmed by existing literature. Seven criteria have been found to be particularly relevant for the evaluation of the customer journey at charging stations: ease of use, green power, comfort, functionality, price, price transparency and availability. The evaluation framework comprises value scores which represent the degree to which a specific charging station satisfies a given quality criterion and combines them with the weights derived in the Analytic Hierarchy Process. The results point to the particular importance of availability and functionality. The framework seems useful for service design by charge point operators, electric mobility providers, and aggregators offering smart charging solutions.

3 - Decisions on the electrification of a road network
Alejandro Gutierrez-Alcoba, Roberto Rossi, Belen Martin Barragan
An electric road system (ERS) is a road that allows compatible electric vehicles to be powered by the electrical grid, while also charging their batteries. Deployed at scale on a wide road network, this technology allows for installing smaller batteries on vehicles, easing the adoption of electric Heavy Goods Vehicles (HGVs). In this talk, we discuss certain aspects regarding decision making on the design of electric road networks. Rolling out such systems in a large area requires time, and one of the challenges that emerge is how to manage the investment resulting in an early adoption by freight operators to switch their fleets from the early stages. Designing an ERS network based only on traffic flow data from road sensors may not result in early adoption of the technology. However, there are some approaches that can be used to generate a comprehensive and realistic set of freight routes that align with the observed traffic flows. To illustrate our points, we also present an inventory routing problem for an HGV navigating an ERS network. A mixed-integer linear programming heuristic chooses the best routes satisfying customer demand, which depends not only on the network design but also on retailers demand over time and the energy requirements of the vehicle, affected by delivery decisions.

4 - A Multistage Electric Vehicle Operational Planning Model for Delivery Allocation, Delivery Routing and Aggregated Energy Demand Management
Pablo Diaz-Cachinero, Jose Ignacio Muñoz-Hernandez, Javier Contreras
Electric vehicle is being promoted to mitigate emerging concerns about global warming associated with emissions from fossil fuels. In particular, in the context of the current deep growth of both e-commerce and parcel delivery, electric vehicle is presented as an alternative to internal combustion engine vehicles. Moreover, the charging process intrinsically implies the interdependence between the transportation and electric power systems. This work proposes a multistage optimization-based approach that considers delivery allocation/routing and aggregated energy demand management in the transportation and electric power systems. For the routing and charging of each independent electric vehicle, technical aspects of electric vehicles and package delivery requirements are considered. An electric vehicle demand aggregator is taken into account to guarantee the synergy between systems, who uses incentives to motivate electric vehicles to remain at charging intersections. However, tempting incentives can create electric power system congestion due to simultaneous charges on nodes. Thus, an iterative decongestion methodology is developed. The resulting stages are threefold: delivery allocation, delivery routing for each independent electric vehicle, and optimal energy management by electric vehicle demand aggregator. Numerical results demonstrate the effectiveness of the proposed model on a real 284-intersection map with a set of 100 electric vehicles and 600 deliveries.

■ TA-13

Tuesday, 8:30-10:00 - U119

Scheduling problems

Stream: Discrete Optimization and Algorithms (contributed)
Contributed session
Chair: Christos Zacharias

1 - Dynamic Inter-day and Intra-day Scheduling
Christos Zacharias, Nan Liu, Mehmet Begen

The simultaneous consideration of dynamic inter-day and intra-day scheduling decisions is an established theoretical and practical problem that has remained open due to its highly stochastic nature, complex structure, and the curse of dimensionality. We develop the first analytical model and associated theoretical results addressing this joint problem within a computationally tractable optimization framework with theoretical performance guarantees. Our model was designed with the intention of bridging two seemingly independent streams of research (inter-day literature and intra-day literature), and to leverage their latest theoretical developments in tackling the joint problem. We build connections between the two independently evolved streams of research by proving novel theoretical results in discrete convex analysis regarding constrained multimodular function minimization. These theoretical results are standalone, independent of our model and underlying problem. They relate to the theory of discrete opimization and its applications within and beyond the area of appointment scheduling.

2 - Single-machine scheduling with an external resource
Morteza Davari, Dirk Briskorn, Jannik Matuschke

This paper studies the complexity of single-machine scheduling with an external resource, which is rented for a non-interrupted period. Jobs that need this external resource are executed only when the external resource is available. There is a cost associated with the scheduling of jobs and a cost associated with the duration of the renting period of the external resource. We look at four classes of problems with an external resource: a class of problems where the renting period is budgeted and the scheduling cost needs to be minimized, a class of problems where the scheduling cost is budgeted and the renting period needs to be minimized, a class of two-objective problems where both, the renting period and the scheduling cost, are to be minimized, and a class of problems where a linear combination of the scheduling cost and the renting period is minimized. We provide a thorough complexity analysis (NP-hardness proofs and (pseudo-)polynomial algorithms) for different members of these four classes.

3 - A Hybrid Metaheuristic for the Optimization of Job Shop Scheduling Problem with Transport Resources
Dalila Fontes, S. Mahdi S. Homayouni, Fernando A. C. C. Fontes

We address a job shop scheduling problem in which jobs are transported around the shop floor by a limited number of vehicles. Since the machining operations and transport tasks are highly intertwined, the production operations and transport tasks must be scheduled simultaneously. Reduced waiting times for jobs, machines, and vehicles is an immediate consequence of such an integration which improves the overall system efficiency, i.e., the makespan and/or exit time of the last job from the system. We propose a hybrid particle swarm optimization and simulated annealing (PSOSA) algorithm aiming at finding good solutions quickly. The PSO is combined with a simulated annealing algorithm (SA) through which one can take advantage of the exploration capabilities of the former and of the local search capabilities of latter. The PSOSA algorithm composed of two nested loops: the outer loop handles the swarm of particles and controls the temperature, while the inner loop searches the neighborhood of the incumbent solution and decides on whether to accept or not a worse neighbor solution. The computational experiments conducted on three sets of problem instances show that PSOSA outperforms state-of-the-art solution approaches. To compute the optimality gap of the PSOSA solutions and of the previously best-known solutions, we also propose a very fast lower bounding procedure.

4 - Greedy Algorithms for Solving the Resource Sharing and Scheduling Problem
Gavriel David Pinto, Yehuda Hassin, Daniel Lifshitz, Inessa Ainbinder, Gad Rabinowitz

The collaboration of renewable resources as robots is important for the efficient performance of complex operations in the industry 4.0 revolution. Here we considered a key feature of the resource sharing and scheduling problem (RSSP). Alternative modes by which to execute an operation. Every operation mode uses a specific set of collaborating resources to perform the operation. This structure allows the scheduling engineer to incorporate in each operation a set of activities using few resources, where each resource performs some of the activities during a portion of the operation's duration. As such, this setup allows the reuse of previously designed solution segments in a manner that conserves engineering efforts and reduces model size while retaining the flexibility conferred using alternative modes. Existing algorithms for solving the RSSP, suffer from scalability limitations. In this paper we propose a new greedy approach: (1) Greedy mode; (2) Greedy precede (Longest preceding path; Shortest preceding path; Most needed by children; Most needed); (3) Greedy order. The greedy algorithms relay on a simple procedure to produce a phenotype, which consider cross-order schedule and efficiently solves much larger RSSP cases. Via a wide experimental design, we compared the performance of the greedy algorithms versus existing methods (branch and bound a genic algorithm) and demonstrate the significant benefit of the new algorithms especially in runtime. Another option for using th

■ TA-14

Tuesday, 8:30-10:00 - U261

Application of multi-criteria decision making to energy management

Stream: Energy Management
Invited session
Chair: *Aliyeh Kazemi*

1 - Identification and prioritizing of suitable cities to construct zero-energy buildings using MCDM techniques (Case study: Iran)
Aliyeh Kazemi, Parichehr Nouri

Increasing demand for energy due to population growth and global warming, which has led to numerous environmental issues, have encouraged many researchers to seek new ways to utilize clean renewable energies. The construction of zero-energy buildings in suitable cities can be a significant step forward in economic development and reducing pollution in metropolitan areas. This study aims to identify and prioritize proper cities in Iran to build zero-energy buildings. For this purpose, fuzzy Delphi and multi-criteria decision making (MCDM) methods have been used. The cities suitable for the construction of zero-energy buildings were selected through literature review, and interview with experts in architecture, urban planning, energy management familiar with the construction of zero-energy buildings. Then, using the fuzzy Delphi method, the attributes to prioritize the selected cities were identified, and their weights were calculated. Attributes included solar location, wind farm location, geothermal, technical, climate, and urban planning. After that, the cities were prioritized using SAW, TOPSIS, and VIKOR methods. Finally, using the Copeland method, the results of the three methods were combined, and the final prioritization of cities was determined. The results showed that Yasuj, Shiraz, Tabriz, and Arak cities are suitable cities to build zero-energy buildings in Iran.

2 - A Multi-criteria Decision Making Process to Prioritize Applying of Wave Energy Converters
Sadaf Nasrollahi, Aliyeh Kazemi, Mohammad-Hossein Jahangir

In the last decade, plenty of research has been conducted on wave energy technologies. While many companies have developed a large variety of technologies worldwide, the next phase of extracting this energy will most likely be deploying parks with wave energy technologies. This paper evaluates existing wave energy converters (WECs) intending to apply in the seas and oceans. For this purpose, major technologies to extract wave energy are identified. These wave energy converters are mostly mature ones and have already passed the R&D phase and are currently planted in the sea. Technological factors of each existing system consist of reliability, availability, technological features, economic factors, technical knowledge, social and environmental factors are considered as the main criteria. Twenty converters and 52 criteria are taken into consideration. The Caspian Sea with average wave energy of 5-14 kw/m is regarded as a case, and a decision matrix is established by integrating the gathered data and the experts' opinions. The most suitable technology is chosen based on combining the fuzzy Delphi method and preference ranking organization method for enrichment evaluations (PROMETHEE) method. The outcomes of this paper can significantly reduce the ambiguity of the decision-making for both the private and public sectors interested in investing in wave energy converters and attaining sustainable development by regarding socio-environmental factors in addition to competitive ones.

3 - The potential of greenhouse technology in various climate zones: An energy-saving analysis using a fuzzy decision-making approach (case study of Iran)
Farzin Ahmadi, Hossein Nasrollahi, Shima Najafi Nobar

The heating energy demand poses an important obstacle to greenhouse use, making energy-saving measures vitally important. In this work, the impact of implementing energy-saving strategies on the heating energy requirement was explored using a probabilistic approach for ten climate zones. To provide a proper estimation of the heating energy required for a typical greenhouse, 225 climate data points from meteorological stations have been gathered. Next, a probability density function (PDF) for each climate zone has been created based on the interpolation method and the probability density of actual results. We have assessed the impact of six common strategies for energy reduction in greenhouses within each climate zone. According to energy-saving effectiveness, the night curtain has the best average result (ranging from 18% to 28%), whereas the solar energy storage rock bed is the most sensitive one to climate conditions (ranging from 12% to 32%). The integrated fuzzy AHP-TOPSIS method is used to rank the energy-saving strategies based on technical, economic, social, and energy criteria. The results showed that the night curtain is the best energy-saving strategy in most climate zones. An in-depth view of greenhouse heating energy consumption is presented in this study. Taking into account the continuous evolution of greenhouse technology, the understanding of heating energy requirements and how different environments affect it is of great importance.

■ TA-15

Tuesday, 8:30-10:00 - U262

Decision Support and Information Sharing

Stream: Decision support (contributed)
Contributed session
Chair: Shani Alkoby

1 - A Game-Theoretical Approach for Assisting Humans in Online Information Sharing
Shani Alkoby, Ron Hirschprung

While the use of information-sharing platforms (e.g., online social networks) continues to increase worldwide, it introduces significant risks to both privacy and security. The ability to protect one's privacy and security is considered essential not only to individual autonomy but also for maintaining a liberal society. Information-sharing introduces an inherent trade-off between the benefits gained and the accompanying costs. Resolving this inherent trade-off is highly complex due to the problem's stochastic nature and the size of the decision tree spanned. This phenomenon is exacerbated by users' lack of technological literacy and cognitive laziness. Therefore, individuals are often helpless when attempting to optimize their utilities in these environments. As a response to this problem, this study introduces a novel game-theoretic-based framework, the "Online Information-Sharing Assistance" (OISA), which represents information-sharing environments as a formal mathematical model to create an approximate real-life model. Using the OISA framework, we developed a set of AI-agents that calculate a strategy for balancing this trade-off and attempt to produce a heuristic solution for a given online scenario. Finally, as a proof of concept, we conducted an empirical study including both human and OISA-based agents in a simulated Facebook environment subjected to real-time constraints, and show that significantly higher utility can be achieved using OISA.

2 - Reshaping decision conferencing for current times: what can we learn from experience and how should it be adjusted to virtual settings?
Edgar Mascarenhas, Mónica Oliveira

Since its birth in the late 1970s, Decision Conferencing has become an established socio-technical methodology to supporting group decision-making in many organizations worldwide. It consists of face-to-face working meetings attended by key players, assisted by an impartial facilitator, using a decision analytic computerized model of relevant data and judgements developed interactively and on-the-spot. Its use has been shown to stimulate group interaction, mutual learning and committed alignment on the way forward. Yet, in today's fast-paced digital world, many organizations are moving to remote work with managers and decision-makers placed in different locations (and even in different time zones). In this context, there is a need to combine web-based group decision support systems with scientifically grounded socio-technical approaches to assist effective group decisions in virtual settings. In this study, we will revisit the concept of decision conferencing and explore how it can be effectively adapted to the digital context. Departing from a systematic literature review and from interviews with decision conferencing facilitators from the operational research field, we will analyze how decision conferences have been applied over the past decades, what we can learn from real-world applications, as well as map current challenges and emerging opportunities for conducting decision conferences in virtual environments.

3 - An Application of Evidential Reasoning for Categorical Data Preprocessing
Fatima Almaghrabi, Swati Sachan

Data pre-processing is an essential step in building decision supporting systems. Uncertainty that arises from missing data and data categorisation can affect data pre-processing through obscuring unrepresented values in the dataset. Many missing data handling techniques are programmed to handle numerical data. Moreover, although data categorisation has its advantages, part of the data can be hidden during the process. This could impact the decision-support systems building process mainly in areas where automated decision-making systems have a huge impact on human life, such as health care and finance. An analysis of three types of uncertainty in categorical attributes, which are informational uncertainty, unforeseeable uncertainty in the decision task environment, and the uncertainty due to lack of pre-modelling explainability, are discussed in the proposed methodology based on maximum likelihood evidential reasoning (MAKER). The MAKER framework is capable of handling uncertainty in data caused by randomness, ambiguity, and inaccuracy, integrates these unrecognised uncertainties in the input transformation process, and results in trustworthy pre-processing and post-modelling explainability. The application of the proposed methodology has been demonstrated using real-world finance and healthcare data.

■ TA-16

Tuesday, 8:30-10:00 - U264

Computational Methods in Multivariate Statistics/Finance

Stream: Set Valued Models in Finance
Invited session
Chair: Daniel Kostner
Chair: Daniela Visetti

1 - Fast computation of Tukey trimmed regions and median in higher dimensions
Pavlo Mozharovskyi, Xiaohui Liu, Karl Mosler

Given a multivariate data set, a Tukey trimmed region is the upper-level set of the Tukey depth function. As they are visual, affine equivariant and robust, Tukey regions are useful tools in nonparametric multivariate analysis. While these regions are easily defined and interpreted, their practical use in applications has been impeded so far by the lack of efficient computational procedures in higher dimensions. Two novel algorithms are constructed to compute Tukey trimmed regions, a naive one and a more sophisticated one that is much faster than known algorithms. Further, a strict bound on the number of facets of a Tukey region is derived. In a large simulation study the novel fast algorithm is compared with the naive one, which is slower and by construction exact. Finally, the approach is extended to an algorithm that calculates the innermost Tukey region and its barycenter, the Tukey median. The developed algorithms are implemented in R-package TukeyRegion downloadable from CRAN.

2 - On Duality in Polyhedral Projection Problems
Benjamin Weißing

The class of Polyhedral Projection problems (PP) contains the class of Vector Linear Programmes (VLP) (and the class of multiple objective linear programmes (MOLP)); but it can also be used to concisely represent geometric operations on convex polyhedra (like, for instance, the Minkowski sum or the intersection of several polyhedra, or the conversion between V- and H-representations). Thus, (PP) can be viewed as a link between (set-valued) optimisation and geometry. In both fields well-known duality concepts exist, so it is natural to ask for a dual problem to (PP). A desirable property for a duality theory is that the dual of a problem instance is an instance of the same problem class as the original problem. In this talk, We will achieve such a kind of duality for (PP) by utilising an "intermediate" dual problem based on the duality between V- and H-representations of convex polyhedra.

Computational Geometry is a tool indispensable in Multivariate Statistics. For instance, Polyhedral Projection can be used to construct cone quantiles, as it is done by Kostner & Hamel in a recent paper (2022) in the bivariate setting. Evaluating the empirical lower cone distribution function involves partitioning of the dual ordering cone. Therefore, duality for (PP) can be useful for extending the computation of quantile sets from the bivariate case to higher dimensions.

3 - Backtesting Systemic Risk Forecasts using Multi-Objective Elicitability
Tobias Fissler

Backtesting risk measure forecasts requires identifiability (for model validation) and elicitability (for model comparison). The systemic risk measures CoVaR (conditional value-at-risk), CoES (conditional expected shortfall) and MES (marginal expected shortfall), measuring the risk of a position Y given that a reference position X is in distress, fail to be identifiable and elicitable. We establish the joint identifiability of CoVaR, MES and (CoVaR, CoES) together with the value-at-risk (VaR) of the reference position X, but show that an analogue result for elicitability fails. The novel notion of multi-objective elicitability however, relying on multivariate scores equipped with an order, leads to a positive result when using the lexicographic order on R2. We establish comparative backtests of Diebold–Mariano type for superior systemic risk forecasts and comparable VaR forecasts, accompanied by a traffic-light approach. We demonstrate the viability of these backtesting approaches in an empirical application to DAX 30 and S&P 500 returns.

The talk is based on the preprint https://arxiv.org/abs/2104.10673 which is joint work with Yannick Hoga.

■ TA-17

Tuesday, 8:30-10:00 - U356

MIP Solving: Latest Techniques

Stream: Software for Optimization
Invited session
Chair: Timo Berthold

1 - Learning to Use Local Cuts
Matteo Francobaldi, Timo Berthold, Gregor Hendel

Cutting planes play an indispensable role in solving mathematical optimization problems, and today they are at the heart of all competitive solvers for mixed-integer (linear) programming. Non-trivial algorithmic decisions are required when integrating cutting plane methods into a branch-and-bound solver, given the need of finding the trade-off between the effectiveness of the cuts and their computational cost. One of the most crucial questions is whether to use cutting planes only globally at the root node or also locally at internal nodes of the search tree, or equivalently, whether to run a cut-and-branch or rather a branch-and-cut algorithm. We address this question by a machine learning approach, in which we train, within a regression framework, a Linear Model, a Random Forest and a Neural Network, to predict the speed-up (or slow-down) provided by the use of local cuts. Through an extensive computational study, conducted with FICO Xpress over a large test bed of problems, we show that the produced strategies are able to provide, upon the existing policies, a significant improvement to the performance of the solver. In fact, a variant of the random forest suggested by our work has already been implemented by the development team of Xpress, and released with version 8.13 of the software.

2 - Schreier-Sims Cuts meet Stable Set: Exploiting Problem Structure to Derive Symmetry Handling Inequalities
Christopher Hojny, Marc Pfetsch, Jose Verschae

Symmetries of mixed-integer programs (MIPs) are well-known to deteriorate the performance of branch-and-bound solvers. The reason for this phenomenon is that many symmetric subproblems are created from which a solver cannot extract essential new information. Therefore, several symmetry handling inequalities have been developed that, if incorporated into branch-and-bound, avoid generating symmetric subproblems.

In this presentation, we focus on a special class of symmetry handling inequalities that have been suggested recently by Salvagnin as well as Liberti and Ostrowski: cuts derived from the Schreier-Sims table. Despite their simplicity, these inequalities admit many degrees of freedom in how they are used to handle symmetries. We discuss several of such strategies to add Schreier-Sims cuts to a MIP and illustrate the impact of these strategies on the MIP solver SCIP. These empirical findings are complemented by a theoretical investigation of the effect of Schreier-Sims cuts on the stable set problem. This investigation allows us to derive new symmetry handling inequalities for arbitrary binary programs and to obtain an indication which Schreier-Sims cuts might be beneficial to handle symmetries for stable set.

3 - Symmetry handling in binary programs through propagation
Jasper van Doornmalen, Christopher Hojny

Symmetries of binary programs are known to dramatically slow down branch-and-bound procedures. A classical approach to handle permutation symmetries is to enforce that only one representative of equivalent (symmetric) solutions can be computed. In classical integer programming literature, among others, this is established by introducing symmetry handling constraints. This way, solutions that are not lexicographically maximal among the permuted solutions are cut off.

We present a propagation-based symmetry handling technique. Given a set of fixed variables (e.g., due to branching decisions), this technique identifies further variables that can be fixed to ensure that only lexicographically maximal solutions are computed. We present efficient algorithms to find such additional symmetry-based variable fixings for arbitrary sets of permutations and cyclic groups. In particular, for cyclic groups, we show that all possible fixings can be found in polynomial time even if the cyclic group has exponential order.

Our methods are implemented as a plugin in the academic integer programming solver SCIP, and we discuss the effectiveness of these methods on various symmetrical instances.

4 - The chebyshev center as an alternative to the analytic center in the feasibility pump heuristic
Daniel Baena Mirabete, Jordi Castro

Finding a feasible solution of a Mixed-Integer Programming (MILP) model is a challenging problem. Many heuristics, which aim at finding a feasible (hopefully good) solution for a MILP, have been developed. Among the the most successful ones we find Feasibility Pump (FP). A variant of the original FP heuristic (named AC-FP), which used the analytic center of the polytope of the relaxed problem, was shown to increase the chances of finding a feasible integer solution. The computational results showed that AC-FP improved the standard FP in some MILP instances. In this work, we consider an alternative to the analytic center, namely, the Chebyshev center, within FP. The main benefit of using the Chebyshev center in FP is that the center computed does not depend on how the polytope of the linear problem is defined; in particular, CC is not affected by redundant constraints. The new FP variant based on the Chebyshev center (named CC-FP) reported better solutions than FP and AC-FP heuristics for some instances.

■ TA-18
Tuesday, 8:30-10:00 - U358

Advances in Optimization under Uncertainty 1

Stream: Stochastic and Robust Optimization
Invited session
Chair: *Steffen Rebennack*
Chair: *Markus Gabl*

1 - First-order methods for two-stage-stochastic StQPs
Immanuel Bomze, Markus Gabl, Francesca Maggioni, Georg Pflug

We study two-stage stochastic optimization of (nonconvex) Standard Quadratic Optimization Problems (StQPs). While rigorous lower bounds are obtained by dissecting the probability measure, we here focus on new scalable tighter upper bounds for discretizations, leading to nonconvex quadratic problems over polytopes which we treat by a Pairwise Frank-Wolfe method, generating high-quality feasible solutions quickly (and more generally, guaranteed in finite time).

2 - Robust Optimization of Uncertain Multiobjective Problems via Epigraphical Reformulations
Ernest Quintana, Gabriele Eichfelder

The epigraphical reformulation of uncertain scalar optimization problems is a well known trick with important theoretical and practical consequences in robust optimization. In the uncertain multiobjective setting however, the existence of a corresponding equivalent formulation is still an open problem. The main challenge in this case comes from the fact that the robust counterpart of an uncertain multiobjective problem is not a deterministic multiobjective problem but rather a so called set optimization problem, that is, a problem in which a set-valued mapping is minimized in a specific sense. In this talk, we present a partial answer to this question. Specifically, we show that for uncertain multiobjective problems there is not one but a countable family of monotonic (in a specific sense) epigraphical reformulations whose solution sets approximate, with desired accuracy, that of the original problem. In addition, we discuss sufficient conditions in order to have the equivalence between the robust counterpart problem and one of the reformulations in the family. The described reformulations are now deterministic semi-infinite multiobjective problems with a particular structure in the semi-infinite constraints, and can be shown to generalize the epigraphical reformulation in the scalar case. The tractability of the semi-infinite constraints is also analysed with duality tools.

3 - Approaches for robust bi-objective mixed-integer linear problems
Anita Schöbel, Fabian Chlumsky-Harttmann, Marie Schmidt

Robust optimization aims to find solutions which are best in the worst case. In this talk we go a step further and discuss robust multi-objective optimization problems. There exist concepts on how to define robust Pareto solutions but algorithms for finding such solutions are scarce.

We propose two classes of algorithms for solving robust bi-objective mixed-integer linear optimization problems. The idea is to combine dichotomic search from multi-objective optimization with an iterative cutting-plane approach known as optimization-pessimization from robust optimization in two different ways. In the first approach we interpret the robust bi-objective optimization problem as deterministic problem with max-min objective functions. The resulting scalarized problem can then be solved by optimization-pessimization or by dualization in the case of purely linear programs. In the second approach we generalize the optimization-pessimization approach to multiple objective functions and solve the resulting bi-objective subproblem with small scenario sets by dichotomic search.

We tested these approaches experimentally on randomly generated instances. The numerical results show superiority of the first approach with dualization for purely linear problems. For linear integer or mixed-integer problems we compare both approaches and show ways on how the runtime can be further improved.

4 - Uncertainty Preferences in Robust Mixed-Integer Linear Optimization with Endogenous Uncertainty
Markus Gabl, Immanuel Bomze

In robust optimization one seeks to make a decision under uncertainty, where the goal is to find the solution with the best worst-case performance with respect to the so-called uncertainty set. In many scenarios, a decision maker may influence the uncertainty regime they are facing, for example, by investing in market research. Recently, this situation was addressed in the literature by introducing decision dependent uncertainty sets, whose structure depends on decision variables. However, with different uncertainty regimes, not only do the worst-case optimal solutions vary, but also other aspects of that solutions such as max-regret, best-case performance or predictability of the performance. A decision maker may still be interested in having a performance guarantee, but at the same time be willing to forgo superior worst-case performance if those other aspects can be enhanced by switching to a suitable uncertainty regime. We introduce the notion of uncertainty preference in order to capture such stances. We present three ways to formalize uncertainty preferences and study the resulting mathematical models. The goal is to have reformulations/approximations of these models that can be solved with standard methods. We apply our framework to the uncertain shortest path problem and conduct numerical experiments for the resulting models. We can demonstrate that our models can be handled very well by standard mixed-integer linear solvers.

■ TA-19
Tuesday, 8:30-10:00 - Y228a

Stochastic Processes and Applications 1

Stream: Performance Evaluation of Queues
Invited session
Chair: *Maria Vlasiou*

1 - Clustering in time-dependent data and block Markov chains
Jaron Sanders

Understanding hidden structures that underlie sequential data is an important challenge in data science. Not only do these structures give insight into the complex process which generates the data; once the structure is determined, any subsequent analysis can benefit from a reduction in dimensionality.

An attribute that however complicates the accurate discovery of hidden structures in sequential data is that the past and future samples are dependent. We therefore require clustering algorithms specifically designed for models with time-dependencies to solve this issue.

In this talk I will discuss research on clustering in block Markov chains. Block Markov chains are the Markov chain analogue of the stochastic block model and correspondingly serve as a model for Markov chains with clusters. The talk will introduce clustering algorithms for sequences generated by such Markov chains and primarily discuss the application of said algorithms to different datasets taken from real-life. The talk will secondarily indicate a relation to spectra of random matrices with dependencies.

2 - Exploitation of idleness for maintenance in an M/D/1 production queue
Maayan Eyal, Yoav Kerner

We study a production system that operates as an M/D/1 queue. To avoid overhitting, the server must be idle for a single time unit after working continuously for at most predetermined period. The cooling time occurs either when there are no items to process or when the machine is too hot. We analyze the system's performance by studying a Markov chain is embedded at production completions and at arrivals to an empty system. We provide analytical and numerical procedures that compute the steady-state distribution, the optimal maximal 'on' period, and the analytical analysis of lead time.

3 - Spatial appointment scheduling in a random environment
Bharti Bharti, René Bekker, Michel Mandjes

In this work we investigate single server delivery problems from a stochastic approach. In our model we distinguish two factors; namely given the number of delivery locations, we wish to decide both on an appropriate route, as well as on appropriate delivery times. Here both the travel times between the locations and the service times at the locations are random variables. The aim is to optimize the objective function determined by a given route and inter-appointment times, using the well known Lindley recursion from queuing theory. Providing quality service in competitive environment with limited resources is of great importance. Appointment scheduling helps in achieving a trade-off to balance waiting- and idle times of clients and delivery person for effective utilisation of resources. For routing, which itself is an NP-hard problem, classical heuristic methods like local search algorithms (which are firmly backed for the stochastic TSP) have been tested and implemented. The overall process for both routing and inter-arrival times is challenging since it is difficult to obtain closed-form expressions for the density- and distribution functions of the idle- and waiting times. We therefore follow an accurate approximation approach using phase-type distributions. The objective function is further reduced to a closed form to accelerate computations with the help of heavy-traffic approximations.

4 - Fork-join queues
Maria Vlasiou, Dennis Schol

In this paper, we study an N server fork-join queueing network with nearly deterministic arrivals and service times. Specifically, we aim to approximate the length of the largest of the N queues in the network. From a practical point of view, this has interesting applications, such as modelling the delays in large supply chains. We present a fluid limit and a steady-state result for the maximum queue length, as N goes to infinity. These results have remarkable differences. The steady-state result depends on two model parameters, while the fluid limit only depends on one model parameter. In addition, the fluid limit requires a different spatial scaling than the backlog in steady state. We extend these results to the case of the same scaling. In order to prove these results, we use extreme value theory and diffusion approximations for the queue lengths.

■ TA-20

Tuesday, 8:30-10:00 - Y228b

DEA applications in Education and Health

Stream: Data Envelopment Analysis and Performance Measurement
Invited session
Chair: Giovanna D'Inverno

1 - The relative efficiencies of higher education in OECD countries
Zilla Sinuany-Stern

Studies of productivity of systems of Higher Education (HE) on the national level are of interest for two main reasons: education is an important factor for productivity growth for the macro-economy, and the efficiency of spending public resources on HE is of key interest in the context of accountability specifically relative efficiency compared with other developed countries. The objective of this study is to evaluate the relative efficiency of HE in OECD countries from the public viewpoint; how well OECD countries utilize their public resources to achieve their outputs relative to each other. For this study two inputs and six outputs were used. The data was taken, mostly, from OECD report on education in 2019. The stress on efficiency from the public viewpoint is a strength of this study in relation to previous OECD efficiency studies. The original Data Envelopment Analyses (DEA) basic models were used, which provide dichotomy of the countries into two groups: efficient and inefficient. Moreover, several efficiency rank-scaling methods based on DEA, and several multivariate statistic methods were utilized here. The use of a variety of efficiency rank-scaling methods, while choosing the robust one, is another strength of this research. The results indicate that the robust method is cross efficiency, as it is significantly correlated with each of the other efficiency methods, and it has the highest average correlation with other efficient methods.

2 - How funds and commitment to innovation turn into wealth and educational growth? The Quality of Government effect in EU regions through time-varying conditional DEA
Anna Rita Dipierro, Chiara Colamartino, Pierluigi Toma

Since innovation represents the key of modern business, investments in innovation paths are critical to competitiveness. And, EU is on the high road to tackle what encompasses innovation, especially since the establishment of Smart Specialization Strategy (S3), an inclusive, shared and placed-based approach. However, one-size-doesn't-fit-all, most likely because of the Quality of Government (QoG). In this light, the study aims at measuring efficiency, through a Data Envelopment Analysis (DEA) conditional to time and QoG, of the turning process of S3 funds, human resources in science and technology, expenditures on research and development into tertiary education and gross domestic product. By examining 230 EU regions in 2009-2018 period, between and within differences arise, especially in the case of less-scored QoG regions. Besides, changes are likely to be work-in-progress and require time. Insights on power of places in terms of hidden governmental aspects shaping the regional growth are meaningful. The role of government in resources' optimization is suggested to be enhanced through educational projects, as well as via steps forward towards whistle-blowing. In this way, overall laxity and old mechanisms affecting citizens' perception of their own government are likely to shrink.

3 - Estimating the Revenue Efficiency of Public Service Providers in the Presence of Demand Constraints
Hong Ngoc Nguyen, Chris O'Donnell

Evaluating the performance of public service providers is often complicated by the fact that they must choose input levels before demands for service are known. We consider an even more complicated situation in which service providers have no opportunity to directly influence demands. This means that their predetermined inputs may be more than what is required to meet realised demands. In such cases, conventional measures of revenue efficiency will generally mis-classify rational and efficient managers as inefficient. We develop a more appropriate measure of revenue efficiency that accounts for exogenously-determined demands. We explain how data envelopment analysis (DEA) methods can be used to estimate our measure and decompose it into measures of technical and allocative efficiency. We also explain how DEA methods can be used to assess the consequences (if any) of providers having to choose input levels before demands for service are known. The methodology is applied to hospital and health service (HHS) providers in Queensland (Australia). We obtain estimates of revenue efficiency that are quite different from estimates obtained using a conventional approach. Our results also indicate that HHS providers were not disadvantaged by having to choose input levels before demands for service are known.

4 - Is your school really better than mine? An innovative proposal to perform school efficiency evaluation in a more fair way
Giovanna D'Inverno, Antonio Peyrache, Gabriela Sicilia

School efficiency evaluation is increasingly needed to provide policy makers and school managers with evidence to learn from best practises and improve performance. In this context, non-parametric techniques have become quite popular to assess school technical efficiency as they allow to deal with multiple-outputs, do not require information about input or output prices and do not assume any distributional form. Quite often student level data from national evaluations or international large-scale assessments are aggregated at the school level to perform the analysis, overlooking the heterogeneity across schools at the risk of unfair assessments. In this paper, we propose an extension of the traditional DEA formulation to directly take into account the inputs and outputs distribution within each school, without resorting to common aggregate measures such as the average or the standard deviation. The suggested framework allows different specifications to model input and/or output composition and to capture heterogeneity across schools. For illustrative purposes, we apply our proposal to an extensive dataset of more than 600 schools in Spain, coming from the last wave of the international large-scale assessment of PISA 2018. This empirical application shows how this tool could support educational policy making assessment while considering the possibility of a heterogeneous working and learning environment.

■ TA-21

Tuesday, 8:30-10:00 - Y229a

Individual differences in OR

Stream: Behavioural OR
Invited session
Chair: Ayşegül Engin

1 - On the influence of decision-making style and competence on the use and evaluation of multiple criteria decision-making methods
Tomasz Wachowicz, Ewa Roszkowska, Marzena Filipowicz-Chomko

There is a constant discussion in MCDA literature regarding selecting a support method for a particular decision-making problem and context. In this paper, we focus on the cognitive capabilities of decision-makers (DMs) to effectively use MCDA techniques. Using the online multiple criteria decision-making experiment concerning a problem of comparing flat renting offers, we analyze the DMs' ability to use three different MCDA methods (i.e., SMART, TOPSIS, and AHP) to elicit their preferences reliably and produce coherent rankings. We try to verify if using MCDA techniques coherently is related to their behavioral profiles described by decision-making competence and information processing style. Finally, we try to confirm if these behavioral issues and the results obtained affect the DM's opinion regarding the functionality of these methods, which may have consequences on their intention to use similar techniques in the future to solve real-life decision-making problems. All the relationships were verified using a structural equation model, and most of them occurred to be significant. One of the strongest effects was between coherence in methods use and the DM's opinion on their functionality. It shows that DM's satisfaction and willingness to use MCDA tools in the future is related to the practical effects of these tools that DMs can verify in advance. Hence pre-decision-making training and exercises may be required to show DM the efficiency and reliability of MCDA tools.

2 - Fostering individual analytic reasoning-style with dashboards
Michael Leyer, Ayşegül Engin, Jürgen Strohhecker

Dashboards are popular performance-management tools to support the decision-making of operations managers within dynamic systems. Consisting of stocks, flows, and feedback, these systems pose specific challenges for human managers that often result in poor performance. Taking a cognitive perspective and building on dual-processing decision theories, visualization comprehension theory, need for cognitive closure and cognitive fit theory, we propose an integrated theoretical framework that predicts that decision makers reflection decision making property can be triggered towards reflective decision making if a dashboard fits the dynamic system's causal and stock-flow structure. We conducted laboratory experiments in which participants made repeated decisions in a production system. According to the results, providing a structure of decision variables and performance indicators can contribute to increase the chances of individuals activating analytic reasoning-style. Individuals with a higher preference for order have an even higher effect for activating reflection decision making property especially when provided with a visualization of stocks and flows and causal links between decision variables and performance indicators in a dashboard. This finding contributes to theory building in behavioral operations management and enhances our understanding of how structural visualization interacts with human decision-makers' cognition processes.

3 - Individual differences and group conflict in a decision support environment
Ayşegül Engin, L. Alberto Franco, Etienne Rouwette

We report on an ongoing study exploring the effects of individual differences on group decision processes and outcomes. The primary individual characteristics that we consider are the need for cognition/faith in intuition inventories and the need for cognitive closure. Specifically, the aim of this study is to understand how individual characteristics of group members can lead a whole group into and out of conflicts and affect its path to consensus in a decision-support environment. We approach this question by adopting a sequence analysis approach to uncover all stages that the groups go through during their process.

4 - Towards a competency framework for participatory modeling: Identifying core competencies
Raimo P. Hämäläinen, Sondoss Elsawah, Elena Bakhanova, Alexey Voinov

Participatory modeling (PM) is a craft that is often learned by training 'on the job' and mastered through years of practice. We aim to set the foundation for both the practice and capacity-building efforts for PM by identifying the relevant core competencies. We review the literature on competencies in problem-solving research areas related to

PM (e.g., systems thinking, facilitated model building, operations research, and so forth). We carried out a practitioners' survey to learn how they perceive the importance of different competencies and how the scope of these competencies may vary across the roles in PM. Five core competencies were identified: systems thinking, modeling, group facilitation, project management and leadership, and, more recently, designing and running virtual workshops and events. An important signal which came from the survey results is that there is a clear need for more training in facilitation and social skills. People active in PM typically have had their training in modeling and know how to use models. People can have very limited skills when it comes to the types of modeling approaches, they would need to use in practice. The fact that process skills and facilitation are increasingly emphasized today may lead to a situation where we forget about the importance of core modeling skills. Thus, there can be an important hidden training deficiency in the field, which is the limited breadth of the modeling skills of the PM practitioners.

■ TA-22

Tuesday, 8:30-10:00 - Y229c

Sustainable Food & Retail Supply Chains

Stream: Sustainable Supply Chains
Invited session
Chair: Renzo Akkerman

1 - A review on intermediate short food supply chains

Marije Renkema, Per Hilletofth

Direct producer-to-consumer short food supply chains (SFSC) have been presented as a possible solution to unsustainable long food supply chains but fail to address the interdependencies within the agri-food systems where food is largely processed, distributed, and provided by intermediaries. Recently researchers have changed their focus towards intermediate SFSC as a possible solution to create sustainable food systems while overcoming the limitations of direct producer-to-consumer SFSC. Intermediaries in SFSC fulfill a wide range of functions; they connect existing supply and demand and create supply and demand in different markets. They scale up and expand local markets. They are service providers within food systems, including packing, distributing, or shipping local products through conventional supply chains resulting in the movement of larger volumes of local food along the supply chain. To understand the current state of the art and expose future research directions, this review synthesizes the available literature in the field of intermediate SFSC until December 2021, excluding research that is focusing on global food supply chains. Results include four themes in the field of intermediate SFSC: the place of intermediate SFSC in food systems, stakeholder relationships in intermediate SFSC, governance of intermediate SFSC, and role of intermediate SFSC in obtaining sustainability.

2 - Local vs. global procurement in the humanitarian context: is local more environmentally sustainable?

Sarah Joseph

Improving resiliency of local food systems is an increasingly important topic in humanitarian operations, and local procurement is often considered more environmentally sustainable than global. To analyze this question, we investigate global vs. local procurement from an environmental sustainability perspective using Life Cycle Assessment (LCA). We model the entire life cycle (from raw material production, to processing, distribution, use, and disposal) of a fortified food product commonly distributed to beneficiaries in Africa for two scenario supply chains - a local supplier in East Africa and a global supplier in Western Europe. Data includes a mix of primary data (collected directly from local farmers, both suppliers, and humanitarian organization responsible for distribution) and background data from the LCA database to quantify and compare the environmental impacts of local vs. global procurement along multiple categories. The results indicate that in general the global supplier has a higher environmental impact than the local, but the question of environmental sustainability of is not necessarily one of where, but rather one of how. In comparison to the production phase, the role of transportation is minor, and the inputs used at the farm level have a significantly larger impact on the environmental sustainability than transporting the product, even from far away.

3 - Developing a donation suggestion tool for retailers to reduce food waste

Renzo Akkerman, Sem Albers, Soodeh Jahdi, René Haijema

Food waste is a significant environmental problem throughout the supply chain, contributing a substantial share of the global emission of greenhouse gasses. One of the ways to prevent food waste is by donating excess inventories to charitable institutions such as food banks. Especially in retail environments, donation is often part of waste reduction strategies. However, donation often involves perishable products that have very limited shelf life left at the time of donation. Earlier identification of products that could be donated would help improve the opportunities to efficiently use the donated products at the receiving organizations. In this presentation, we discuss the development of donation suggestion tools for retailers. Such a tool builds on demand forecasting methods and simulated inventory behaviour to identify early donation opportunities. The modelling approach helps understand and quantify the interactions between donations, food waste, service levels, and inventory replenishment and holding costs. Numerical results show that a significant number of products could be donated with longer remaining shelf life, leading to better opportunities to efficiently use these donations at food banks.

■ TA-23

Tuesday, 8:30-10:00 - Y307

Pricing and Revenue Management 2

Stream: Pricing and Revenue Management
Invited session
Chair: Epaminondas Kyriakidis

1 - The motivation to purchase concerning quality, price, and risk attitude

Arik Sadeh

While it is well known that revenue management is affected by the customers' conduct and their attitude toward risk. Online shops can offer a variety of products with various levels of quality and corresponding prices. This research deals with the motivation of potential buyers to conduct a purchase in online stores concerning their risk aversions in several dimensions of risk attitude. We use findings from a survey of 104 respondents exposed to technology working in the hi-tech industry. We used the structural equation modeling approach to conduct statistical analysis. The relationships between risk aversion, the reliability of the products, the stores, and the motivation to purchase are modeled in one set of equations. We use a mathematical programming approach to solve the problem of assigning prices for different decision-makers. The study's findings can help entrepreneurs how to market products that may be perceived as not reliable.

2 - Price Discrimination with Robust Beliefs

Jun Han, Thomas Weber

This paper considers the problem of second-degree price discrimination when the type distribution is unknown or imperfectly specified by means of an ambiguity set. As robustness measure we use a performance index, equivalent to relative regret, which quantifies the worst-case attainment ratio between actual payoff and ex-post optimal payoff. We provide a simple representation of this performance index, as the lower envelope of two extremal performance ratios, relative to beliefs that lie at the boundary of the ambiguity set. A characterization of the solution to the underlying robust identification problem is given, which leads to a robust product portfolio, for which we also determine the worst-case performance over all possible consumer types. For a standard linear-quadratic specification of the robust screening model, a worst-case performance index of 75% guarantees that the robust product portfolio exhibits a profitability that lies within a 25%-band of an ex-post optimal product portfolio, over all possible model parameters and beliefs. Finally, a numerical comparison benchmarks the robust solution against a number of alternative belief heuristics.

3 - When is Assortment Optimization Optimal?
Will Ma

Assortment optimization describes a retailer's general problem of deciding which variants in a product category to offer. In a typical formulation, there is a universe of substitute products whose prices have been pre-determined, and a model for how customers choose between these products. The goal is to find a subset to offer that maximizes aggregate revenue. In this paper we ask whether offering an assortment is actually optimal, given the recent emergence of more sophisticated selling practices, such as offering certain products only through lotteries.

To formalize this question, we introduce a mechanism design problem where the items have fixed prices and the seller optimizes over (randomized) allocations. The seller has a Bayesian prior on the buyer's ranking of the items along with an outside option. Under our formulation, revenue maximization over deterministic mechanisms is equivalent to assortment optimization, while randomized mechanisms allow for lotteries that sell fixed-price items. We derive a sufficient condition, based purely on the buyer's ranking distribution, that guarantees assortments to be optimal within this larger class of randomized mechanisms. Our sufficient condition captures many preference distributions commonly studied in the assortment optimization literature – Multi-Nomial Logit (MNL), Markov Chain, Tversky's Elimination by Aspects model, a mixture of MNL with an Independent Demand model, and simple cases of Nested Logit.

4 - Optimal pricing of a hotel room in a finite-time horizon consisting of n periods
Epaminondas Kyriakidis, Athanassios Balis

Consider a touristic season consisting of n periods, for example n weeks. The price for renting an available room for one period is determined at the beginning of each period. It is allowable for a customer who resides in a room for a period to renew his residence for the next period with price that corresponds to the next period. It is assumed that the number of possible customers that appear at the beginning of each period is a discrete random variable with known distribution. The probability that a customer renews his residence for the next period depends on the price of the room for the next period. The objective is to determine the expected total revenue for the whole season. A stochastic dynamic programming formulation is developed that determines the optimal price of the available rooms at the beginning of each period.

■ TA-24

Tuesday, 8:30-10:00 - Y307a

Warehouse Operations and Distribution

Stream: Demand and Supply in Consumer Goods and Retail
Invited session
Chair: *Kris Braekers*

1 - On-line Order Batching for Robot-based Order Picking Systems using Deep Reinforcement Learning
Bhoomica Nataraja, Zumbul Atan, Ivo Adan, Niek Brouwers

Recent advancements in robotics and automation have enabled warehouses in the e-commerce era to adopt new ways to stay competitive under highly volatile customer demands with shorter deadlines. Uniquely, we consider an autonomous robot-based order picking system that fulfils orders from a multi-deep gravity flow rack in a dynamic environment, wherein orders arrive continuously. For such a system, we make two decisions: (i) when to pick orders and (ii) which orders compose a batch. We study the online order batching problem with an objective to minimize the weighted earliness and tardiness. While earliness results in increased inventory holding costs, deterioration of perishable goods, or opportunity costs, tardiness is undesired with regard to customer satisfaction. Subsequently, we formulate a Semi-Markov decision process to represent the problem that allows us to create a deep reinforcement learning (DRL) agent. The agent learns a policy by interacting with the environment and solves the problem with Proximal Policy Optimization algorithm. We use several benchmark heuristics to evaluate the performance of the DRL agent. The agent is able to create a policy that produces feasible solutions superior to the benchmark heuristics in most of the tested cases. We demonstrate that the learning agent shows potential performance under fluctuating order environment, which implies that it is effective and efficient, particularly in the online retailing of fast-moving consumer goods.

2 - Combining robotic and manual picking for store-specific palletizing in a parts-to-picker distribution center
Moritz Hundhammer, Michael Sternbeck, Heinrich Kuhn

We examine an internal retail chain with a highly automated distribution center (DC) and associated stores. In the DC, two different technologies are used sequentially for loading store pallets. One part of the case packs (CPs) is packed by robots and another part by conventional order pickers according to the parts-to-picker principle. The stores are regularly supplied with several pallets by the DC. The allocation and sequence of the CPs on the pallets has a significant influence on instore efficiency during shelf-filling operations. At the same time, due to the different technologies used in the DC, CPs cannot be assigned to pallets in an arbitrary manner. Likewise, the allocation of CPs to pallets also influences the operational costs in the DC. This paper takes an integrative perspective and considers the interdependencies and cost effects of both subsystems (i.e., DC and store) and represents them by means of a directed graph. The problem is formulated similarly to a route planning problem and solved for practical instances of a European retail company. Compared to the existing approach, the non-optimal solutions for the problem instances already promise a reduction of distances to be covered during shelf filling in the stores by 22% and a reduction of the decision-relevant costs in the DC by 67%. Across the internal supply chain, savings of 21.5% on average can be realized.

3 - Experimental study on a collaborative model for inventory routing in city logistics
Titi Iswari, Kris Braekers, An Caris

This project considers two scenarios to observe the impact of a city hub in a B2B city logistics setting in terms of inventory and routing aspects. The first scenario is the basic scenario in which there is no city hub. In this scenario, each retailer defines its replenishment policy, and each supplier determines its optimal delivery plan independently. In the second scenario, retailers decide on their order size and suppliers send their products via a city hub. The city hub plans the optimal routes to deliver to the retailers with cargo bikes and vans, where cargo bikes can also perform multiple trips if necessary. For the inventory part, five different replenishment methods are used to define the order size from each retailer in each period. A metaheuristic algorithm based on Large Neighbourhood Search (LNS) is developed to solve the route optimization problem. An experimental study with several test variables, including the number of suppliers, number of retailers, holding cost, and replenishment method, is conducted. Performance measures, such as total cost, distance travelled, loading degree, and the number of trips, are used in the evaluation criteria. Based on the results of the experimental study, we investigate in which situation the city hub's implementation will improve the city logistics performance and how each variable affects the performance measures.

4 - Customer crowd-shipping: An agent-based approach
Christa Searle, Philip Christian Malan

Customer crowd-shipping is a crowd logistics solution to the challenge of effective last-mile deliveries for retailers. The approach involves utilising in-store customers, in addition to regular delivery vehicles, for delivering orders to online customers. These occasional drivers are offered an incentive as compensation for performing deliveries. In this research, a dynamic and stochastic agent-based simulation model is proposed for studying the mechanisms of the customer crowd-shipping initiative. This integrated modelling approach comprises a traditional last-mile delivery system, the behaviour of occasional drivers maximising their personal utility, a novel incentive scheme and a proposed methodology for selecting online customers for outsourcing.

Traditional vehicle routing techniques are employed to simulate efficient delivery routes for regular deliveries in estimating the cost of deliveries in addition to the cost of incentives. The results indicate that customer crowd-shipping may successfully function as an extension to an existing last-mile delivery system, with the potential of reducing both the total delivery cost and customer waiting time. These benefits are, however, shown to be influenced by the incentive scheme, the strategy by which online customers are selected as crowd-shipping candidates, the maturity of the customer crowd-shipping system and the occasional driver population's perceived value of time.

■ TA-25

Tuesday, 8:30-10:00 - Y308

Organizational and Information Management

Stream: Emerging Research and Specific Applications of OR
Invited session
Chair: *Ewa Wiecek-Janka*
Chair: *Athanasios Yannacopoulos*

1 - Uncovering "dynamism" in annual reports: A methodological approach using resource mapping
Martin Kunc, Federico Barnabè

This study explores the role of qualitative System Dynamics (SD) in analyzing, evaluating, and representing the information of corporate annual reports to increase their value by uncovering their hidden "dynamism". Financial statements are often said to be too static, not able to show clearly, holistically, and comprehensively an organization's value creation, thereby entailing the need for several complementary sources of information (in addition to the balance sheet and the income statement) - often provided textually through accompanying reports, such as the management commentary. To translate the information contained in a traditional annual report into a holistic, dynamic, and synthetic representation of the organization's value creation processes, this study employs a specific qualitative SD technique, Resource Mapping, and outlines a methodology to apply it in practice. Examples from real case studies are provided to support our methodological proposal. This study has several contributions. First, we provide methodological guidelines and practical insights on how to apply qualitative SD in the field of financial accounting and corporate reporting. Second, we test the benefits of applying qualitative SD to financial reporting tools to develop new knowledge useful to represent and face the dynamic complexity implicit in a business environment. Third, the study expands the role traditionally assigned to financial statements in SD-based studies.

2 - What can OR do for measuring Small and Medium Enterprises (SMEs) performance in the context of Digital Transformation without neglecting Sustainability?
Isotilia Costa Melo, Geandra Alves Queiroz, Paulo Nocera Alves Junior, Wilfredo Yushimito, Jordi Pereira

Digital Transformation (DT) is a global process provoking considerable impacts on the bottom line of sustainability (economic, social, and environmental). Although DT has been a challenge for all enterprises' competitiveness, Small and Medium Enterprises (SMEs) face different challenges than larger enterprises (e.g., more limited resources and specialization capabilities). Consequently, these factors reflect on their DT process. So, Operational Research (OR) brings essential tools for ensuring their SMEs' competitiveness in the context of DT as they are globally responsible for 90% of all business and 50% employment. In this sense, this presentation aims to describe and analyze the state-of-the-art OR tools applied to research sustainable DT performance in SMEs employing a systematic literature review. For this purpose, until December 2021, we executed two loops of systematic literature review in Scopus and Web of Science. After filtering 331 papers, we selected 35 papers related to aspects of sustainability beyond the economic one. With these 35 papers, we performed a content identifying the frequency of methodological approaches and relationships among variables. It was also possible to determine sustainable DT's driving forces (e.g., entrepreneurship, innovation, etc.). The findings are an initial step for the debate in the literature of OR and DT in SMEs by systematically bringing the currently used tools and debating future research.

3 - An Interactive Method for Multiresponse Robust Design Problem with Continuous and Ordinal Quality Characteristics
Leman Esra Dolgun

This study proposes an interactive method for simultaneous consideration of continuous and ordinal quality characteristics in robust design of products or processes. Although the literature presents several approaches for the multiresponse robust parameter design problem when all of the responses are continuous, the methods for the problem involving ordinal as well as continuous responses are limited in number and effectiveness. Often design parameter settings that give desirable results for some quality characteristics give inferior results for the others. Therefore, determination of the best compromising solution requires incorporating decision maker preferences into the solution process. For this purpose, the proposed method estimates preference parameter values interactively using the preference information provided by a decision maker in the form of comparisons of some alternatives. The performance of the proposed method is analyzed for different cases generated by considering different values of preference parameters and stopping conditions.

4 - Interdiction of Interdependent Networks: A Look at Illicit Trafficking Networks
Victor Jose, Jun Zhuang, Nafisa Mahbub

Illicit trade networks often involve the trade of various illicit commodities which often interact and generate synergies in illicit trafficking networks. In this talk, we examine the problem of interdicting interconnected (and often dependent) illicit networks by examining the benefits and problems of jointly considering the interdiction problem. In particular, we focus on the human trafficking network problem and its strong connection to the drug trafficking problem, that are often considered separately. Given the limited resources often available to government agencies in interdicting these networks, structural and operational dynamics within and across these interconnected (often interdependent) networks could potentially be exploited to provide a better coordinated response. Using a joint bi-level maximum flow network interdiction model, we illustrate the benefits of pooling interdiction resources to address this issue and illustrate scenarios when the notion of pooling is sub-optimal. Numerical illustrations, sensitivity analyses, and extensions to other various contexts and set-ups will also be briefly discussed.

■ TA-26

Tuesday, 8:30-10:00 - Y309b

Humanitarian and healthcare operations: challenges and way forward

Stream: EWG HOpe, EURO working group on Humanitarian Operations
Invited session
Chair: Abdelsalam Hamid Abakar

1 - Addressing the uncertainties over cash assistance and local procurement in complex emergencies
Amin Maghsoudi, Wojciech D Piotrowicz, Russell Harpring

There is a growing interest in the decision between cash assistance and/or in-kind assistance through local procurement in humanitarian operations. Yet, finding an optimal solution is complicated due to the number of measurable and immeasurable factors. There is much literature on the benefits, cost-effectiveness, and efficiency of cash and voucher assistance (CVA) compared to in-kind assistance. But even so, a number of implicit factors need to be considered which may influence outcomes. In this research, we attempt to address some of the context-specific features that create uncertainties in humanitarian operations, and this affects the types of aid (cash or in-kind) that is delivered in complex emergencies. The findings of the research can help decision and policymakers to include these implicit factors in their decision-making between cash, in-kind, or a combination of both through the local procurement in such settings. The challenging factors can be considered for further multicriteria decision-making analysis in the future. The research results are part of the Cash and/or Carry research project funded by Academy of Finland.

2 - Leveraging Humanitarian Supply Networks to Improve Information Sharing
Russell Harpring

This paper explores the complexities involved in procuring financial services during a humanitarian emergency and provides insights into how organizations can leverage their supply network to overcome challenges. This research expands upon the concept that supply chain learning by analyzing how information is shared within a network of humanitarian actors, and how that information can mutually enhance actors' capabilities within the network. These concepts are then illustrated through a case study of a group of five different international humanitarian organizations conducting a joint procurement exercise to establish multi-year contracts with financial service providers in Mexico amid the COVID-19 outbreak. Each humanitarian organization has a unique network of stakeholders (including beneficiaries who will receive the cash transfer) as well as their own SOPs, capacities, and internal regulations to abide by. Barriers to access, including financial literacy and service availability added another layer of complexity to the problem. Thus, the primary objective of this research is to understand how collaborative partnerships influence capabilities at the organizational level and inter-organizational level, and how the network structure influences information flows between partners, thereby enhancing knowledge creation and retention.

3 - Mobile Laboratories - An innovative approach to bridging the diagnostics gap in low- and middle-income countries
Thomas Breugem, Tim Sergio Wolter, Luk Van Wassenhove

Mobile laboratories provide great opportunities to improve access to health in low- and middle-income countries. Over the past years, they have been a successful part of outbreak response for epidemic-prone diseases (e.g., Ebola). However, like for most technological innovations in health and humanitarian supply chains, there are many alternative potential use cases for the technology, especially outside of periods of emergency response. In case of mobile laboratories, such applications include surveillance and screening, patient follow-up for chronic diseases, or providing an integrated testing and care package to rural areas, refugee camps, or following natural disasters. Each use case leads to a different preferred operational model. In this research, we present insights from our collaboration with a start-up specialized in mobile health laboratories. We combine a field study with quantitative modeling to assess key factors determining the best operational model for each service. We also provide recommendations regarding the most impactful combinations of services and operational models. Our results highlight the potential of mobile health innovations, but also underline that one should carefully determine their usage to unlock their full potential.

4 - Prediction of Migration Paths Using Agent-Based Simulation Modeling: The Case of Syria
Dilek Gunnec, Ozlem Gungor, Sibel Salman, Eda Yücel

The Syrian civil war, which started in 2011, has caused a great wave of forced migration in the Middle East. One of the most popular destination points for Syrian refugees has been Turkey. The purpose of this study is to predict the routes of refugees who leave the conflict areas in Syria to reach the refugee camps located in Turkey during a crisis. The study proposes an agent-based model to simulate the decision mechanisms of refugees in a highly uncertain environment. The model employs the A* algorithm to calculate the cost of each available destination point (refugee camp) for each agent, based on their risk preferences and starting locations and allows agents to choose the camp with the minimum cost as the destination point. By use of the model, we simulate a moment of crisis namely the South Idlib bombardment (from December 2019 to January 2020) under four different scenarios that are generated considering the real-life data gathered from the newspapers of December 2019 and various other sources. The simulation results show the main pathways of Syrian refugees and give insights about the required camp capacities. The results are compared with the gathered secondary data to validate the proposed model.

■ TA-27

Tuesday, 8:30-10:00 - Y313

Computational Methods

Stream: Splitting and ADMM Methods
Invited session
Chair: Dimitri Papadimitriou

1 - Computational advances in polynomial optimization with RAPOSa solver
Brais González Rodríguez, Joaquín Ossorio-Castillo, Julio González-Díaz, Ángel Manuel González Rueda, David R Penas, Diego Rodriguez Martinez

In this paper we introduce RAPOSa, a global optimization solver specifically designed for (continuous) polynomial programming problems with box-constrained variables. Written entirely in C++, RAPOSa is based on the Reformulation-Linearization Technique developed by Sherali and Tuncbilek (1992) and subsequently improved in Sherali et al. (2012) and Dalkiran and Sherali (2013). We present a description of the main characteristics of RAPOSa along with a thorough analysis of the impact on its performance of various enhancements discussed in the literature, such as bound tightening and SDP cuts.

2 - A Superlinearly Convergent Method for Minimizing Max Functions
Mina Saee, Russell Luke

We present a numerical method for minimizing the maximum of smooth convex functions which incorporates recent developments in nonsmooth analysis. Our proposed method is a two-phase approach where in the first phase random sampling and "cutting quadratics" are applied to identify the active manifolds at the solution. This phase of the algorithm is finitely terminating. The second phase of the algorithm proceeds along the lines of conventional approaches, through our analysis shows superlinear convergence without the usual assumptions of strong convexity.

■ TA-28

Tuesday, 8:30-10:00 - Y405

Data Science and Analytics Applications 3

Stream: Data science and Analytics (contributed)
Contributed session
Chair: Ragnar Eggertsson

1 - Anomaly Detection for Cash Operations in Retail Stores
Buse Mert, Ilknur Bektas, Defne İdil Eskiocak, Birol Yüceoglu, Basak Ayfer Erdem, Karin Çakan, Işıl Öztürk

FMCG companies operate a large number of stores in a wide variety of locations throughout the country. Cash operations in such a distributed setting can be difficult to audit and is prone to fraud. For this reason, we study the cash operations in one of Turkey's leading FMCG retail companies with more than 2500 stores using anomaly detection techniques to detect fraudulent activities carried by the employees. In this setting, each store keeps a certain amount of cash to carry their daily operations smoothly, such as returning change in cash payments. The remaining cash is regularly transferred to banks. Along with the sales, these operations constitute the flow of cash in retail stores. As the store safes are handled by store managers, this operation is open to fraud and cause significant losses for the company. In this study, we aim to detect anomalies in safe of stores and to determine if there is malicious intent. To identify anomalies, we examine the transactions affecting the safe of stores and create features based on past frauds. The aforementioned transactions are essentially the cash in and out transactions and the audits that are carried out. By considering the cash transactions with the employees, bank transfers, the remaining cash amount in the store and audits we employ Local Outlier Factor and Isolation Forest algorithms to detect frauds in the data. We share our results, including real life frauds.

2 - Portfolio Optimization across Financial Market States: An application of Clustering Algorithm
Salah Ayari, Hayette Gatfaoui

Investing in a multi-asset class fund provides exposure to a variety of asset classes. This diversification aims to reduce unsystematic risk. At the same time, each asset class has its own distinctive characteristics in terms of risk and return that may vary over time. Moreover, financial markets are becoming more and more interconnected and respond in diverse ways to each new piece of information available on the market. Therefore, identifying the various states of the financial markets is extremely essential in order to adjust the portfolio's exposure towards the different asset classes. It is within this context that we analyzed the Russell 2000 and the commodities market (energy, agricultural products, metals) from 2006 to 2022.We identified the different states of the markets using a machine learning technique based on the observed change in the structure of the correlation matrix. Then, we have built an actively managed portfolio composed of stocks and commodities and which is rebalanced at each change in the behavior of indicators anticipating the transition from one market state to another. We finally compared the performance of this strategy to a portfolio composed of indices reflecting the Russell 2000 and commodities.

3 - Discrete-Time Survival Analysis of Aircraft Maintenance Data for Planned Maintenance
Young H. Chun, Seong-Jong Joo

We focus on the failure patterns of a complex electronic and armament system in the military aircraft in the US Air Force. As soon as the system fails, the aircraft aborts a mission and returns to the Air Force base immediately. Under the current reactive or breakdown maintenance plan, the mission-critical system is repaired or replaced only when it fails. The successive system failures can be modelled as a renewal process.

In practice, the cost of aborting a training or combat mission is much higher than the cost of replacing the mission-critical system. Thus, it would be more cost-effective to replace the complex system on a regular basis even before it breaks down. Under the preventive or planed maintenance plan, the system is replaced after a certain number of flights.

The number of flights or sorties is a discrete variable, and we propose a discrete-time survival model and analyze the failure patterns of the system. We fit the military aircraft maintenance data and flight records into a discrete-time Weibull model and estimate its two parameter values. The Weibull model is then used to develop a preventive maintenance plan that minimizes the expected total cost per sortie in the renewal-reward process of system failures.

4 - Maintaining capital goods under incomplete information and constrained maintenance capacity
Ragnar Eggertsson, Rob Basten, Geert-Jan van Houtum

Condition-based maintenance is a maintenance paradigm that minimizes interventions and the revenue losses associated with breakdowns of capital goods. This is achieved by performing maintenance based on the capital goods' health, such as maintaining when the capital goods' health indicates failure is imminent. We study how the Dutch Railways can use condition-based maintenance for the heating, ventilation, and air-conditioning units (HVACs) used in a fleet of trains. Maintenance planning for these components has two primary challenges: environment-dependent degradation information and limited maintenance capacity. First, the failures of HVACs only become obvious in the summer when passenger car temperatures rise above desired levels, indicating that an HVAC's cooling system has failed. For the heating system, there is a backup. Second, only limited maintenance capacity is available for HVAC maintenance. These challenges come together in the summer if the number of HVACs requiring maintenance exceeds the maintenance capacity. We introduce a Markovian model that considers both the uncertainty about the degradation state and the maintenance capacity constraint. Furthermore, we formulate numerical experiments based on the company case of the Dutch Railways. We solve these large-scale problems using machine learning methods from computer science. This leads to managerial insights on mitigating the combined risks of information uncertainty and constrained resource capacity.

■ TA-29

Tuesday, 8:30-10:00 - M1

Manufacturing III

Stream: Industrial Production, Planning and Inventory Management
Invited session
Chair: Joaquin Sicilia-Rodriguez

1 - The influence of responsiveness on the design and asset cost of a make-to-order multiproduct batch plant
Amy Van Meir, Trijntje Cornelissens, Johan Springael

Having a responsive production environment is of utmost importance to be competitive in today's business world. An important performance indicator for responsiveness is the delivery lead time, i.e. the time a customer waits between ordering and receiving a product. In a make-to-order (MTO) situation, this delivery lead time includes the production lead time. In this research, we study the responsiveness of a multiproduct MTO batch plant by introducing a target production lead time to the plant design model, and observe the impact of this lead time on the capital costs of all production and storage tanks needed to cover the target demand over a specific planning horizon. In our MTO batch plant model, each customer order is treated as a single production batch to be produced and stored until loaded. All batches remain in storage tanks for at least two hours, to account for quality control. Since customer orders have a due date (out-of-factory date), and the production lead time is constrained by the target production lead time, the earliest start date for production and end-of-storage date of all batches are known. The number and sizes of production and storage tanks are obtained by minimizing the total capital cost of the plant. The effect of the target production lead time is analyzed for different sets of customer orders. The mathematical model is solved by means of exact methods and heuristics in case of respectively small and large instances.

2 - An optimization model based on flexible lead times for semiconductor wafer fabrication

Sungwon Hong, Younsoo Lee, Kyungsik Lee

In this talk, we consider the production planning problem which arises in a semiconductor wafer fabrication industry. The wafer fabrication is one of the most complex production systems which involves a number of process steps and machines, as well as re-entrant process flows where products must return to the workcenter multiple times. In this regard, it is challenging to model the wafer fabrication process for establishing an efficient production plan. In this talk, we propose an optimization model based on flexible lead times that considers the transition of the WIP states over time as well as the relationship between WIP levels and lead times to properly capture the dynamics of the process. The results of simulation experiments using SMT2020, the real-size FAB instance, show the advantages of the proposed model compared to the existing models.

3 - Optimal feature selection for new product development considering economies of scale

Shaghayegh Ramezanpour Shalmani, Laurent Alfandari, Sara Rezaee Vessal

Feature selection across different versions of a product, to create a sufficient level of differentiation and yet satisfy customers' expectations, is one of the complex decisions that companies need to make frequently. In this research, using mathematical modeling (Mixed-Integer Linear Programming), we consider feature selection decisions for different versions of a product. In this problem, we include the decision on including several features and the levels of each feature in various versions. We study the trade-off between the cost of the products, customers' utility based on a first-choice model, and firms' profit. We also consider economies of scale as a process in the market which impacts firms' decisions in product design and pricing policy, by taking into account reduced per-unit costs when purchasing more components of the same level across versions of the product. We conduct extensive numerical experiments and provide managerial insights for new product development.

4 - Optimal production-inventory policy for products with time-dependent demand pattern and backlogged shortages

Joaquin Sicilia-Rodriguez, Luis A. San-José-Nieto, Manuel Gonzalez-De-la-Rosa, Jaime Febles-Acosta

In this work, we study a production-inventory system for items with a time-dependent demand pattern. Shortages are allowed and these are met with the arrival of the next production run. We analyze the fluctuations in the net inventory level and calculate the costs related with the production and inventory management. The aim is to maximize the profit per unit time. That profit is equal to the difference between sale revenue and inventory costs. In the analysis of the production-inventory system, different scenarios can occur. All these possible cases are studied in detail and, for each scenario, we determine the optimal production-inventory policy and the maximum profit per unit time. Moreover, we present several numerical examples to illustrate the solution methodology.

■ TA-30

Tuesday, 8:30-10:00 - M237

Metaheuristics in Scheduling

Stream: Project Management and Scheduling
Invited session
Chair: *Jürgen Zimmermann*

1 - Order acceptance and scheduling: revenues versus holding, tardiness and machine costs

Federico Perea, Juan Camilo Yepes Borrero, Mozart Menezes

In a production scheduling setting, the Order Acceptance and Scheduling (OAS) problem consists of deciding which orders to accept, and how to schedule them, to optimize a certain objective. The OAS has been deeply studied in the literature. In this talk we study an OAS with the following specifications: a number of machines is available for producing a number of jobs. Each job can be produced by one of the available machines, and processing times are known. Also, machines need setups between processing two jobs, which are also known. Jobs yield revenues if they are accepted. Releasing times and due dates are known. Also, holding costs and tardiness penalty costs are considered. The use of machines also involve costs, both fixed and variable. The problem consists of deciding which jobs to accept, how to schedule the accepted jobs, so total net profits are maximized. We propose a mixed integer linear programming model for this problem, as well as a GRASP metaheuristic algorithm. Both are tested over a number of randomly generated instances. Results show that the mathematical model can only solve to optimality small-sized instances, whereas the metaheuristic finds good-quality solutions in short computational times.

2 - Exploring the potential of a genetic algorithm on a real-world complex scheduling problem

Szilvia Erdős, Bence Kovari

Genetic algorithms on NP-complete problems are widespread since it is easy to obtain a solution to the problem. However, its optimality gives the real issue, and it is not guaranteed to be achievable. In our research, we address a special subproblem of scheduling problems, the final exam scheduling, in which special requirements restrict the state space, which often contradicts each other. The task's difficulty is the huge size of the state space. Genetic algorithm-based solutions were considered since we could not find a solution using a MILP solver. We built a model that can solve this large problem using the genetic algorithm. Most of the possibilities were seen in the different mutation procedures, so we investigated them in more detail. A question for genetic algorithms is what parameters and probabilities to run the model with, since the more freedom we give to the run, the larger the runtime, and finding the threshold between the two is essential. Therefore, our experiments performed measurements on large real data sets to find the optimal values for this complex problem. The resulting algorithm can significantly facilitate the lengthy manual scheduling processes carried out so far in our university.

Ack.: The work has been carried out in the frame of project no. 2019-1.1.1-PIACI-KFI-2019-00263, implemented with the support provided by the National Research, Development and Innovation Fund of Hungary, financed under the 2019-1.1. funding scheme.

3 - A hybrid genetic algorithm for the re-entrant flexible flow shop with labour resource constraints

Johanna Mlekusch, Richard Hartl

The re-entrant flexible flow shop scheduling problem is a special version of the well-known flow shop problem. In addition to the classical flow shop problem, identical parallel machines are grouped in stages. Furthermore, stages may be skipped and operations may return to the same stage one or more times before completion. Our problem is inspired by a real-world problem of a company using screen printing techniques. The production process requires every machine to be operated by a skilled worker, and not every worker can operate every machine. Scheduling problems that are constrained by workers and machines, are referred to as Dual-Resource Constraint (DRC) problems. We refer to our problem as the Dual- Resource-Constrained Re-entrant Flexible Flow Shop problem (DRCRFFS). The objective is to minimize the maximum completion time, which indicates production costs. We solve the problem by using a mixed-integer program formulation (MIP), implemented using IBM ILOG CPLEX, and a hybrid genetic algorithm (HGA) based on an indirect and single-level solution representation combined with an effective decoding method. The results show that the proposed HGA outperforms the solutions of the formulated MIP in the majority of cases and performs well overall. The methods are compared on a set of instances up to 20 jobs, 10 stages, 9 workers and 2 re-entrances. Furthermore, we analyse the performance of our method on benchmark instances in a setting without labour constraints.

4 - Resource overload problem with makespan-dependent cost: structural properties and solution approaches

Lena Wohlert, Jürgen Zimmermann

To minimize high resource utilizations in projects, the resource overload problem with a prescribed project deadline has been considered in literature. However, project scheduling is an inherently multi-objective problem, and typically exceeding the prescribed project duration is allowed at additional cost, which can represent penalties for missed deadlines. In this work, these extension cost are added to the objective of the resource overload problem. Apart from the practical application, the problem is also interesting from a theoretical perspective because of its structural properties. Depending on the characteristics of the extension cost function, we divide the problem into subproblems with different specifications for the project duration. Given integer input, we prove that for each subproblem, a candidate set of schedules with only integer activity start times contains at least one optimal solution.

To solve the presented problem, a time-discrete MIP formulation is introduced. The extension cost function can be linearized because the applicable extension cost for every integer project duration can be calculated in advance. Moreover, we propose a genetic algorithm based on a random key representation. The encoding scheme only constructs schedules within the candidate set by using an objective-oriented schedule generation scheme. Experiments indicate that the heuristic obtains significantly better solutions for medium to large instances compared to the MIP.

■ TA-31

Tuesday, 8:30-10:00 - M240

Methodological and practical contributions of Soft OR/PSMs to Policy Making - A

Stream: Problem structuring and soft OR

Invited session

Chair: *Ine Steenmans*

Chair: *Irene Pluchinotta*

1 - Co-designing policies for the resilience of the Water-Energy-Food nexus

Raffaele Giordano

The Water-Energy-Food (WEF) Nexus has been proposed to emphasize the need to focus on the detection and analysis of the interdependencies among the different ecological resources and ecological processes affecting the three domains. Improvements in the design of intersectoral policies are still lacking. Interdependencies among resources have been often neglected in sectoral policies with the consequence of persistent trade-offs rather than the strengthening of synergies. The nexus should be governed with a focus on the interaction between policy fields and not on policy fields in isolation. Although the arguments in favour of collaboration and the studies supporting these claims are numerous, there is also ample evidence that collaboration does not always deliver substantial benefits. In highly contested policy contexts - such as those related to environmental management - not necessarily collaboration has a substantial impact on the effectiveness of the policy design process. This work describes an innovative approach based on the combination of Problem Structuring Methods and System thinking to map and analyse the complex and non-linear interactions among human behaviour, ecological resources and processes, and ecosystem services provided for the WEF Nexus. The method has been implemented for enhancing collaboration and overcoming socio-institutional fragmentation in the Nexus management.

2 - Cognitive Maps and Value Trees in Conflict Transformation and Management

Halil Berkay Tosunlu, Joseph Guillaume, Irene Pluchinotta

The paper analyses cognitive maps and value trees as tools for managing and transforming conflicts with a policy design study in Tunisia. Our first aim is to help stakeholders involved in the conflict by using two well-known Problem Structuring Methods in decision aiding: cognitive maps and value trees. We combine cognitive maps and value-focused thinking for constructive conflict transformation. Our research's first leg is about applying a formal construction method from a cognitive map to a value tree. For this purpose, we propose a value-cognitive map as an intermediate step. Theoretically, the construction method of value tree out of cognitive map needs unique algorithms in terms of graph theory. We applied the Tunisia groundwater management case study with a formal interviewing guide; we had 14 interviews, including administration, researchers, and local farmers. We constructed cognitive maps and derived value trees from cognitive maps. Such value trees could be used as input for structuring knowledge and concepts, a method for the generation of alternatives based on design theory.

3 - Pathways for improving heat pump performance in the UK: understanding the complex network of socio-technical influencers

Eleni Oikonomou, Tadj Oreszczyn, Mike Davies, Nici Zimmermann

The UK Government views heat pumps (HPs) as an increasingly important technology that can contribute significantly towards heat decarbonisation in the building sector and has committed to the annual installation of 600,000 HPs in existing houses by 2028. However, the efficiency of HPs in real life is often very different to that predicted by technical design experts. The aim of this study was to offer deeper insights into HP performance influencers and address the emerging enablers to high-performing domestic HPs in the UK.

The research design was based on a multiple case study approach, utilising the quantitative data of the larger Renewable Heat Premium Payment field trial population as the basis for the selection of 21 case studies. Systems thinking, in the form of causal loop diagrams, was utilised as the integrating framework for the interpretation of the qualitative and quantitative data collected through field monitoring and in-depth site investigations.

The findings showed that HP performance relies on an extensive network of complex socio-technical system interactions, ranging from the strictly technical system aspects to a variety of boundary conditions acting within the building envelope and including interactions with the household. The study achieved new insights into the requirements for well-performing HPs, which have important implications for policy makers, manufacturers, installers and users of HPs.

4 - Differences in system boundary perceptions: comparing Causal Loop Diagrams

Irene Pluchinotta, Giuseppe Salvia, Gemma Moore, Nici Zimmermann

Participatory modelling approaches have become increasingly popular tools to support policymaking thanks to the ability of clarifying and integrating participants' diverse views, knowledge, values and perceptions of system boundaries. This is important because not only stakeholder groups but also modellers, whose work supports decision-makers, or decision-makers themselves are bounded by their view of the system. Differences in system boundary perceptions may lead to misperceptions, polarisation and wrongly focused decisions that could potentially have negative knock-on effects to wider issues. Within this context, some research exists to compare the mental model of different actors involved in a policy problem. However, there is limited research that compares the system perception of modellers, of decision-makers and other groups of stakeholders. We also lack comparing methods for large Causal Loop Diagrams (CLDs) providing results that are comprehensible by a diverse range of stakeholders. This talk presents advances on a method to compare CLDs, and more generally causal maps, based on qualitative (thematic analysis) and quantitative analysis (centrality index). The talk describes the methodology applied to an urban sustainability case study. It provides also preliminary insights on stakeholders' feedback on the usefulness of this approach.

■ TA-32

Tuesday, 8:30-10:00 - F101

EVs and Green Transportation

Stream: Sustainable Development and Green Technologies
Invited session
Chair: Bilgenur Erdogan

1 - Efficient Emission Reduction Through Dynamic Transportation Mode Selection
Melvin Drent, Poulad Moradi, Joachim Arts

We study the inbound transport and inventory management decision making for a company that sells an assortment of products sourced from outside suppliers. Stochastic demand for each product arrives periodically and unmet demand is backlogged. The inbound transport is outsourced to a third party logistics provider that offers two distinct transport modes for each product. These modes differ in terms of their carbon emissions, speed, and costs. The company needs to decide when to ship how much using which transport mode such that total holding, backlog, and procurement costs are minimized while the total carbon emissions from transportation for the entire assortment remains below a certain target level. Such assortment-wide constraints will be increasingly prevalent, either voluntarily or enforced by government regulation. Since the optimal policy for this inventory/distribution system is highly complex, we assume that shipment decisions for each product are governed by a dual-index policy. We formulate this decision problem as a mixed integer linear program that we solve through Dantzig-wolfe decomposition. We benchmark our decision model against two state-of-the art approaches in a large testbed based on real-life carbon emissions data.

2 - A spatio-temporal approach for EV charging infrastructure deployment
Marc-Olivier Metais, Oualid Jouini, Yannick Perez, Jaâfar Berrada, Emilia Suomalainen

A transition in this sector towards greener mobility is an important lever to reduce global greenhouse gas emissions. The solution currently at work is to transform the fleet of internal combustion vehicles into a fleet of electric vehicles, with much lower emissions. Such a transformation cannot take place without the acceptance of electric vehicles by users. To achieve this user acceptance, electric vehicles must be as convenient as internal combustion vehicles in their daily use, including for those who cannot charge their vehicle at home. An important step required to achieve this goal is the existence of a charging infrastructure adapted to the needs of vehicle users. But due to the high cost of deploying such an infrastructure, it cannot be a prerequisite for the pre-eminence of electric vehicles in the fleet on the road: the infrastructure cannot precede the democratization of electric vehicles but must accompany it, pulling this two-sided market upwards.

We propose in this paper an infrastructure deployment model focussed on user needs, considering the integration of both spatial (where to place the charging stations) and temporal (in what order to place them) aspects in charging infrastructure deployment. The objective of the analysis of this model is to obtain the charging infrastructure that offers the best possible service to users.

3 - Finding an Energy Efficient Path for a Plug-In Electric Vehicle via Speed Optimization
Bilgenur Erdogan, Mustafa Kemal Tural, Arsham Atashi Khoei

In recent years, due to increased environmental and social awareness, sustainability related studies have gained popularity. Due to their adverse effects to the environment, greenhouse gas emission reduction has been a major concern in several areas of studies. In particular, there has been an increased interest in the logistics sector to control carbon dioxide emissions. The use of electric vehicles has a great potential due to their lower tailpipe carbon dioxide emissions compared to vehicles with internal combustion engines. In the direction of this advantage, a problem for Plug-In Electric Vehicles (PEVs) is proposed in this study. Given an origin-destination pair over a directed network, the problem of determining a path joining origin and destination, the speed of a plug-in electric vehicle on each road segment, i.e., arc, along the path, the charging stations the vehicle will stop by, and how much to recharge at each stop so as to minimize the total amount energy consumption of the vehicle is considered. There are speed limits on each road segment, and the vehicle has to arrive at the destination on or before a given time-limit. For this problem, a mixed-integer second order cone programming formulation is proposed. Secondly, to be able to solve larger size instances, a matheuristic is developed. Lastly, an iterated local search (ILS) algorithm is designed for this problem. Solution quality and computation times of the heuristics and the exact algorithm are compared.

■ TA-33

Tuesday, 8:30-10:00 - F102

Game Theory and Operations Management 3

Stream: Game Theory and Operations Management
Invited session
Chair: Ignacio García-Jurado

1 - Government subsidy, Micro-Small-Medium- Enterprises channel power, and product and process innovation
Nandan Kumar Singh, Vinay Ramani

Medium-Small-Micro-Enterprises (MSMEs) in emerging markets such as India are adopting many of the disruptive technologies associated with Industry 4.0 such as Additive Manufacturing, Machine Learning, and Blockchains. The MSMEs have received support from the government, which runs several schemes - one among them being a subsidy. We study the impact of such schemes by considering a supply chain with an upstream and downstream firm, and ask the following questions. First, should the government subsidize product or process innovation? Second, what is the optimal subsidy provided by the government? We have constructed a simple stylized analytical model consisting of a supply chain where either the upstream or downstream firm invests in innovation efforts. Through our stylized model consisting of the government, upstream firm and downstream firm, we study the impact of government subsidy on the strategic choices of the firms as well its impact on social welfare. Our model has two main findings - First, we show that the government's decision on which type of innovation to subsidize critically depends on which entity in the supply chain is the leader and which entity is the follower. Second, the government's decision of subsidizing a particular type of innovation also depends on the trade- offs related to social welfare and profit of the upstream and downstream entities. Our work may be useful in explaining the government's policy of subsidizing both types of innovation.

2 - Incomplete cooperative games and 1-convexity
Jan Bok, Martin Cerny

The model of incomplete cooperative games incorporates uncertainty into the classical model of cooperative games by considering a partial characteristic function. Thus the values for some of the coalitions are not known. The main focus of this talk is the class of 1-convex cooperative games under this framework.

We are interested in two heavily intertwined questions. First, given an incomplete game, in which ways can we fill in the missing values to obtain a classical 1-convex game? Such complete games are called 1-convex extensions. For the class of minimal incomplete games (in which precisely the values of singletons and grand coalitions are known), we provide an answer in terms of a description of the set of 1-convex extensions. The description employs extreme points and extreme rays of the set. We also provide bounds on sets of 1-convex extensions for such games.

Second, how to determine in a rational, fair, and efficient way the payoffs of players based only on the known values of coalitions? Based on the description of the set of 1-convex extensions, we introduce and compare generalisations of three solution concepts (values) for complete games: the tau-value, the Shapley value and the nucleolus.

We shall also briefly talk about incomplete games with defined upper vector, asking the same questions and this time arriving to different conclusions. This will highlight both importance and difficulty of considering more general classes of incomplete games.

3 - Priority coalitional games and claims problems
Iago Núñez Lugilde, Estela Sanchez-Rodriguez, Arantza Estévez Fernández

In this lecture, we analyze priority coalitional games as an extension of cooperative games with transferable utility. Conditions imposed by an allocation used in the past need to be respected when deciding on a new allocation of the revenues obtained by the grand coalition. On one hand, benefit obtained by cooperation has to be shared without harming a protected group and, on the other hand, no agent outside the group should benefit. Pulido et al.(2002) extend claims problems by adding a vector of references representing the minimal agents' rights. Pulido et al.'s model can be embedded in our model when the references are given from an allocation of the estate and the purpose is to benefit or harm a group of agents. Using claims problems, we define weak and strong priority games with respect to a given allocation and study their properties. Moreover, priority games can be used to analyze cooperation restricted by a hierarchical structure. First, we select a solution to the game without hierarchy. Second, we consider the associated weak or strong priority game to establish an allocation respecting the hierarchical structure where the priority is induced by this hierarchical structure. We focus on the class of games with a non-empty core and take as starting point a value satisfying core selection. We then define the corresponding hierarchical value that satisfies a weak or strong monotonicity property. Finally, we establish differences with the model of Fiestras et al.(2015).

4 - A new Shapley value-based rule for distributing delay costs in stochastic projects
Ignacio García-Jurado, Juan Carlos Gonçalves, Julian Costa

In this paper we propose a new allocation rule for stochastic projects with delays based on the Shapley value and compare it with an- other Shapley value-based rule introduced in a recent paper. First we justify the interest of considering a new rule of this kind, then we compare it with the old one in some examples and nally we study some theoretical properties that distinguish them.

■ TA-34
Tuesday, 8:30-10:00 - T003

E-Grocery Home Delivery

Stream: Smart Mobility and Logistics
Invited session
Chair: *Niels Agatz*

1 - Personal Shopper Systems in Last-Mile Logistics
Alp Arslan, Jelmer Van der Gaast

A personal shopper system (PSS) plays an intermediary role between retail stores and online customers. In the PSS, couriers visit stores to pick and purchase ordered goods and deliver them to customers. This study explores the PSS as an alternative instant last-mile logistics strategy compared to an inventory owned instant delivery system (IOD) operating typically through distribution centres or so-called dark stores. Even though PSSs are asset-light, and hence attractive for investors, maintaining a good level of PSS service and carrying out instant delivery operations is more complex than the IOD. Therefore, we introduce the Instant Delivery Problem (IDP), which explicitly addresses PSS specific features such as real-time store selection and in-store product collection. We propose a tailored rolling horizon framework that utilizes column generation to browse updated delivery plans for arriving customer orders. Computational studies both in real-life inspired settings and in case studies on selected urban areas show the PSS is a highly competitive strategy compared to the IOD, particularly when dealing with small-sized customer orders. We observe that the performance of the PSS is robust when varying the delivery service time frame. The case studies also suggest that the PSS becomes even more competitive in areas where the retail store density is high.

2 - Machine Learning-Based Feasibility Checks for Dynamic Time Slot Management
Liana van der Hagen, Niels Agatz, Remy Spliet

In e-grocery, the customer must be at home to receive the bulky and temperature sensitive goods. Online grocers usually offer a menu of delivery timeslots for customers to choose from. They aim to only offer those time slots that allow for a timely delivery given the available vehicle capacity. Therefore, to ensure a reliable service, the retailer may want to close certain time slot options as capacity fills up. Which customers can be served in each time slot largely depends on the specific order sizes and delivery locations. Conceptually, checking whether it is possible to serve a certain customer in a certain time slot given a set of already accepted customers involves solving a vehicle routing problem with time windows. This is challenging in practice as there is little time available as e-grocers strive for almost instant response times. We explore the use of machine learning to support time slot decisions in this context. Our results on realistic instances using a commercial route solver suggest that machine learning can be a promising way to assess the feasibility of customer insertions. On large-scale routing problems it performs better than insertion heuristics.

3 - Estimation of a Consider-Then-Choose Customer Choice Model for Tractable Assortment Optimization
Jonas Schwamberger, Moritz Fleischmann, Arne Karsten Strauss

In attended home delivery services, the time slot offering problem is of high importance, as it significantly impacts the retailer's efficiency in providing this service. Customer choice behavior is a crucial factor to be considered in this planning problem. To facilitate this task, customer choice models have been developed that reflect the customer decision-making process. A particularly realistic choice model is the consider-then-choose model. This non-parametric customer choice model consists of two steps: in a first step, all eligible time slots are identified and in a second step, the considered time slots are ranked and the highest-ranked time slot is chosen. In this study, we use the consider-then-choose model to solve the time slot assortment problem. We propose an approach to estimate this choice model from historical transaction data and incorporate a structure that can be exploited in the online time slot offering decision. We evaluate our estimation and optimization approach in a realistic numerical study.

4 - A model-based approach to strategic demand management for attended home delivery

Katrin Waßmuth, Niels Agatz, Moritz Fleischmann

In recent years, e-commerce is continuously growing and new business models and services are entering the home delivery market. For example, in the case of e-grocery, on-demand startups promise 'instant' grocery delivery within a few minutes. This innovative service offering challenges many assumptions of existing fulfillment strategies. In this talk, we focus on attended home delivery, where the service provider and customer typically agree on a specific time window to ensure a successful delivery of the purchased goods. This step involves the customer directly in the service creation process. In managing the service offering, service providers thus face complex trade-offs between customer preferences and the efficiency of service execution. These trade-offs drive demand management decisions on various levels, from strategic design decisions to operational real-time control. While prescriptive analytics methods have been frequently applied to optimize demand management decisions on the operational and tactical level, model-based approaches for strategic service design are scarce to date. In this talk, we present new ideas on how to apply prescriptive analytics to strategic demand management in order to profitably capture the demand potential for attended home delivery services.

■ TA-35

Tuesday, 8:30-10:00 - T004

Freight transportation and logistic II

Stream: Transportation
Invited session
Chair: *Moritz Stinzendörfer*

1 - A three-stage service network design model in synchromodal transport

Thibault Delbart, Yves Molenbruch, Kris Braekers, An Caris

Synchromodal transport is potentially cheaper and more sustainable than unimodal road transport. However, capacity on high-capacity transport modes such as trains is usually determined a longer period in advance than truck capacity. When logistics service providers buy capacity on those services, they might lack complete information on their transport demand. Capacity decisions are then updated when additional information becomes available. This study proposes a service network design model to assist capacity decisions from the perspective of logistics service providers in a synchromodal setting. Existing literature addresses this stochastic problem with two-stage models in which the initial capacity decisions are taken based on a known demand distribution and recourse actions are taken once complete demand information is available. Our model differs by including a third intermediate stage during which updates are performed with partial information. Two types of uncertainty are included: stochastic demand and a stochastic decrease of the capacity available on the market, taking into account the overall demand on the market.

2 - Agent Based Simulation for Synchromodal Transport

Shafagh Alaei Jordehi, Javier Durán-Micco, Cathy Macharis

Synchromodal transport is an emerging concept that aims to transport freight efficiently by using dynamically several modes of transport. To this end, many decisions should be made in real-time, such as mode choice or vehicle routing, imposing several changes on how the players of the system operate. This study aims to model the interactions between different players in the transport network. Moreover, it is analyzed how collaboration between shippers and logistics service providers enhances the supply chain's sustainability and cost-efficiency. Therefore, the primary purpose of the paper is to study the problem of the delivery of containers transported by rail and roads in a synchromodal transport network. Using an agent-based modeling approach, the system is modeled as a collection of autonomous and heterogeneous agents (trains, trucks, terminals, DCs, retailers, etc.). The simulation model also includes different types of disruptions, such as service delays and cancellations, in order to provide robust solutions to the decision-makers. Moreover, several algorithms are executed inside the simulation model to optimize the operations of the logistic network. This work contributes to the field by providing a testbed for different actors in the supply chain to assess different scenarios and ideas inexpensively and in a risk-free environment.

3 - Integrated last-mile deliveries with truck and cargo bikes

Moritz Stinzendörfer, Philine Schiewe

Nowadays, the environmental aspect plays a major role in last-mile delivery concepts. Furthermore, parcel service providers are also facing increasing difficulties due to higher traffic and poor parking facilities. To address these challenges, we focus on two already established means of transport, the truck and cargo bike. In times of rising fuel prices and regulations such as car-free city centers, delivery by bike becomes even more attractive. Opposed to solving a two-step problem, where bike depots are installed and stocked separately, we are considering an integrated approach without further infrastructure needs. This results in a hybrid model of a truck, starting and ending at a depot with all goods, and a cargo bike that has to be resupplied during the delivery route. The main difference from related approaches is the general framework, which does not require predefined truck or bike nodes and allows transshipment at customer sites or specified locations. Moreover, we present a subclass of problems where we replace the truck with existing public transport vehicles such as a tram with fixed stations and schedule. We show that the resulting problem of scheduling only the bike tour can be solved by a polynomial algorithm if the bike capacity is one. In fact, this particular case can also be considered as a drone and tram (or bus) delivery concept.

■ TA-36

Tuesday, 8:30-10:00 - U006

Integrated Planning in Home Health Care

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: *Gréanne Leeftink*
Chair: *Melanie Reuter-Oppermann*

1 - An integrated nurse re-rostering and routing problem in home hospitalization

Anisha Maharani, Yasemin Arda, Véronique François

Home hospitalization provides home-based, short-term acute care to patients for a condition that otherwise would require inpatient admission. This research focuses on operational scheduling decisions in home hospitalization. Given the baseline roster of the nurses and the patients' requirements, the following decisions are taken simultaneously over the planning horizon: select new patients to be treated at home, assign the nurses to the patients, schedule the care visits, build the daily tours of each nurse, and update the roster if necessary. Therefore, the studied problem is a combination of nurse re-rostering, task scheduling, and nurse routing problems. In the literature, the underlying subproblems are generally solved separately as this approach is less complex and thus more computationally practical. However, this sequential decision-making process may lead to inefficient solutions or even infeasibility since the subproblems are strongly interrelated.

Before exploring the heuristic solution methods, a MILP model was developed to formalize the integrated problem. A variety of complex real-world characteristics are considered, yielding a rich model that relies on a stepping horizon approach in order to properly address the connections between consecutive scheduling periods. The presentation will discuss several challenges encountered due to the integration of scheduling, routing, and re-rostering decisions.

2 - Integrated decision-making in home health care: review and first model
Arne Delaet, Kris Braekers, Yves Molenbruch, Katrien Ramaekers

Home health care (HHC) may be defined as care workers visiting patients following predefined schedules in order to provide medical services in their home. As maintaining a sustainable and effective health care system is a major challenge, HHC providers must discover new ways to decrease costs and enhance productivity by optimizing the use of resources.

First, the findings of a literature review on OR models applied in HHC will be discussed. It was found that a key opportunity for improvement is the integration of decisions at different decision-making levels. Second, the specific problem setting on which we focus will be defined and its contributions will be stressed. This project contributes to the current state-of-the-art by integrating tactical (staff dimensioning) and lower decision-making (clustering, rostering, routing and scheduling) levels. A third part of the presentation will focus on the solution algorithm that is developed to solve the model under study. The solution algorithm first finds an initial feasible solution by using a combination of a tailored k-means heuristic to cluster patients and by solving a binary integer linear programming model to roster care workers. In a second phase of the solution algorithm, the initial solution is improved by executing iterations of a tailored large neighbourhood search heuristic. Finally, the results of some experiments conducted to assess the performance of the solution algorithm will be discussed.

3 - A decision-support framework for home health-care delivery – transportation planning with joint staff scheduling and multi-vehicle routing
Janny Leung, Yong-Hong Kuo, Jamal Abdul Nasir

Due to the ageing population, the provision of coordinated Home Health Care (HHC) to patients, many with chronic diseases, in their homes is increasing. The scope of HHC services is also expanding from typical nursing and post-operative care at home to other needs of elderly patients (e.g, personal care, drug delivery, meal services). We develop a mathematical model and solution method for health-care service delivery. Our decision-support framework captures the real needs of HHC services, including the simultaneous planning of schedules and routes for a set of HHC staff and Home Delivery Vehicles (HDVs) under the requirements of synchronization of visits between them, multiple visits to patients, multiple routes and pickup/delivery precedence for HDVs. We develop a Mixed Integer Linear Programming (MILP) model and a Hybrid Genetic Algorithm (HGA) to recommend HHC transportation decisions. The model and HGA are tested on real-life instances to examine its practicality, and on randomly generated instances to assess the scalability of the proposed approach. Experimental results indicate that the proposed algorithm performs well, even with an increasing number of required synchronized services, whereas the heuristic tactics facilitate the HGA to produce better-quality solutions in a significantly shorter time. We hope this work contributes to improving the effectiveness and efficiency of joint routing and scheduling of HHC, an important aspect of shared healthcare mobility.

4 - An integrated mobility concept for home care workers and ambulant patients
Lorena Reyes-Rubiano

Hospital treatment and home care face rising demand in Europe. Thus, the demand for transport of home care workers and vulnerable people is increasing. Today, the transport of home care workers and vulnerable people is performed independently of each other, leading to congestion of urban areas. We propose an integrated mobility concept to deal with the transport of home care workers and non-time-critical patients. The integrated mobility concept involves a trip-sharing system combined with the additional option of walking for home care workers. The home care service provision is related to the drop-off and pick-up of home care workers at the home of patients. Different qualification levels, service time windows, maximum ride times and maximum working hours have to be considered. We implement a matheuristic algorithm to determine this integrated transport. We design a series of computational experiments to evaluate the impact on the waiting and driving times of the home care workers and non-critical patients. Afterward, we will compare the waiting time and driving time of individual trips versus shared trips. This evaluation may shed light on standards for the waiting and ride times.

■ TA-37

Tuesday, 8:30-10:00 - V001

Rich Vehicle Routing Problems I

Stream: Vehicle Routing and Logistics
Invited session
Chair: Emanuele Pizzari

1 - Optimal Control of Autonomous Flying Vehicles in a Highly Dynamic Environment
Luigi Bobbio, Joerg Fliege

Autonomous flying vehicles are becoming more and more prominent nowadays and have manifold applications, some only about to emerge: collecting traffic data, surveillance and security, disaster management, wildlife observation, delivery services, and defence. Providing such vehicles with enough computational intelligence to automatically steer according to given objectives is a challenging task, only recently tackled with control algorithms working in soft-real time and computationally feasible for the limited on-board resources. Researchers and practitioners historically address the problem concentrating on two subproblems separately: (i) vehicle routing (VR), aiming at finding optimal itineraries for multiple vehicles visiting a set of locations, and (ii) trajectory optimisation (TO), whose purpose is to establish flight paths between locations optimising some performance measures while satisfying a set of constraints. This study aims at unifying the two aspects, also providing solution algorithms to the overall problem. First, a unique model for VR and TO is proposed where trajectory constraints are linearised through a Taylor expansion around a known solution to vehicles' equations of motion within predefined settings. Second, the above model is iteratively deployed in an adaptive configuration scheme, overcoming the local nature of Taylor's approximation and resulting in enhanced solutions to the overall problem. Further research developments are finally discussed.

2 - Simulated Annealing for the Vehicle Routing Problem with Drone
Mahdi Moeini, Oliver Wendt, Marius Schummer

We study the Vehicle Routing Problem with Drones (VRPD), which is an extension to the classical Vehicle Routing Problem (VRP). In the VRPD, we search for serving a given set of customers in the shortest possible time by means of a mixed fleet of trucks and drones. The VRPD is formulated as Mixed Integer Linear Program (MILP), which can be solved by any standard MILP solver. However, due to computational challenges of the VRPD, solvers can solve only small instances. To address larger instances, we introduce a two-phase algorithm based on the Simulated Annealing metaheuristic. Through extensive computational experiments using benchmark instances, we prove efficiency of our algorithm. In addition, we investigate the impact of using drones on energy consumption of the truck-drone fleet. According to the numerical results, we observe substantial benefits of using drones on reduction of makespan as well as energy consumption.

3 - Assessing Energy Usage of Public Service Vehicles in Urban Areas
Tudor Stincescu, Erica Ballantyne, David Stone

The growing popularity of electric vehicle (EV) technology has led to the adoption of EVs for passenger cars. Similarly, as computational capabilities expanded, model-based automotive applications of software simulation have also gained traction in various contexts due to their ability to simulate many types of complex electric powertrains with ease. However, there appears to be a lack of research presenting real-life applications that examine the impact of electrified powertrains in economic and environmental contexts. The featured material aims to look at the impact of implementing a fully electric refuse collection (eRCV) truck fleet in a specific urban environment (Sheffield, UK) by performing analysis of energy usage. It also presents potential solutions concerning the charging of the vehicle fleet. The presented analysis is carried out backed by a novel energy prediction software model. The analysis provides the public sector and private EV fleet users and manufacturers with energy usage figures for an eRCV fleet operating in an urban environment. Additionally, the research has developed a robust methodology that will consist as a reliable starting point in the design or optimisation processes of electrified heavyweight powertrain fleets, but also predictions of other important performance indicators (greenhouse gas emissions).

4 - Clustering and Routing in Waste Management: A Bilevel Optimization Approach
Emanuele Pizzari, Diego Maria Pinto, Massimiliano Caramia, Giuseppe Stecca

We propose a bilevel optimization approach to tackle a hierarchical problem arising in Waste Management. The higher-level problem is interested in locating sorting facilities in a regional area, as well as defining the corresponding capacities. The lower-level problem defines an effective routing for servicing clients' pickup demand. The main idea behind the model is that the leader aims at finding the best location-allocation solution by clustering clients and by assigning facilities to these clusters without generating overlaps. In doing so, the leader tries to (i) assign clients' demand to facilities by considering a safety stock within their capacities, in order to avoid shortages during the operational phase, (ii) minimize Greenhouse Gases emissions, (iii) be as compliant as possible with the solution found by the lower-level problem, the latter aiming at balancing tour lengths performed by vehicles. After properly modeling the problem, we propose a metaheuristic solution algorithm, based on tabu search approach, and conduct an extensive computational analysis on a real-world scenario. Validation of the approach is achieved with promising results.

■ TA-38

Tuesday, 8:30-10:00 - V002

Optimization under uncertainty in Humanitarian Logistics

Stream: Humanitarian and Healthcare applications (contributed)
Contributed session
Chair: Joris Wagenaar

1 - Optimal depot locations for humanitarian logistics service providers using robust optimization
Joris Wagenaar

When a disaster strikes an area, often international assistance is requested to help responding to and recovering from the disaster. The response is often characterized by the dispatch of relief items to the affected regions via depots from Humanitarian Logistics Service Providers (HLSPs). One of the challenges an HLSP faces is how to organize its network of depots. Important questions are how many depots should be opened and what should their locations be? We develop a method that uses historical data to determine depot locations that minimize the cost of transportation and minimize the maximum response time to a disaster. We examine the trade-off between the two objectives using the Pareto front. Furthermore, we use robust optimization to find solutions that are robust against uncertainty in the location and scale of future disasters. We provide a case study of the United Nations Humanitarian Response Depot (UNHRD), a large globally operating HLSP. Among other things, we compute potential cost savings that could be obtained when expanding the network with additional depots. Then, we generalize the approach by applying it to the independent disaster database EM-DAT, in which we focus on examining the added value of using a robust optimization framework. Solutions based on nominal and robust optimization perform similar on individual years that are not included in the optimization, but robust solutions guarantee a smaller cost of transportation for worst case scenarios

2 - Robust Optimization Solution Approach for the Earthquake Shelter Location-Allocation Problem
Levent Erişkin, Mumtaz Karatas

The North Anatolian Fault Line is expected to create a disastrous earthquake near Istanbul, Turkey's most populous city, in the near future. One of the important decisions that the decision makers should make before an earthquake occurs is to determine the locations of the shelters for affected people. To that end, in this study, we seek to improve the disaster preparedness level of Turkey by developing a robust optimization approach for the problem of shelter area location and allocation to provide decision support to decision makers after an earthquake in Istanbul. We first generate a number of possible ground shaking scenarios for Istanbul which target demand (the number of affected people that need sheltering) uncertainties. Using seismology theory and the results of empirical earthquake risk assessment studies performed for Istanbul, our shelter demand prediction approach allows capturing the effect of uncertainties in seismic parameters as well as the exposure level of the urban vulnerability. We also employ a set of closest assignment constraints which assigns each demand to its nearest open shelter area, thereby implicitly capturing the notion of evacuation decisions. Then, we show the performance of our modelling approach using real data for Kartal district of Istanbul. Additionally, we assess and compare the quality of solutions obtained from the proposed formulation with those of the stochastic approach with respect to various performance measures.

3 - Two-Stage Stochastic Program for Multi-Period Environmental Displacement Planning Under Demand Uncertainty
Kash Barker, Buket Cilali, Andres Gonzalez

Forced displacement is a global problem that requires planning for the relocation and integration of displaced people. Most studies focus on conflict-driven forced displacement, and hence the refugee resettlement problem. These studies generally focus on short-term planning and assume that demand within the fixed time interval is given. However, forced displacement, including environmental displacement as well as the conflict-driven displacement, is not a one-time event. On the contrary, it is an ongoing and long-term process with dynamic parameters. We are interested in the long-term displacement problem, especially for climate-driven cases in which people will be forced to leave uninhabitable regions in order to escape slow-onset climate change impacts such as water stress, crop failure, see level rise. To reflect the long-term planning requirements of the climate-driven displacement problem in the parameters and the model, we take a stochastic approach. To this end, we present a two-stage stochastic program where demand uncertainty is represented with various demand scenarios, demand and capacity are managed dynamically, and integration outcomes and related costs are optimized.

■ TA-39

Tuesday, 8:30-10:00 - U8

MAI: How to collect information from stakeholders to construct effective optimization models - a panel discussion

Stream: Making an Impact
Invited session
Chair: *Tuomas Lahtinen*

1 - How to collect information from stakeholders to construct effective optimization models - a panel discussion
Tuomas Lahtinen

Optimization is a mature technology which has taken leaps forward in the 21st century. Since optimization models aren't one-size-fits-all, operations research practitioners are central in rolling out the benefits to industry. In this panel discussion we dive deeper into the part between sales and technical implementation, i.e. all the preliminary work where we translate client expectations and expert knowledge into mathematics and, further down the line, programming code. In practice, the problems are owned by clients, so collecting information is crucial to avoid irrelevant solutions.

What is the best way to construct the information gathering process? How do you bridge the gap between commercial broad-level perspective and the necessary technical details? What are best practices and what should be avoided? Join in on the discussion to hear more! Maybe you have a story to share as well?

Tuesday, 10:30-12:00

■ TB-01

Tuesday, 10:30-12:00 - A

Emilio Carrizosa

Stream: Keynotes
Keynote session
Chair: *Ruth Misener*

1 - Predicting and deciding with machine learning: (try to) understand what you do and (try to) be fair
Emilio Carrizosa

Machine Learning methods to predict and decide tend to be black boxes, making it difficult to explain the output and to avoid discrimination caused by bias in the data. Expressing the training process as a Mathematical Optimization problem allows us to control critical issues such as the amount of information used by the model, measuring the relevance of the different input data, and strengthening the robustness or fairness of the procedures and decisions. Furthermore, once the prediction model is built, Mathematical Optimization can also be used to build counterfactual solutions, by identifying how the input should be to obtain a more desirable output. This paradigm will be illustrated in this talk in different Machine Learning domains.

■ TB-03

Tuesday, 10:30-12:00 - C

Machine Learning in Energy Systems

Stream: Machine Learning and Mathematical Optimization
Invited session
Chair: *Farzaneh Pourahmadi*

1 - Bringing Data Science and Machine Learning into Electricity Markets
Yury Dvorkin

Integration of volatile and uncertain renewable energy resources and synergistic energy storage and demand response technologies motivates the pursuit of stochastic electricity market designs to accommodate these resources and technologies efficiently and reliably. However, until recently the primary means of achieving these goals rested on the use of traditional optimization techniques and, in particular, on stochastic optimization and its proxies. However, recent developments make it possible to "re-invent" stochastic electricity markets borrowing results from data science, machine learning and financial engineering. This presentation will first describe how stressing of load and renewable time series can be achieved using principal component analysis and generative adversarial networks, and then how these stressed time series could be integrated into a stochastic electricity market design. Building on this result, we will describe a machine learning approach to stochastic-market clearing that affords both market- and operation-feasible solutions and reduces computational requirements.

2 - Strategies for Virtual Power Plant Bidding in Energy and Ancillary Service Markets
Lesia Mitridati, Riccardo de Nardis di Prata

The Virtual Power Plant (VPP) concept has recently been proposed to effectively aggregate the flexibility from a large number of Distributed Energy Resources (DERs) and facilitate their market participation. In this context, this talk presents a safe reinforcement learning (RL) algorithm for the optimal bidding problem of a large-scale VPP in energy and ancillary service markets. Complexity of the problem is increased by the non-convex nature of the distribution grid constraints, and a number of uncertain internal parameters (e.g. loads and DER output). While model-free deep RL algorithms, such as the Deep Deterministic Policy Gradient (DDPG) algorithm, are powerful tools to learn continuous actions, their online implementation may lead to unsafe states during training. In the proposed approach, the agent relies on a DDPG algorithm to learn the optimal price-quantity bids, while a projection-based safety layer restores feasibility of the agent's actions.

3 - Neural Networks for GNSS data Analysis, Positioning and Attitude Determination
Raúl de Celis, Luis Cadarso

Accurate navigation and control of Aerial Vehicles are inextricably connected to position and attitude estimations. An aircraft's rotation can be estimated by measuring two vectors in two different reference frameworks, such as the inertial and body reference frames. With a GNSS sensor-based matrix with at least three sensors and calculating their position to fix these pairs of vectors may be done using GNSS carrier phase measurements only resolving carrier phase ambiguity. Multipath, frequent lock loss, cycle slips, and severe clock drifts, on the other hand, hinder accurate integer ambiguity resolution, particularly in low-cost GNSS receivers. This novel neural network-based technique can optimize the management of the huge amount of data and increase the reliability of carrier phase ambiguity resolution. Using the carrier phase difference and pseudorange information from observable GNSS satellites, as well as the expected solutions, several neural network configurations can be trained to solve the ambiguity and, as a result, estimate the precise position of the GNSS sensor matrix. The suggested methods for estimating attitude measurements allow for a generally reliable determination of the vehicle's attitude using just GNSS sensors or to act as assistance in the hybridization of information in conjunction with other sensors such as gyroscopes.

4 - Combining learning and optimization for real-time scheduling problems
Farzaneh Pourahmadi

Most scheduling problems in power systems must be handled many times per day by system, market, and transmission operators. However, solving scheduling problems in real-time for realistically sized systems can be computationally difficult from optimization perspective, owing to the combination of complex physical laws, binary nature of some decisions and tight latency requirements. This computational complexity is getting worse as more renewables are integrated into the system. This necessitates resolving complex models at much faster paces unreachable by standard optimization solvers, resulting in a solution with a high optimality gap. In this presentation, we describe how we may utilize machine learning to address real-time scheduling problems in a computationally efficient way by predicting binary variables and active constraints and then using that prediction as an input to solvers. We demonstrate the improvements in computational performance may lead to better modeling of uncertainty and many sorts of constraints.

■ TB-04

Tuesday, 10:30-12:00 - D

Machine learning for optimizing business decision-making III

Stream: Machine Learning and Mathematical Optimization
Invited session
Chair: *Wouter Verbeke*
Chair: *Kristof Coussement*

1 - Robust Instance-dependent Cost-sensitive Learning
Simon De Vos, Toon Vanderschueren, Jeroen Berrevoets, Tim Verdonck, Wouter Verbeke

Instance-dependent cost-sensitive (IDCS) learning methods have been proven useful for binary classification tasks when individual instances are associated with variable costs or rewards. However, as we demonstrate using a series of toy examples, these methods are prone to noise and outliers. Hence, their performance strongly depends on the cost distribution of the data sample. To address this vulnerability, we first propose a general three-step framework to robustify IDCS methods in order to make them less sensitive to the effects of random variability and noise: (i) detect outliers, (ii) impute the amounts of outliers, (iii) apply an IDCS learning method on this filtered set of amounts. Second, we apply this general framework on cslogit, a logistic regression-based IDCS method, to attain its robust version, which we denominate r-cslogit. The robustness of this method is introduced in steps (i) and (ii) where we make use of robust estimators to detect and impute outlying amounts of individual instances. The newly proposed r-cslogit method is tested on synthetic and semi-synthetic data and proven to be superior in terms of savings compared to its non-robust counterpart.

2 - Self-Supervised Anomaly Detection for Detecting Rogue Sensors in IoT Data
Boje Deforce, Bart Baesens, Jan Diels, Estefanía Serral

IoT data has become an integral part of many business operations, introducing new challenges inherent to IoT data. E.g., the risk of data contamination due to rogue sensors can have real consequences for business decisions. A sensor is considered rogue when it provides incorrect measurements over time. Some sensors are faulty from inception, while others can go rogue due to poor power supply, harsh weather conditions, etc. To ensure correct analytical results, an essential preprocessing step when working with IoT data is the detection of such rogue sensors. Existing methods assume that well-behaving sensors are known or that a large majority of the sensors is well-behaving, making those methods semi-supervised. However, real-world data is often completely unlabeled and voluminous, calling for self-supervised methods that can detect rogue sensors without prior information. Building on existing work for time-series representation learning, we present a fully self-supervised anomalous sensor detector based on neural networks with a triplet loss. A core contribution of our paper is the use of Dynamic Time Warping in the negative sampling process for the triplet loss. This novelty makes the use of triplet networks feasible for anomalous sensor detection. We demonstrate our method on a challenging dataset of sensors deployed in an agricultural context. The results show that our method successfully separates well-behaving sensors from rogue sensors without any prior information.

3 - NICE: An Algorithm for Nearest Instance Counterfactual Explanations
Dieter Brughmans, Pieter Leyman, David Martens

In this paper we suggest NICE: a new algorithm to generate counterfactual explanations for heterogeneous tabular data. The design of our algorithm specifically takes into account algorithmic requirements that often emerge in real-life deployments: (1) the ability to provide an explanation forall predictions, (2) being able to handle any classification model (also non-differentiable ones), and (3) being efficient in run time. More specifically, our approach exploits information from a nearest unlike neighbour to speed up the search process, by iteratively introducing feature values from this neighbour in the instance to be explained. We propose three versions of NICE, which optimize the explanations for one of the following properties: sparsity, proximity or plausibility. An extensive empirical comparison on 10 datasets shows that our algorithm outperforms the current state-of-the-art. Our analyses show a trade-off between on the one hand plausibility and on the other hand proximity or sparsity, with our different optimization methods offering users the choice to select the preferred trade-off. An open-source implementation of NICE can be found at https://github.com/ADMAntwerp/NICE.

■ TB-05

Tuesday, 10:30-12:00 - E

Integrating Machine Learning in Optimization Methods

Stream: Data Science Meets Optimization
Invited session
Chair: Michael Römer

1 - Learning to solve a stochastic orienteering problem with time windows

André Hottung, Kevin Tierney

Recently, many machine learning based approaches have been proposed that learn to solve simple routing problems (e.g., the traveling salesperson problem) on their own. However, real-world routing problems are usually significantly more complex (e.g., with respect to the number of different constraints) than these simple problems. We propose a deep reinforcement learning based approach for a time-dependent orienteering problem with stochastic travel times and time windows that mimics the difficulty of real-world problems. Our approach combines and extends multiple components that have been proposed in the literature to support the new stochastic problem setting. We show that our problem is able to tackle this heavily constrained routing problem. Our results also suggest that deep reinforcement learning based approaches are well suited to solve stochastic reinforcement learning approaches.

2 - Learning to Approximate State-Expanded Network Models

Michael Römer

Mixed-integer linear programming formulations based on flows in state-expanded networks in which nodes correspond to states and edges represent transitions between theses often have very strong LP relaxations and have been used with considerable success in various applications. One of the challenges of these formulations is that for large-scale problems, the size of the model instances become huge. In previous work, we proposed to use machine learning to guide the reduction of large state-expanded networks based on learning from optimal solutions for sets of similar problem instances. In this talk, we propose an approach that does not rely on such offline-training but that uses machine learning to heuristically filter and iteratively improve state-expanded network models based on initial approximate networks. We demonstrate the efficiency of this approach with instances from different types of resource scheduling problems, showing that in many cases, optimal or near-optimal solutions can be obtained in a fraction of the computing time needed for solving the full state-expanded network models.

3 - State-based Reinforcement Learning for Hyper-heuristics

Lucas Kletzander, Nysret Musliu

To avoid the need to specifically adapt an algorithm to new problem domains, hyper-heuristics aim at using a set of simpler low-level heuristics (LLH) and a strict domain barrier. This barrier enforces them to be domain-independent, as they only know the set of available LLHs, their type (local search, mutation, crossover, or destroy-and-repair), and the current solution value and remaining runtime.

When a hyper-heuristic is applied to a new instance, intuitively certain combinations of LLHs might be useful in different parts of the search. The idea of this work is to provide a representation of the current search state from the limited information that is available, by introducing new features like the number of LLH applications since the last improvement, the average improvement per LLH application overall or among the last 10 applications and many more.

Based on this state representation, reinforcement learning with a tile coding value function approximation is used to learn which combinations of LLHs are useful in different parts of the search. Further, since Iterated Local Search (ILS) is the basis for many leading hyper-heuristics, the exploration part of reinforcement learning uses preferences based on ILS.

With this approach, we can obtain very good results in comparison to other hyper-heuristics using the competition CheSC 2011 as a benchmark, where the second place against the 20 original participants is reached.

4 - Application of artificial neural networks in predicting cost of mechanical projects

George Aretoulis, Christina Livitsanou

Mechanical works are a large and integral part of many technical projects. In collaboration with a mechanical construction company, project financial and other data were processed and recorded from an archive for 87 completed mechanical projects. Based on a meticulous screening of this sample, 48 projects were finally selected to be studied so that the sample would be reliable, representative and homogenous. The 48 construction projects were implemented in the last ten years by the same company in four provinces of the Republic of Cyprus and included projects regarding Water, Sewerage, Heating / Cooling, Fire and Ventilation. Furthermore, costs regarding supply of materials and machinery were also recorded. Then, the best prediction models based on artificial neural networks were introduced with the aim to forecast the percentage deviation among the actual cost at completion with the budgeted cost. Correlation analysis produced coefficients of the variables associated with the percentage change of the project cost. Then, using the artificial neural networks of the IBM SPSS STATISTICS 27 program, models were developed to quantify the cost difference. These models were developed with both the Radial Basis Function RBF and the Multi-Layer Perceptron (MLP) methodologies. Finally, the predominant neural network networks were identified as being those with independent variables that included the contract award cost and the labor costs in the tender offer.

■ TB-06

Tuesday, 10:30-12:00 - U1

Complexity questions of linear and integer linear programming

Stream: Combinatorial Optimization
Invited session
Chair: Sergei Chubanov

1 - Autonomous transportation using platoons: approximation and hardness results

Tiberiu-Iulian Sirbu, Alexandru Popa

In this paper we consider a scenario of travelling between different cities autonomously, using a partial autonomous car capable of communicating with other cars. In our scenario, there are various platoons that travel along some predefined paths. The goal is to find a path from a source to destination that is shorter than a given value and moreover, the overlap with the paths of the platoons is maximized. We formulate two versions of the Platooning Problem using graphs. In the first variant we aim to maximize the time spent as member of a platoon. In the second variant, we aim to maximize the percentage of the total road traveled as member of a platoon. We prove that that the two versions are not solvable in polynomial time, unless P = NP. Moreover, we propose a polynomial time approximation algorithm for the first variant and two approximation algorithms for the second variant. In particular, one of the approximation algorithms, uses a reduction to the Minimum Steiner Tree problem.

2 - Using PQ-Trees for Feasibility of Clustered TSP
Michal Stern, Nili Beck, Hadas Sayag

Let H = < V, S> be a hypergraph, where V is a set of vertices and S is a set of clusters containing vertices from V, such that the clusters in S are not necessarily disjoint. This paper considers the Feasibility Clustered Traveling Salesman Problem, denoted as the FCTSP, known also as the Consecutive Ones Property. The feasibility problem is to decide whether there exists a simple path that visits each vertex exactly once, such that the vertices of each cluster are visited consecutively. We focus on hypergraphs with no feasible solution path and consider removing vertices from clusters, such that the hypergraph with the new clusters has a feasible solution for FCTSP. The offered solution is considerably better than the trivial one. The algorithm uses PQ-tree data structure and runs in linear time. The main idea of this paper is to introduce an extended version of the algorithm presented by Booth and Lueker, in order to gain feasibility for any given hypergraph.

3 - On algorithmic complexity of infinite-dimensional linear programming
Sergei Chubanov

Many optimization problems like binary classification tasks in machine learning or the quickest flow over time problem in combinatorial optimization can be naturally stated in the form of operator equations and inequalities over a Hilbert space. This problem statement can be viewed as a direct generalization of a finite-dimensional linear program; the solution space is not limited to a finite-dimensional Euclidean space anymore, but allowed to be a Hilbert space, with infinitely many dimensions. In this talk, I wish to present an algorithm, for infinite-dimensional linear programming, whose complexity estimates are polynomial in the complexity of the simplest solution and in the reciprocal of the admissible proportion of the violated constraints compared to the entire constraint set. The algorithm is stated in a model of computation including computations of linear operators and their adjoints, computations of inner-products and some other operations specific to Hilbert spaces. When stated in a Euclidean space, the algorithm is a polynomial-time algorithm for linear programming in the usual sense.

■ TB-07
Tuesday, 10:30-12:00 - U3

Contagion in Financial Network

Stream: Financial Risk Measurement and Management
Invited session
Chair: Markku Kallio

1 - Estimation of some optimal cointegrated trading strategies
Michal Cerny, Vladimír Holý

We assume a cointegrated portfolio of assets the price of which follows the Ornstein-Uhlenbeck process. Its mean-reversion feature admits the arbitrage trading strategy to open positions when the process deviates from its long-term mean and to close the positions after mean reversion. We also assume nonzero transaction costs. Profit is measured on average per time unit and the riskiness of the strategy is measured by the per-time-unit variance of profit. The goal is to estimate the optimal thresholds for opening and closing the positions. We augment the original Bertram's strategy by constraints on riskiness. As a result, we arrive at a non-convex optimization problem where both the objective function and the constraint functions are described by non-elementary functions; nevertheless, we show that the problem is still efficiently solvable. This process leads to the optimal trading strategy as a function of the parameters of the Ornstein-Uhlenbeck process. However, in reality, these parameters are rarely known exactly; rather, they are estimated from a sample of a finite number of observations of the prices of the underlying assets consituting the portfolio. The statistical estimates of the parameters differ from the true values. We study how the optimal profit from the strategy is affected (and how the efficient frontier is shifted) when a trader works with "erroneous" estimates of the parameters instead of their exact values.

2 - Cooperative Mitigation of Contagion in Financial Networks
Markku Kallio, Aien Khabazian, Rudan Wang

Since the beginning of the financial crisis in 2007-2008, several mitigation policies have been considered in order to monitor and stabilize the financial system in the event of a shock. In this paper, we examine the financial network of systemically important banks as a cooperative game. Governments can act as facilitators enforcing incentives for banks to cooperate and prevent the escalation of the financial crisis. The threat of escalating crisis may not be sufficient to incentivize the formation of cooperation; however, the government can enforce additional incentives by providing credible threats and bail-in assistance. To evaluate the characteristic function of the cooperative game, we develop clearing payment models for alternative coalitions competing in the market. As a fair division concept, we use nucleolus which implies a possible subsidizing pattern among the banks. For a demonstration, we use major European banks and a scenario which is linked to the adverse economic scenario used in 2016 EU-wide stress testing.

3 - A graph-based semi-supervised reject inference framework for credit scoring
Zongxiao Wu, Yizhe Dong, Yaoyiran Li

Many existing studies for credit scoring suffer from sample selection bias and have limited generalizability since the predictive models only use approved samples instead of a through-the-door sample. To address this issue, some research has developed reject inference (RI) approaches to infer the repayment status of rejected applicants and then refines credit scoring models by incorporating the predicted outcomes. However, these methods usually ignore the different distribution of defaults between accepted and rejected populations. Therefore, this study proposes a novel graph-based RI framework to capture inter-individual information for credit scoring that integrates 1) clustering of accepted and rejected samples using spectral clustering; 2) anomaly detection for rejected data through isolation forest; 3) relabelling rejected cases using iterative label spreading; and 4) binary classification of the relabelled data. Based on a real-world commercial bank dataset, we find that our proposed framework not only improves the performance of credit scoring models, but also outperforms other classical RI techniques in predicting defaults. It can also handle the class imbalanced distribution problem between good and bad applicants better. Furthermore, we conduct an ablation study to demonstrate the usefulness of each stage in our proposed method. The results show that each part of this framework plays its role, with iterative label spreading, in particular, being most useful.

4 - Multi-objective Leverage Optimization Method with Bayesian Stock Price Predictions
Risto Heikkinen

Leverage is the proportion of capital that an investor allocates to risky assets. For example, 0.5 leverage indicates that the investor allocates half of the capital to risky assets and keeps the other half in risk-free assets. Leverage higher than 1 indicates borrowing money for investing. Traditionally, the optimal leverage is defined based on the investor's utility function that describes his/her risk preferences. However, it is challenging to determine one's personal utility function in practice.

We propose a multi-objective optimization approach for leverage optimization, where the investor can define objectives that are the most relevant and familiar for his/her. As an example, we use three objectives, namely capital growth rate, mid-term downside risk and short-term downside risk. A Bayesian statistical model that estimates the distribution of the S&P 500 index's future returns is used for calculating the objective values. The Bayesian model allows combining an investor's subjective prior knowledge with historical data. An appropriate multi-objective optimization method is used for making the leverage decision.

In the approach, we first study the properties of the historical return of the S&P 500 index. Second, we build a Bayesian model for future returns. Finally, we make an allocation decision based on three objectives and compare the decision to the traditional mean-variance approach and to the Kelly criterion.

■ TB-08

Tuesday, 10:30-12:00 - U4

Public Transportation: Models, Analysis and Solution Approaches

Stream: Combinatorial Optimization
Invited session
Chair: *Alena Otto*
Chair: *Erwin Pesch*

1 - Pairing Night-shift and Morning-shift Duties on a complex Metro Line

Zixuan Zhu, Fangsheng Wang, Pieter Vansteenwegen

Scheduling the night-shift and morning-shift duties pairing plan (NMDPP) is a common process in Chinese metro crew management. It is situated between solving the crew scheduling problem and the crew rostering problem. NMDPP will affect the rest time of crews. Due to the special working environment of metro crews, sufficient rest is important for them. Nowadays, Chinese metro companies schedule the NMDPP in some simple ways without considering the impact of the NMDPP on rest time. Besides, as metro lines become longer, multiple depots and handover points occur on a line and this makes the planning much more complex. This paper proposes a binary programming model to optimize the rest time of crews. Moreover, a hybrid algorithm combining General Variable Neighborhood Search (GVNS) with an Assignment Algorithm is designed to find high-quality solutions for this problem. Finally, computational experiments with both artificial data and real-life data are conducted. The results indicate that the proposed algorithm can obtain high-quality solutions efficiently for various NMDPPs. Besides, the proposed method can significantly increase the rest time of crews compared to the practical method used in metro companies.

2 - A MILP model for timetable compression in large railway networks

Inneke Van Hoeck, Pieter Vansteenwegen

Due to the growing demand of railway transport, a thorough understanding of the available capacity is necessary. The capacity can be measured by the capacity occupation. This is the minimal amount of time a sequence of trains needs to drive through a network. Timetable compression is a well-known method to determine the capacity occupation. It is however not straightforward to apply this to a large network on microscopic scale. Therefore, we propose a MILP model to perform the compression. The network is divided into small, non-overlapping pieces of infrastructure called resources. A train driving through the network is represented by blocking times of the resources that are used. The model is based on a machine scheduling problem, the resources are the machines and the blocking times of a train are the jobs. An additional advantage of using a mathematical model is the freedom when imposing the constraints. This allows the impact on the capacity occupation of alternative scenarios to be analyzed. For example, it is possible to not assume a fixed order of (all of) the trains. The model can then determine which order is optimal from a capacity occupation point of view. Another option is to have a number of possible routes that a train can take and determine which one leads to a minimal capacity occupation. The model and the results obtained for different instances will be presented at the conference.

3 - Gradual deployment of electric bus systems by coordinated optimization of charging infrastructure and mixed vehicle fleets

Miriam Stumpe, David Rößler, Guido Schryen, Natalia Kliewer

Given the global efforts to reduce emissions and fossil fuel dependency, public transport operators are under growing pressure not only to replace their diesel buses with electric buses, but also to provide a supporting charging infrastructure. However, the transition from traditional fuel-based bus transport to electric bus systems is still in its early stages in most European cities. This is mainly due to the uncertain technological environment, from which different paths for a gradual expansion may emerge in the foreseeable future. While several studies focus on the strategic implications of uncertainty (e.g., charging stations), few consider the operative side (e.g., vehicle schedules) in sufficient detail. We contribute to closing this research gap by (1) simultaneously optimizing the charging infrastructure and vehicle schedules and (2) analyzing the robustness of the resulting charging infrastructure against technological factors. We extend an application of a Variable Neighborhood Search (VNS) from prior work by considering mixed fleets and by repeatedly executing the VNS, using the result from each iteration as the starting point of its successor. In each iteration, technological factors are varied, such as the fleet share of electric vehicles, battery capacity, and charging power, following realistic development and expansion paths. We present a comprehensive analysis of the effect of such multidimensional variation in factors.

4 - Analysis of a static demand-responsive bus system with capacitated vehicles

Dilay Aktas, Kenneth Sörensen, Pieter Vansteenwegen

When demand for transportation is much larger in one direction than in the other, buses tend to overcrowd in one direction while being almost empty in the other. Many traditional systems face that situation mostly because of the lack of flexibility during operations. In this study, we focus on a demand-responsive system operating during morning peak hours where the passenger flows towards a city center are usually much larger than the flows in the opposite direction. Considering a single line, the demand responsive system allows express services away from the city center, in order to increase the frequency of the service towards the city center during morning peak. Based on the expected demand, whether a bus should visit all the stops ahead or skip some of them when going away from the city center is optimized in advance. The system is considered as stop-based and many-to-many where passengers can be picked up from and dropped off to any one of the predefined stops by a fixed fleet of identical and capacitated vehicles. The aim of this study is to analyze under which circumstances (e.g. demand pattern, fleet size, vehicle capacity, peak hour duration) the demand-responsive system could be preferred over a traditional bus system operating on this line, regarding the total passenger travel time.

■ TB-09

Tuesday, 10:30-12:00 - U5

Uncertain mixed-integer optimization

Stream: Mixed Integer Linear Programming
Invited session
Chair: *Henri Lefebvre*

1 - A Two-Stage Stochastic Programming Approach for Rotating Workforce Scheduling With Uncertain Staffing Requirements

Tristan Becker

Many industries rely on rotating schedules in their personnel scheduling. In a rotating workforce schedule, every employee works the same schedule, which repeats after a specific time. When devising a rotating schedule, the precise staffing requirements on each day and shift are not known but uncertain. Therefore, we present a two-stage stochastic optimization problem for rotating workforce scheduling accounting for uncertain staffing requirements. The first stage devises a rotating schedule considering the possibility of overstaffing and scheduling on-call duties. After the uncertain staffing requirements have been realized, several recourse actions are available in the second stage. To recover from staff shortages, on-call duties can be activated, employees can be called in, and agency workers can be hired. Depending on the first-stage decisions, the number of on-call duties and call-in employees are limited for each day and shift. The model minimizes the costs of coping with the uncertain staffing requirements. We use a scenario approach to include the uncertainties into our two-stage stochastic model. In a case study, we compare the performance of the solution of the stochastic optimization model against a deterministic approach across a large sample of simulated staffing requirement realizations. Our results indicate that the workforce scheduling costs can be significantly reduced by choosing a schedule that anticipates the uncertainties of the staffing requirements.

2 - Robust optimization for the integrated berth allocation and quay crane scheduling problem under uncertainty

Filipe Rodrigues, Agostinho Agra

We consider an integrated berth allocation and quay crane assignment and scheduling problem where the arrival times of the vessels may be affected by uncertainty. The problem is modeled as a two-stage robust mixed-integer program where the berth allocation decisions are taken before the exact arrival times are known, and the crane assignment and scheduling operations are adjusted to the arrival times. To solve the robust two-stage model, we follow a decomposition algorithm that decomposes the problem into a master problem and a separation problem. A new scenario reduction procedure for solving the separation problem is proposed as well as a warm start technique for reducing the number of iterations performed by the decomposition algorithm. To scale the proposed decomposition algorithm for large-size instances, it is combined with a rolling horizon heuristic. The efficiency and effectiveness of the proposed algorithms are demonstrated through extensive computational experiments carried out on randomly generated instances with both homogeneous and heterogeneous cranes as well as on instances from the literature.

3 - Adjustable Robust Optimization with discrete uncertainty

Henri Lefebvre, Enrico Malaguti, Michele Monaci

In this work, we consider Adjustable Robust Optimization (ARO) problems in which the uncertainty set is given as a discrete set and mixed-integer decisions are allowed in both the first and second stage. Under a very general modelling framework, we show that such problems can exactly be reformulated as ARO problems with objective uncertainty only, thus allowing us to rely on the work of [Kämmerling, N et al., 2020], which we extend, for deriving practical solution approaches. Our reformulation relies on Lagrangian duality and polyhedral analysis results.

From a computational viewpoint, we show that the approach introduced in [Kämmerling, N et al., 2020], originally designed for ARO problems with convex uncertainty set and binary first-stage decisions, can be extended to problems with binary uncertainty and mixed-integer first-stage decisions. This considerable extension introduces spatial branching for continuous first-stage variables and requires careful convergence analysis. The algorithm is proved to asymptotically converge to an optimal solution.

Finally, we report computational results for this class of hard optimization problems by study- ing two two-stage uncertain variants of well-known problems from the optimization literature.

■ TB-10

Tuesday, 10:30-12:00 - U6

Pricing and Risk management

Stream: Financial Risk Measurement and Management
Invited session
Chair: *Mariacristina Uberti*

1 - Living on the Edge: An Unified Approach to Antithetic Sampling

Roberto Casarin

We identify recurrent ingredients in the antithetic sampling literature leading to a unified sampling framework. We introduce a new class of antithetic schemes that includes the most used antithetic proposals. This perspective enables the derivation of new properties of the sampling schemes: i) optimality in the Kullback-Leibler sense; ii) closed-form multivariate Kendall's tau and Spearman's rho; iii)ranking in concordance order and iv) a central limit theorem that characterizes stochastic behavior of Monte Carlo estimators when the sample size tends to infinity. Finally, we provide applications to Monte Carlo integration and Markov Chain Monte Carlo Bayesian estimation.

2 - The estimation error in the Basel II IRB approach: floors to the estimated parameters

Mariacristina Uberti, Simone Casellina, Simone Landini

Risk measures, like the Value-at-Risk or the Expected Shortfall, are usually dependent on model's parameters that are unknown and must be estimated. This introduces an additional source of uncertainty that is easily not accounted for. The Prudential Regulation has formally raised the issue of errors stemming from the internal model estimation process in the context of credit risk, calling for margins of conservatism to cover possible underestimation in capital. We investigated the effect of the estimation error in the context of the Internal-Ratings Based (IRB) approach and we also suggested how to introduce the margin of conservativism called by the Regulation. A feature of this approach is that it does not require introducing additional elements in the Asymptotic Single Risk Factor model like prior distributions or other parameters which, having to be estimated, would introduce other sources of estimation error. In this paper we further investigate along the lines suggested above by studying what happens when dealing with low probabilities of default. This in turn leads to study another aspect of the Prudential Regulation which is the setting of floors to the estimated parameters. These floors are heuristically justified by the difficulties to estimate the parameters when the default event becomes rare. Moreover we provide a more robust justification to the floors as well as a framework that would enable to calibrate the floors depending on other parameters.

3 - Geo-referenced data and complex networks for measuring road accident risk

Gian Paolo Clemente, Francesco Della Corte, Diego Zappa

The assessment of risk related to car crashes in road networks is a relevant topic for both social and political decisions and for insurance companies. To this end, we show how the spatial objects and the information concerning the structure of the roads, that can be collected e.g. from open data sources, along with the crash history can be used to map the risk related to each road. In particular, we follow a combined approach. On the one hand, a statistical model is developed in order to assess the risk on the basis of a set of features related to the characteristics of the streets. On the other hand, from the spatial object we build a weighted network, where vertices and arcs correspond to geographical elements as junctions and roads respectively and where the assessed risk of each segment is used as a weight. We study the topology structure of the graph obtained and we show how classical network indicators can provide meaningful insights about the risk of an area. To achieve our aim, we adapt the current methodology about geospatial modelling to the constraints derived from the maps of the roads of a particular area and to exploit supervised/unsupervised statistical learning algorithms to estimate the local risk of the frequency of accidents. The spatial object and the accident risk assessed by the model for each road are then converted in a directed and weighted graph. A numerical application based on Milan area in Italy (city and province) is provided.

4 - Correlation expansions methods in derivatives pricing
Alessandro Ramponi

Correlation expansion methods have been used to obtain approximate pricing formulas for different financial instruments. We present some applications of such a methodology in the context of (i) default-free option pricing in stochastic volatility market models and (ii) pricing of defaultable instruments in intensity-based frameworks involving various kinds of price adjustments like CVA, DVA, LVA.... In particular, this methodology allows us to consider exchange (or Margrabe) options in stochastic volatility models, vulnerable options and CVA valuation, the more general XVA pricing problem, and the case of defaultable bonds in a Vasicek-CIR model.

■ TB-11

Tuesday, 10:30-12:00 - U7

MCDM for project portfolio problems

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Maria Barbati*

1 - Commitment and Justice - new multiobjective optimization model for project portfolio management
Jorge Noro, Luis C. Dias

The article presents a new bi-objective optimization model for project portfolio management. The objective functions maximizes the economic gains of the project portfolio selected while ensuring the maximization of the skills development of the agents allocated to these projects. This approach promotes the improvement of the team's performance over time. The constraints to the choice and allocation of projects take into account the workload of the agents and the way the distribution of work affects their employment commitment, considering the dimensions of Absorption, Dedication and Strength of the UWES (Utrecht Work Engagement Scale), in its reduced form. Also, the individual perceptions of organizational justice resulting from the projects allocation were collected and the data from surveys was considered. Experimental results are presented, for a scenario based on the experience of administration offices for the management of research and innovation projects at a higher education institution.

2 - A new elicitaion procedure to handle multiobjective project portfolio selection problem: the case of a sustainable Ecovillage
Maria Barbati, Salvatore Greco, Isabella Lami

In this paper we propose to define a project portfolio considering the distribution in the time and in the space of a set of functions thanks to the proposal of a new elicitation procedure. The project portfolio we consider is conveniently formulated as an interactive multiobjective combinatorial optimisation problem in terms of the space-time model. We propose an interactive procedure in which the Decision Maker provides preference information in terms of ranking and pairwise comparing some portfolios suggested by the optimisation model. Our procedure is user friendly and aims to reduce the cognitive burden for the decision makers. We apply our methodology in a real world problem to define the planning of a sustainable ecovillage in the province of Turin (Italy). We interact with the President of the cooperative owning the ecovillage to define a suitable plan that details what functions of the ecovillage should be selected, where they should be located and when they should be scheduled.

■ TB-12

Tuesday, 10:30-12:00 - U9

Policy-enabling models in the power sector

Stream: OR in Energy
Invited session
Chair: *Afzal Siddiqui*

1 - The Austrian path to climate neutrality using the open-source LEGO model
Sonja Wogrin

In Europe, we have embarked on the journey towards net-zero power systems and want to reach full decarbonization by 2050 (European Commission "A clean planet for all"). Austria wants to reach carbon neutrality in the power system already by 2030 (Erneuerbaren Ausbau Gesetz) and the decarbonization of the entire energy system by 2040, which will require coupling the power, transport, heat, and gas sectors. In this talk, we discuss how we use the open-source Low-carbon Expansion Generation Optimization (LEGO) model to achieve such ambitious climate goals by tackling relevant challenges in energy economics.

2 - Pathways to decarbonizing electricity in northeastern North America
Michel Denault, Florian Mitjana, Dominique Orban, Pierre-Olivier Pineau

To analyze pathways to GHG targets in 2050, we develop a stochastic multi-stage investment & operations model that covers generation, transmission, and storage capacities. Long-term uncertainties are handled, such as demand growth and investment costs. The best strategies show that early decisions, as well as transmission investments, play a crucial role in decarbonizing at reasonable costs.

3 - Understanding Regulatory Fit
Ann van Ackere, Erik Larsen

We analyse the evolution of regulation to understand how the interaction between the regulator and the market can lead to what we label a misfit, i.e., the market and its regulation move at different speeds and end up being out of synch. We start from the assumption that regulation is a behavioural adaptive process, influenced by internal and external forces. External influences include, among others, technological evolution and policy changes, while internal influences relate to industry stakeholders, feedback and inertia. We develop a system dynamics model capturing these dynamics to gain a better understanding of the interaction between an industry and its regulation. We explore how misfits occur and how they evolve over time, i.e., instances where regulation is not adapted to the state of the regulated industry. We are particularly interested in the underlying behavioural reasons for such misfits, which include inertia (i.e., lack of responsiveness), stakeholders' unanticipated responses and regulators' misperception of the consequences of a regulatory change. These elements are crucial for today's electricity markets, which are facing a rapid transition to renewables. We aim to provide guidance on how to design regulatory frameworks that minimise the creation and persistence of misfits that could lead to obsolete market practices and put a brake on innovation, making it more difficult to achieve this transition while maintaining a desirable capacity adequacy.

4 - Evaluating retrospective performance of electricity system models in 31 European countries
Xin Wen, Marc Jaxa-Rozen, Evelina Trutnevyte

Cost optimization-based energy system models are commonly used to generate plausible future energy scenarios at a national level. Retrospective evaluations of modeled scenarios can cast light on the areas where models need to improve their representation of the energy system and its transition. While retrospective modeling is informative, it is also demanding and has been undertaken only by a handful of models. Hence, retrospective evaluations currently lack systematic methods in order to be more holistic and informative. Following this research gap, we assess retrospective performance of a technology-rich, perfect foresight, cost-optimization modeling framework D-EXPANSE by setting up 31 national models of European countries from 1990 to 2019. We quantify 24 accuracy indicators that we gather from literature and compare the retrospective accuracy performance of all key model outputs in each of the 31 countries. Based on the dissimilarity analysis with correlation calculations and hierarchical clustering, we identify a small suite of most informative accuracy indicators (symmetric mean percentage error, symmetric mean absolute percentage error, symmetric median absolute percentage error, root-mean-squared logarithmic error, and growth error) to evaluate the model outcomes in many countries. This is a first step towards developing a model accuracy testbench to assess energy models and scenarios retrospectively in multiple dimensions.

■ TB-13

Tuesday, 10:30-12:00 - U119

Scheduling applications

Stream: Discrete Optimization and Algorithms (contributed)
Contributed session
Chair: *Pablo A. Rey*

1 - A Decentralized Problem Decomposition Scheme for Sequencing and Scheduling: Application in Outpatient Appointment Systems

Pardis Seyedi, Michael Carter, Kourosh Eshghi

Early diagnosis and prevention play a crucial role in community health and health system quality. However, patients often experience significant wait times for various diagnostic technologies worldwide. An efficient appointment scheduling system has a defining role in controlling wait times. This study addresses the variability and length of wait times. We reduce them by a form of restricted central intake. We believe that this is the first study that expands the appointment scheduling sequencing model to include multiple sites and incorporate patient preferences and priorities. This study shows this approach provides better workload balance across hospitals, better responding to demand fluctuations, and alleviates excessive wait times. The problem is large-size as it combines all requests from a geographical region into one stream. The solution approach is a combination of dual decomposition and augmented Lagrangian. The approach is examined by a real situation of MRI in Ontario, Canada. The computational results show that the proposed method offers relatively reliable, reasonable quality solutions with much lower CPU power and time than solving by GAMS-CPLEX (as a centralized approach). In the end, this is a computationally advantageous and theoretically sound framework suitable for solving a large-scale problem of dynamic, uncertain systems. Therefore, it can be embedded in IT-baed tools and generalized to other appointment systems (e.g., various consulting services).

2 - Investigating Hyper-heuristics for Real-World Test Laboratory Scheduling

Florian Mischek, Nysret Musliu

Selection hyper-heuristics are a class of high-level problem solving methods that operate on a set of problem-specific low-level operators, instead of directly over a solution space. This allows them to be adaptive and problem-independent, even for previously unknown problem domains. One such domain is the Test Laboratory Scheduling Problem (TLSP), which is an extension of the well-known RCPSP. In the TLSP, solvers have to produce a schedule by first grouping tasks into jobs and then assigning a mode, time slot, and resources to the jobs. We have modeled the TLSP as a problem domain for selection hyper-heuristics, using the HyFlex framework, which has become the de-facto standard in this area. This includes defining a solution representation and evaluation function, as well as a diverse portfolio of low-level operators of different types, including large neighborhood operators.

Using a newly developed and problem-independent hyper-heuristic based on reinforcement learning, we were able to find high-quality solutions for the TLSP that are competitive with the current state of the art and could even improve the results for some instances. In addition, our hyper-heuristics produce good results on both small and large instances, compared to the existing problem-specific approaches, whose performance depends a lot on the instance size.

3 - An integer programming approach to intraday scheduling of chemotherapy patients

Pablo A. Rey, Alejandro Cataldo, Antoine Sauré, Gustavo Angulo, Alejandro Cifuentes, Gabriel Lyon

Chemotherapy scheduling at cancer treatment centers is a challenging problem. This process is frequently split into two phases: first, treatment centers assign patients to specific days (interday scheduling) and then assign the patients to specific times within each day and define medication preparation times (intraday scheduling). In this work, we propose a solution approach for the intraday scheduling problem based on an integer programming model that attempts to simultaneously schedule all patients assigned to the horizon and the preparation of the medications to be administered. We design and implement a column generation algorithm to solve it. A case study is conducted using actual data from a Chilean cancer center to compare the schedules generated by the proposed approach and the center's manual method through simulation. Compared to the manual method currently in use, the proposed approach improves performance measures such as makespan, treatment chair occupancy, and the number of nurse overtime hours.

4 - Course Allocation with Friendships

Tal Grinshpoun, Ilya Khakhiashvili, Lihi Dery

Many universities face a course allocation problem as demand for popular courses exceeds supply. Quite often, there is a constraint on the number of students who can attend each course and a few courses are highly popular while in others demand is scarce. Monetary solutions are not relevant in such settings. Therefore, institutes have to decide how to allocate students to courses under these limitations. Previous studies on course allocation disregarded a factor that is important to students - they value being assigned to the same course as their friends. We propose a model that considers not only the students' preferences over courses but also their preferences over classmates. We formulate the problem as an asymmetric distributed constraint optimization problem (ADCOP). Such formulation yields another interesting feature: it is solved in a distributed manner, thus removing the need to directly share private preferences with anyone. An additional contribution in this study is a new (A)DCOP algorithm for solving problems with resource capacity constraints, such as the constraint over the allowed seats in a course. An extensive evaluation of our proposed method on real-world student preferences over courses shows that it obtains high utility for the students, while keeping the solution fair and observing courses' seat capacity limitations. Our model can be adapted to solve a variety of multi-allocation problems in which it is required to consider friendships.

■ TB-14

Tuesday, 10:30-12:00 - U261

Decision making under uncertanity in energy systems

Stream: Energy Management
Invited session
Chair: *Ayse Selin Kocaman*

1 - Operational Benefit of Transforming Cascade Hydropower Stations into Pumped Hydro Energy Storage Systems
Ayse Selin Kocaman, Parinaz Toufani, Emre Nadar

This study evaluates the potential benefit of retrofitting existing conventional cascade hydropower stations(CCHSs) with reversible turbines so as to operate them as pumped hydro energy storage (PHES) systems. We examine the energy generation and storage problem for a CCHS with two connected reservoirs that can be transformed into a PHES system in a market setting where the electricity price can be negative. We formulate this problem as a stochastic dynamic program (SDP) under uncertainty in the streamflow rate and electricity price. We analytically derive an upper bound on the profit improvement that can be obtained from the PHES transformation. We conduct numerical experiments with data-calibrated time series models and observe that the PHES system provides a greater benefit under more limited streamflow conditions or more frequently observed negative prices.

2 - Optimal Hour-Ahead Commitment and Storage Decisions of Wind Power Generators
Ece Cigdem Karakoyun, Harun Avci, Ayse Selin Kocaman, Emre Nadar

We study the energy commitment, generation, and storage problem for a wind farm co-located with a battery. The producer decides how much energy to commit to selling to or purchasing from the market, how much energy to generate in the wind power plant, and how much energy to charge into or discharge from the battery. The existence of the battery in our setting not only helps smooth imbalances caused by the fluctuating wind output but also enables price arbitrage in the following two ways. First, the producer can benefit from buying energy when the price is low or sometimes even negative and selling it when the price is higher in the future. Second, the producer can strategically refrain from meeting her commitments when they are due. We model the producer's real-time decision-making process as a Markov decision process with stochastic wind speed and electricity prices. We prove the optimality of a state-dependent threshold policy under positive prices and perfectly efficient battery and transmission line. We employ our structural results to develop an efficient heuristic solution procedure in a more general problem where the electricity price can also be negative and the battery and transmission line are not necessarily perfectly efficient. Our numerical study with data-calibrated instances has revealed the high efficiency and scalability of our solution procedure.

3 - Integration of pumped hydro energy storage and wind energy generation: a structural analysis
Parinaz Toufani, Harun Avci, Ece Cigdem Karakoyun, Ayse Selin Kocaman, Emre Nadar

We study the energy generation and storage problem for a hybrid energy system that includes a wind farm and a pumped hydro energy storage (PHES) facility with two reservoirs fed by a natural inflow. The operator decides how much water to pump or release in the PHES facility, how much energy to generate in the wind farm, and how much energy to buy/sell. We model this problem as a Markov decision process under uncertainty in streamflow rate, wind speed, and electricity price. We prove the optimality of a state-dependent threshold policy under positive prices: The state space can be partitioned into disjoint domains, each associated with a different action type, such that it is optimal to bring the water level of the upper reservoir to a different state-dependent target level in each domain. Once the optimal amount of water that should be pumped or released is found, we can immediately derive the optimal amount of wind energy that should be generated. The existence of inflow in the PHES facility improves the profits in our data-calibrated instances with possibly negative prices. Leveraging our structural results, we develop a policy-approximation algorithm as a heuristic solution method for such instances. This algorithm yields near-optimal solutions up to twenty times faster than the standard dynamic programming algorithm. It also performs significantly better than profit-approximation and rolling-horizon approaches adapted from the literature with respect to objective value.

4 - Online Scheduling of a Rolling Horizon Energy Management Model Under Uncertainty
Jens Hönen, Johann Hurink

Within the last few years, the energy transition, that is the trend towards more renewable energy sources has been become increasingly popular. This trend leads to drastic changes within the current and future electricity system, mainly due to the additional uncertainty and loss of control on the generation side, e.g. by wind and PV production. To tackle this increased uncertainty, techniques from robust optimization are used to model a robust energy management system for a microgrid. This microgrid consists of a set of households, each may be equipped with different controllable devices, and access to two electricity markets on different time scales. The considered uncertainty lies within both, the generation and the demand side, as well as in the electricity prices in the two markets. A Rolling Horizon framework is used to model the different time scales of decisions for the two markets, as well as the realizations of the uncertain parameters. The Rolling Horizon model outperforms the base model and it is analyzed, which uncertainty parameters contribute to this improvement. As computation power is a limited resource, an online decision support tool is developed, which identifies good starting time slots for the iterations of the Rolling Horizon. This tool uses the considered uncertainty sets as well as past realizations of the uncertainty throughout the Rolling Horizon to decide when to re-optimize the robust model. A small case study is presented as a proof of concept.

■ TB-15

Tuesday, 10:30-12:00 - U262

Decision Support Tools in Public Service Applications

Stream: Decision support (contributed)
Contributed session
Chair: *Djamila Ouelhadj*

1 - Bi-objective goal programming for balancing costs versus nutritional adequacy
Melissa Koenen, Marleen Balvert, Hein Fleuren

Already since the first half of the 20th century there has been an interest to create affordable and nutritious diets using linear programming, also referred to as the Diet Problem. Although traditionally used to construct diets for soldiers and feed rations for livestock, the diet problem is nowadays used to give dietary advice to prevent cancer and identify food barriers in low-income regions. The diet problem minimizes the cost of a diet while (among others) satisfying nutritional requirements. It is, however, not always possible to create a feasible diet. In such case it is necessary to find a near feasible solution, where both the nutrient deficiency and cost are considered. In this talk we use a bi-objective approach based on Sandwich algorithms to show all Pareto trade-offs between cost and nutritional adequacy. This helps decision makers, such as the World Food Programme, in case a nutritious diet is either unaffordable or infeasible. The procedure can be extended to include other relevant objectives as well, such as greenhouse gas emissions or water footprint. Furthermore, we discuss and question some commonly made assumptions in the literature.

2 - Police Service District Planning
Tobias Vlcek, Knut Haase, Malte Fliedner, Tobias Cors

We propose a new framework to address the Territory Design Problem of emergency services in collaboration with two police authorities in Europe. Our framework serves as a strategic decision support system to assess different districting layouts, department locations, staffing decisions and dispatching strategies. First, we introduce a novel modification of the p-median problem with a combined approach to the contiguity and compactness of district layouts. A standard commercial solver can determine the optimal district layout within 1 hour in all instances of our case studies with up to 1596 basic areas. Second, we utilize a new discrete event simulation that accounts for the variability of spatial and temporal incident patterns to evaluate the district layouts according to several criteria based upon up to 1.8 million historical incidents. In comparison to the present district layouts and department locations, our simulation demonstrates that our compact and contiguous district layouts can lead to a reduction of the response time by up to 14.52% while lowering the dispatch time, the overall driving time, and the number of unanswered calls for service.

3 - A Decision Support Tool for Sustainable Public Lighting
Djamila Ouelhadj, Ramazan Esmeli, Hassana Abdullahi

For sustainable and smart cities, public lighting has a great deal of economic, environmental, and social impacts. These impacts include economic costs, energy consumption, harmful emissions, mobility, and community integration. Municipalities are also continuously striving towards finding optimal public lighting solutions that ensure residents' feeling of safety and sustainable public lighting that contribute to reducing carbon emissions as well as being cost-efficient. Therefore, in this study, we have developed a Decision Support Tool (DST) to measure and evaluate the sustainability of public lighting installations for the European Interreg 2-Seas Smart Light Concepts (SLIC) project. The SLIC DST is a web-based tool designed to support decision-makers in making decisions regarding the implementation of smart and sustainable public lighting technologies to improve the performance of their public lighting systems. The DST will contribute towards aiding managing authorities in increasing the adoption of smart and sustainable technologies and applications in other sectors that have the potential for reduction in GHG emissions. We present the DST conceptual framework, the multicriteria decision-making optimisation model, and the economic, environmental and social dimensions impact analysis.

Acknowledgment: We acknowledge and thank the Interreg 2seas Mers Zeeen European Regional Development Fund for funding the Smart Lights Concept (SLIC) project. www.smartlightconcepts.e

■ TB-16

Tuesday, 10:30-12:00 - U264

Recent advances in multiobjective optimization and insurance

Stream: Set Valued Models in Finance
Invited session
Chair: *Elisa Mastrogiacomo*
Chair: *Asmerilda Hitaj*

1 - Co-jumps and recursive preferences in portfolio choices
Immacolata Oliva

In this paper we solve a continuous-time dynamic optimal portfolio allocation problem in an incomplete market setup, when the investor faces recursive utilities, and both the stock and variance process are assumed to be subject to discontinuities. Within such a non-affine framework we exploit standard dynamic programming techniques to derive an approximated solution to optimal allocation and consumption. The solutions to the optimal rules are genuinely dynamic, consistently with the well-known Markowitz economic intuition that an inverse dependence of the portfolio exposures with respect to the variability parameters should be observed. To uncover the role of jumps in the optimal allocation, we numerically investigate some instances of the non-affine model proposed and analyse the corresponding risk profile. Furthermore, we perform a calibration procedure on real data, revealing that the performances of our investment strategy benefit from the presence of both derivatives and co-jumps.

2 - Comparison of discretization approaches for the approximate evaluation of the distribution of the random sum of iid random variables
Alessandro Barbiero, Asmerilda Hitaj

Determining the distribution of the sum of N iid continuous positive random variables, with N random, is a well-known statistical problem that covers great importance in the insurance field, where such random variables can represent the size of the claims occurring in a given period and their sum S can be regarded as the aggregate risk the insurance company has to sustain. In general, the exact distribution of S is not easy to derive either analytically or numerically, as it involves the evaluation of convolutions, which typically require a huge computational effort. Alternatively, one can appropriately discretize the continuous random variable modelling the claim size and then apply Panjer's recursive formula, which provides the exact distribution of S if the distribution of N belongs to the (a, b, 0) class and the claim size is a count random variable itself. In this work, we explore different discretization techniques, some of which recently introduced in the literature; they are applied to the above problem, by considering several distributions for the claim size and the number of claims. The approximations of the distribution of S obtained through the application of discretization and Panjer's formula are assessed and compared to the normal approximation obtained by resorting to the central limit theorem and to the approximation obtained by employing the translated Gamma distribution.

3 - Asset allocation for life insurance portfolio under Solvency II using artificial intelligence.
Anna Maria Gambaro

In this paper, we apply Solvency II indicators to find the optimal asset allocation of life insurance funds, for example by minimizing the Solvency Capital Requirement (SCR). SCR is defined as the level of available own fund that enables insurance companies to absorb significant losses of the available capital (AC) and that gives reasonable certainty to policyholders and beneficiaries that payments will be made as they fall due. The AC is the result, in the company balance sheet, of the difference between the fair value of assets and the fair value of all liabilities. The asset-liability interaction is evident in the literature concerning the valuation of life insurance policies. Then, the liability value depends on the chosen asset allocation and this makes the optimization procedure more complex and computational challenging. In literature and among practitioners, the most used numerical methods to reconstruct the AC distribution and to calculate the SCR are nested Monte Carlo, least square Monte Carlo and replicating portfolios. In this work, we propose a neural network approach to manage the optimization of the life insurance portfolio for a wide range of asset allocations. Furthermore, the robustness of the approach is tested and the performance is compared with existing numerical methods.

4 - Multiobjective stochastic problems and their connections with multivariate risk measures
Elisa Mastrogiacomo

In this paper we generalize the study of minimax stochastic programming to the case where the objective function is multi-objective. In doing this, we will consider two possible approaches: the objective-wise worst case approach and the set approach. In both cases, we will provide necessary and sufficient condition of optimality in terms of suitable first order conditions.

Then we compare the proposed approaches with the minimization of vector-valued and set-valued risk-measures recently introduced by Jouini et. al (2004), Cascos and Molchanov (2007) and Hamel and

Heyde (2010). We show that the minimization of a certain of multivariate (respectively, set-valued) risk measure is, in a sense, equivalent to optimize a multiobjective (respectively, set-valued) expected value problem with respect to some weighted distribution in the set permissible distributions. We also introduce and analyze specific optimization problems involving risk functions.

■ TB-17

Tuesday, 10:30-12:00 - U356

Software for (MI)NLP

Stream: Software for Optimization
Invited session
Chair: Susanne Heipcke

1 - New Developments in the SCIP Optimization Suite 8
Ksenia Bestuzheva

We present the new functionality and algorithmic improvements that were introduced in the SCIPOptSuite 8 release. This includes developments in SCIP such as a new framework for handling nonlinear constraints, improvements in symmetry handling, new cutting planes and primal heuristics, and developments in the interfaces for accessing SCIP from other programming languages and modelling platforms, and the components of SCIPOptSuite that SCIP closely interacts with when solving optimisation problems. We discuss SCIP's capabilities as a research tool, demonstrated by the extensions built upon it, and present the latest improvements in these extensions.

2 - Global Optimization of Advanced Formulations with EAGO.jl: Recent Advances
Matthew Stuber, Robert Gottlieb, Matthew Wilhelm

Five years has passed since the inception of the EAGO project and the first public release of an open-source deterministic global optimizer for general nonlinear programs (NLPs). The motivation for creating EAGO was born from the need for an extremely fast global optimizer for solving advanced problem formulations with complicated user-defined functions often encountered in engineering design and operations applications. As such, the development of EAGO is focused on extensibility as a research platform in addition to accessibility and high performance as an out-of-the-box solver. These aims have so far been achieved, aided by the unique features and high performance of the Julia programming language in addition to the active and integrated development communities for optimization (e.g., JuMP-dev), machine learning (e.g., SciML), and general numerical analysis packages.

This talk will focus on recent directions and advances in EAGO's development: compatibility with equation-oriented modeling in Julia; exploiting GPGPU parallel architectures through source-code transformation approaches; enhanced relaxations of composite bilinear forms; and overall improvements in relaxation libraries, including relaxations of artificial neural networks.

3 - A new specialized interior-point method for large-scale multistage stochastic optimization problems
Jordi Castro, Laureano Fernando Escudero, Juan Francisco Monge

A novel approach based on a specialized interior-point method (IPM) is presented for solving large-scale stochastic multistage continuous optimization problems, which represent the uncertainty in strategic multistage and operational two-stage scenario trees. This new solution approach considers a split-variable formulation of the strategic and operational structures. The specialized IPM solves the normal equations of the IPM by combining Cholesky factorizations with preconditioned conjugate gradients, doing so for, respectively, the constraints of the stochastic formulation and those that equate the split-variables. A broad computational experience is reported for large multistage stochastic supply network design (SND) and revenue management (RM) problems; the mathematical structures vary greatly for those two application types. Some of the most difficult instances of SND had 5 stages, 839 million linear variables, 13 million quadratic variables, 21 million constraints, and 3750 scenario tree nodes; while those of RM had 8 stages, 278 million variables, 100 million constraints, and 100,000 scenario tree nodes. For those problems, the proposed approach obtained the solution in 2.3 days using 167 gigabytes of memory for SND, and in 1.7 days using 83 gigabytes for RM; while the state-of-the-art solver CPLEX v20.1 required more than 24 days and 526 gigabytes for SND, and more than 19 days and 410 gigabytes for RM.

■ TB-18

Tuesday, 10:30-12:00 - U358

Applications of Stochastic Programming

Stream: Stochastic and Robust Optimization
Invited session
Chair: *Milos Kopa*
Chair: *Martin Smid*

1 - Stochastic Capacity Investment and Flexible vs. Dedicated Technology Choice in the Presence of Subscription Programs
Onur Boyabatli, Liling Lu, Yini Gao

This paper studies flexible versus dedicated technology choice and capacity investment decision of a two-product firm under demand uncertainty in the presence of subscription programs. The key feature of subscription programs is that some proportion of consumers that are allocated a particular product later switches to using the other product. Several automotive manufacturers have started running such programs in the recent years. We investigate how correlation between two subscription demands affect capacity investment level and profitability with flexible and dedicated technologies, and shape optimal technology choice decision. We make comparison with the benchmark where there is no switching to the other product under traditional ownership model.

2 - Optimization of imperfect condition-based maintenance based on matrix algebra
Bram de Jonge

Industrial systems are in general subject to deterioration, ultimately leading to failure, and therefore require maintenance. Due to increasing possibilities to monitor, store, and analyze conditions, condition-based maintenance policies are gaining popularity. We consider optimization of imperfect condition-based maintenance for a single unit that deteriorates according to a discrete-time Markov chain. The effect of a maintenance intervention is stochastic. We use matrix algebra and renewal reward theory to determine the optimal preventive maintenance threshold.

3 - A Markovian approach for stochastic dynamic traffic assignment
Ricardo de la Paz Guala, Cristian E. Cortes, Pablo A. Rey, Benjamin Heydecker

In dynamic traffic assignment (DTA) applications for transport analysis, it is relevant to consider the uncertainty inherent to motorist route choices as part of the formulations. In particular, motorists' choices made on realistic transport networks are mostly based on the perceived costs of all routes from their origins to their destinations. In this work, we present an approach to address stochasticity in a DTA context based on nested cost operators, where motorists construct their routes taking into account the perceived costs from their current node to their destinations. We present the Markovian dynamic traffic assignment

(MDTA) model, an integration of the Markovian traffic equilibrium by Baillon and Cominetti with the DTA modelling framework by Addison and Heydecker. Our approach considers that motorists, in order to construct their routes, choose arcs according to their perceived costs of the remaining trip, resulting in an arc-based model instead of a route-based one. Our model allows working with overlapping routes with no assumptions of independence of their costs, usually required in the literature. We also develop the MDTA algorithm, a method that solves our model in discrete time and respects the First In First Out (FIFO) rule. Our algorithm works as a dynamic version of Dial's algorithm, where the backward step is performed first. Preliminar results regarding its computational implementation have been obtained for the Sioux Falls network, among others.

4 - Multistage stochastic programming for the optimal bid of a wind-thermal power production pool with battery storage.
F.-Javier Heredia, Ignasi Mañé, Marlyn Dayana Cuadrado Guevara

In this study we present a multistage stochastic programming model to find the joint optimal bid to electricity markets of a pool of dispatchable (thermal) and non-dispatchable (wind) production units with battery storage facilities. The assumption is that these programming units are operated by the same utility that, previous to the market clearing, has to dispatch some bilateral contracts with the joint production of the production pool. The multistage model mimics the multimarket bidding process in the Iberian Electricity Market (MIBEL). First, the utility has to decide how to cover the energy of the bilateral contracts with the available units. Second, the production capacity of each unit, not allocated to the bilateral contracts, must be offered to the seven consecutives spot markets (day-ahead and six intraday markets) plus the secondary reserve market (the most relevant ancillary services market). The stochasticity of the electricity clearing prices and the hourly generation of the wind-power units is considered. The stochastic process associated to this multistage decision-making process is modelled through multistage scenario trees with thirty-four stages that are built from forecasting models based on real data of the Iberian Electricity Market. The numerical results show the advantage of the joint operation of the pool of production units with an increase of the overall expected profits, mainly due to a strong reduction of the operational costs.

■ TB-19

Tuesday, 10:30-12:00 - Y228a

Stochastic Processes and Applications 2

Stream: Performance Evaluation of Queues
Invited session
Chair: Nikki Levering

1 - Algorithmic collusion with multi-agent learning
Janusz Meylahn

Algorithmic collusion can arise in situations where multiple algorithms that should be competing, learn to work together to the detriment of society. Markets in which pricing algorithms are employed by multiple firms are an example of where this could occur. In order for policymakers to legislate against the use of collusive algorithms, they must know which mechanisms lead to algorithmic collusion. Identifying such mechanisms falls in the broader class of research on the explainability of artificial intelligence. In this talk, I will discuss two different types of collusive algorithms. The first makes use of stochastic gradient ascent methods, while the second employs reinforcement learning. In both cases, it is possible to (partially) identify the mechanisms that lead to collusion.

2 - Comparison of stability regions for a line distribution network with stochastic load demands
Mark Christianen

We compare stability regions for different power flow models in the process of charging electric vehicles (EVs) by considering their random arrivals, their stochastic demand for energy at charging stations, and the characteristics of the electricity distribution network. We assume the distribution network is a line with charging stations located on it. We consider the Distflow and the Linearized Distflow models and we assume that EVs have an exponential charging requirement, that voltage drops on the distribution network stay under control and that the number of charging stations N goes to infinity. We investigate the stability of utilityoptimizing power allocations in large distribution networks for both power flow models by controlling the arrival rate of EVs to charging stations. For both power flow models, we show that, to obtain stability, the maximum feasible arrival rate, i.e. stability region of vehicles is decaying as 1/N2, and the difference between those arrival rates is up to constants, which we compare explicitly.

3 - Comparison between the Deterministic and Stochastic Models of Nonlocal Diffusion
Itsuki Watanabe, Hiroshi Toyoizumi

We discuss the difference between the deterministic and stochastic models of nonlocal diffusion. We use a nonlocal reaction-diffusion equation and a multi-dimensional jump Markov process to analyze these mathematical models. These models can be used for a nonlocal dynamics such as information spread on the large networks and population dynamics with high-speed transportation, where long-range interactions are main driver of the system. In this talk, we present two limit theorems. First, we demonstrate that the difference converges to 0 in probability with a supremum norm for a sizeable network. Next, we consider the rescaled difference and show that it converges to a stochastic process in distribution on the Skorokhod space.

4 - Optimal departure time advice in networks with stochastic disruptions
Nikki Levering, Rens Kamphuis, Michel Mandjes

Due to recurrent daily patterns and non-recurrent disruptions, travel times in road networks suffer from time-dependence and randomness. This is challenging for travelers planning a future trip, aiming to ensure on-time arrival at the destination, whilst also trying to limit the total travel time budget. Therefore, we focus on determining their optimal departure time: the latest departure time for which a chosen on-time arrival probability can be guaranteed. To model the uncertainties in the network, we use a Markovian background process that tracks events affecting the driveable vehicle speeds on the links, allowing us to incorporate both daily patterns and incidents. Now, given the state of this process at departure, the resulting travel time distribution on a single link can be derived via a discretization procedure. We present a computationally efficient algorithm that uses these individual link distributions to obtain the optimal departure time and corresponding path for a trip from an origin to a given destination. Then, since the conditions in the road network may change between the time of request and the advised time of departure, we also consider an online version of the problem, in which the traveler receives departure time updates whilst still at the origin. Finally, numerical experiments are conducted to verify the effectiveness of the algorithms and exemplify a selection of optimal departure time properties.

■ TB-20

Tuesday, 10:30-12:00 - Y228b

DEA applications in Finance and Industry

Stream: Data Envelopment Analysis and Performance Measurement
Invited session
Chair: Joseph Paradi

1 - A comparative study of maintenance efficiency across public bus companies in India using DEA

Shivam Kushwaha, Shankar Prawesh, Anand Venkatesh

The Maintenance departments of bus companies play a pivotal role in their overall performance. While maintenance is often seen as a support function, its various nuances and idiosyncrasies in the production process are overlooked. Effective operations and marketing cannot often overcome lacunae in maintenance practices. On the contrary, inadequate maintenance practices result in buses being off-road thereby proving to be detrimental for operations and the overall competitiveness of bus companies. In this paper, we evaluate the production performance across maintenance departments of public bus companies in India. The technique used to measure the production efficiency of maintenance departments is Data Envelopment Analysis (DEA). We have contextualized our DEA model and the associated variables to capture the production performance of maintenance departments of bus companies. The input-output data for maintenance efficiency computation is analyzed for the five years, 2013-2017. The main objective of this research study is to identify the maximum number of buses of the respective bus company which can be operated and subsequently, the achievable Fleet Utilization (FU). This study would help decision-makers understand the relative efficacy of their maintenance practices and envisage improvements therein.

2 - Specification Issues in Diversification Consistent DEA Portfolio Models

Stavros Kourtzidis, Giannis Karagiannis

This paper examines the features of a diversification consistent DEA portfolio model that treats both returns and risk as outputs and the initial investment as an input, in the sense that after the initial investment is made, returns and risk are generated simultaneously. Assuming an orientation towards risk reduction and the same initial investment, we show that models based on weak or constrained weak disposability of risk have non-increasing returns to scale while models based on extended strong disposability, i.e., treating risk as a reverse rather than undesirable output, may have either non-increasing or variable returns to scale. In addition, we show that, under non-increasing returns to scale, the model with constrained weak disposability results in the same efficiency scores as the model with extended strong disposability. We thus end up with three alternative model specifications, for which we provide comparative empirical results using 48 US industry portfolios.

3 - Analysing the export potentials of the Portuguese footwear industry by Data Envelopment Analysis

Dimitrios-Georgios Sotiros, Vasco Rodrigues, Maria Silva

Exports are widely believed to play a central role in economic development and firms' profitability, particularly in countries with small domestic markets. With that aim, governments and firms spend considerable resources on international promotion. Identifying the markets with the greatest potential for export growth is therefore crucial for an efficient allocation of public and private resources. In this paper, we propose a Data Envelopment Analysis framework to identify trading potentials with existing trading partner countries within an industry. To illustrate its applicability, we use data from the Portuguese footwear industry. Specifically, among the countries that currently import Portuguese footwear, we aim to identify those that have the greatest potential for increasing their imports from Portuguese footwear in terms of revenue. We further decompose this potential into price and quantity changes to provide strategic directions to the Portuguese footwear industry. For the analysis, we use panel data of 64 countries analyzed over the years 2011-2018. The results reveal that higher potentials lie among the countries of the European Economic Area. Overall, these potentials may be achieved through different price-quantity strategies.

4 - Mixed Datasets with Partially Deficient Variable Sets Embodied in Mixed Variable DEA (MV-DEA)

Joseph Paradi, Maryam Badrizadeh

Abstract One of the Data Envelopment Analysis (DEA) assumptions is that DMUs should be from the same "culture". However, in real-world environments, managers always want to compare their products/activities with similar such measures with some performance factors in the same industry. It follows that there does not exist a model that can appropriately consider different environments for various products in the same industry. This research introduces a novel DEA model, namely Mixed Variable DEA (MV-DEA) that provides a meaningful environment where DMUs with different cultural assumptions are examined relative to each other while retaining their own specific characteristics. The objective of this study was to develop a model using DEA to examine the private pension funds' performance by considering the specific characteristics of such funds in comparison with mutual funds. The model was applied to Canadian private pension funds which are regulated federally and Canadian open-ended mutual funds. The results of the new MV-DEA model were compared to traditional DEA models, and it was shown that the MV-DEA model provided a more realistic analysis.

■ TB-21

Tuesday, 10:30-12:00 - Y229a

Experiences with online facilitation and modelling

Stream: Behavioural OR

Invited session

Chair: *L. Alberto Franco*

1 - Evidence for the efficacy of rapid capacity building for online facilitation through examining stakeholder perceptions: A case study in South East Asia

Zoe Horsham, Kathy Kotiadis, Tim Hopthrow, Vũ Văn Mạnh, Tomy Perdana, Vu Hoang Linh, Kusnandar Kusnandar, Be Thi Hoang Yen, Fernianda Rahayu Hermiatin

The COVID-19 pandemic has rapidly increased the need for online facilitation. Despite this, very little attention has been given in the literature to online facilitation, meaning little is known about the required skills for online practitioners. Furthermore, research suggests that there is a shortage of facilitators due to the skillset and intense training required, with a lack of opportunities for novices to gain first-hand experience required to develop expertise. Our paper addresses these gaps through a case-study in South East Asia where those with no prior experience of facilitation were rapidly trained to facilitate in an online environment. We utilise a new theoretically driven questionnaire to measure stakeholder's perceptions which draws from common criteria in a range of facilitator competency frameworks. Our findings suggest that facilitators may be rapidly trained without extensive formal Soft OR method knowledge. This could mean that it is possible to rapidly train hard OR practitioners to effectively interact with groups of stakeholders in workshop environments. Finally, we find support for the notion that facilitators may be able to rapidly transfer their skillset to an online environment with the correct support. We identify a new category of facilitator, characterised by no knowledge or experience with facilitation, termed 'emergers'.

2 - Systemic risk management for Covid-19

Colin Eden

During the pandemic (Covid-19) understanding and appropriately reacting to the large system risks has been crucial. This paper reports on the practice of systemic risk management of health care for a region in Norway. A qualitative causal risk system was constructed using special purpose group support software that allowed health care experts across many disciplines to construct the system. They did this from different locations in Norway (with a facilitator in the UK) but at the same time. The resultant model was used to negotiate effective strategies that were subsequently enacted. The group support software permitted the analysis of vicious cycle to locate those most potent for strategy development - the analysis revealed several million vicious cycles (the essence of a pandemic). The total time devoted to constructing, validating, and building strategies involved 4 workshops and was the equivalent of 15hrs work for the group.

3 - Panel discussion: Behavioural issues in online facilitation/modelling
L. Alberto Franco, Kathy Kotiadis, Antuela Tako, Birgit Kopainsky, Hugo Herrera, Mike Yearworth, Colin Eden

Whilst technological advancements have allowed organizations to make greater use of virtual teams in the last 20 years, the recent global Covid-19 pandemic have forced organizations to adopt a mode of remote working worldwide. This increased in demand for remote working has significant implications for the way operational researchers facilitate teams to develop models. This panel session will start with six experts from different domains of practice (discrete event simulation, system dynamics & group model building, problem structuring, strategy) sharing their experiences of online facilitation and/or modelling to highlight the nuances associated with this type of work. Next, the audience will be invited to ask questions to the panel. Following the discussion, potential avenues for conducting behavioural research in online facilitation/modelling will be identified

■ TB-22

Tuesday, 10:30-12:00 - Y229c

Social Factors in Sustainable Supply Chains

Stream: Sustainable Supply Chains
Invited session
Chair: Marina Segura

1 - Assessing the Social Dimension in Strategic Network Design: The Case of Bioethanol Production in the EU
Lukas Meßmann, Lars Wietschel, Andrea Thorenz, Axel Tuma

Unlike site-specific assessments, decision-making on a strategic level relies heavily on aggregated and generic data. Therefore, and in contrast to environmental ones, social indicators are often neglected in strategic supply chain optimization. This work presents a structured process for selecting applicable quantitative social indicators. This approach is applied to the case of second-generation bioethanol (2G EtOH) in the EU, which is a promising substitute for fossil and food crop-based fuels. In total, we compile 9 maximizable social objective functions and 25 categories for hotspot identification, and evaluate impacts and benefits of a large-scale 2G EtOH production network in a MILP model. We identify optimal strategic decisions (biorefinery locations & capacities, feedstock collection, EtOH transportation, and substitution of petrol or first-generation EtOH) and resulting optimal objective values by optimizing each of the social as well as additional economic and 21 environmental LCA-based objectives. Key results show that social optimization mostly leads to large, labour-intensive networks, but social indicators show notable regional differences. We uncover hidden interlinkages between the different objectives in this application case, calculate Pareto-optimal trade-offs between them, and assess the network's social hotspots along global value chains. The approach is novel in its depth both in the fields strategic supply chain design and the European bioeconomy.

2 - The impact of cost auditing on supply chain social responsibility
Zhengping Wu, Haiying Yang

Corporate Social Responsibility (CSR) has become an increasingly higher priority for companies, driven by pressure from key stakeholders including consumers, regulators, and investors. Evidence in recent years, however, suggests that many firms still lack commitment to CSR programs, despite their rapidly growing recognition of the importance of CSR. Motivated by this perplexing observation, we attempt to offer an explanation of firms' underinvestment in CSR through the lens of supply chain management. Specifically, we consider a two-tier supply chain consisting of a supplier (him) and a retailer (her). The supplier has private information about his unit production cost, and the retailer designs an incentive contract with a potential cost audit to induce truth-telling. We concentrate on two major research questions: first, how does the retailer's audit mechanism affect the supplier's social responsibility decision? Second, to what extent does the impact of the audit mechanism hinge on market parameters and consumers' response to social responsibility? We find that the audit by the downstream retailer may induce the upstream supplier to reduces his social responsibility level, and investigate the parametric conditions for the reduction to occur. Our results suggest that, from a managerial point of view, downstream firms should be mindful of noticeable unintended negative consequences of cost auditing on the upstream suppliers' CSR decisions.

3 - Social monetization strategies for the design and planning of supply chain
Cátia da Silva, Ana Paula Barbosa-Póvoa, Ana Carvalho

Currently, there are many concerns about supply chain's sustainability and the impact they can have at an environmental and social level. Decision-makers realized that supply chains are not limited to its economic component and it is necessary to integrate both environmental and social concerns into the decision-making process. In fact, there is a significant number of scientific works that demonstrate the growing concern on the environmental topic, but the social one can still be further explored. Understanding the true social impact for decision-makers is not easy, especially when it is crucial to quantify the impact that their supply chains have. For this reason, social monetization constitutes an important step in the quantification of social impacts in a unit easily understood by decision-makers, who are used to deal with monetary units. This work intends to develop a social monetization method that aims to: i) correlate social indicators with economic indicators and variables; ii) quantify the social impact of the supply chain in monetary units easily understood by decision-makers; and iii) translate both economic and social impacts in the same unit in order to optimize the design and planning of the SC. This is an innovative method as it can simplify the decision-making process and allows the quantification of the supply chains' social performance in an easily understood unit. This work is validated considering a real case study of an international SC.

4 - Hybrid multicriteria model for sustainable technology supplier selection in the banking sector
Marina Segura, Ivan Felipe Barrera, Concepción Maroto

Supplier selection is a key strategic problem in supply chain management. The aim of this research is to provide a new hybrid multicriteria model for evaluating technology suppliers and validate it with a case study in the banking sector. This approach allows companies to perform qualification, selection, ranking and sorting of suppliers on a sustainable basis. Integration of several techniques is necessary to address this complex decision problem with conflicting economic, environmental and social criteria. AHP is useful for problem structuring and weighting criteria collaboratively. MAUT is applied to obtain indicators for product quality and supplier risks, whose utility functions are derived by data-driven models that favour evaluation objectivity and transparency. PROMETHEE is suitable for supplier selection due to its discriminant power among alternatives. Finally, FlowSort is proposed to classify suppliers into ordered groups and the outcomes are compared with results from MAUT. Results show its applicability by increasing process transparency and reducing operational risks in practice.

■ TB-23

Tuesday, 10:30-12:00 - Y307

Pricing and Revenue Management 3

Stream: Pricing and Revenue Management
Invited session
Chair: Luce Brotcorne

1 - Incentivizing Truthfulness in Production-as-a-Service Auctions with Budget Constraints
Christina Liepold, Maximilian Schiffer

A major paradigm shift in servitization-based Industry 4.0 innovations is the Production-as-a-Service concept, which allows an operational exchange of idle production capacities, e.g., through a two-sided combinatorial auction orchestrated by an intermediary connecting buyer and seller companies. To foster participation in this auction, it is necessary to define a core-stable exchange, which also guarantees allocative efficiency and incentivizes bidder truthfulness. So far, no optimization-based model has been brought forward to establish and solve such an exchange related to the operational outsourcing of production capacities through Production-as-a-Service. Against this background, we present a combinatorial, intermediated production capacity exchange problem with welfare maximization and buyer-side budget constraints that preserves core-stability and incentivizes bidder truthfulness. The presented model is not incentive compatible without the involvement of the intermediary. To remedy this drawback, we show how a profit-oriented intermediary can improve the overall incentive compatibility in the Production-as-a-Service market. Moreover, we show how to solve the developed mixed integer bilevel linear program with a tailored column and constraint generation algorithm and present managerial insights for a realistic case study.

2 - Contract pricing in a synchromodal transportation setting
Jasper Paesen, An Caris, Christof Defryn, Lotte Verdonck

In the freight transportation industry, long-term contracts between logistics service providers (LSP) and shippers are common. These contracts typically contain long-term commitments related to, e.g., volume, lead time and price. The latter is mostly based on the expected cost of the transport mode that will be used for the transport of a shipment with the addition of a desired profit margin, i.e., cost-plus pricing. As these contracts apply over a longer period, e.g., a year, commitments need to be made long before the execution of the transport service itself. This long-term decision making contradicts with the fundamentals of synchromodality, which assume flexibility to change decisions with respect to route and transport mode in real time.

In this research, we present an extensive numerical experiment that provides insight in the service quality characteristics, i.e., long-term commitments that have a significant impact on a LSP's cost. In addition, interaction effects between long-term commitments of different shippers are expected, which should also be considered when analysing the cost implications. These results will serve as an input for a service-based pricing strategy for synchromodal transport. Such a strategy sets a price based on service quality characteristics of the transport, rather than the used transport mode. In this way, we aim to justify a contract price while the transport mode and route are still unknown.

3 - New cloud computing resources pricing strategies
Luce Brotcorne, Bernard Fortz, Arnaud Laurent

In this talk, we present a new cloud computing resources pricing model, where a Cloud Service Provider (CSP) rents resources during a short period of time (Pay as you go) or over a larger one (subscription) with a slightly cheaper price. The goal of the CSP is to define a pricing strategy for both types of customers to generate revenue and incentivizing the subscribers to release their resources when they don't need it. Environmental costs will be integrated in the CSP objective function.

A bilevel optimization model is provided to integrate the strategic behavior of the customers into the CSP optimization process. Numerical results are discussed on randomly generated instances inspired from real life.

4 - Optimal Tax Policy for Single Homogeneous Commodity on n Markets with Export Costs as a Stackelberg Game
Zrinka Lukač

Taxation is one of the most powerful instruments of fiscal policy, affecting economic growth and investments, as well as competitiveness of companies. Therefore, designing the optimal tax policy is of crucial importance for any government. This study formulates the problem of determining optimal tax policy for single homogeneous commodity produced by n competing companies located in n different countries with export costs as a Stackelberg game with multiple followers. Companies produce the commodity in their country of origin and sell it on all n markets. Countries have different tax systems. If a company is selling the product in a foreign country, it has to pay export costs consisting of transportation costs and duty costs. Government of country i is the leader and makes the tax amount decision with the objective of maximizing its tax revenue. Companies are the followers. They make decisions about production and export quantities in order to maximize their profit functions. The study derives the optimal tax policy, i.e. the optimal tax amount and the optimal value of tax revenue function as well as companies' optimal production and export quantities. It discusses the properties of the tax revenue function and analyzes the effect of unit increase of taxes on optimal production and export quantities as well as on companies' revenue and profit functions. Finally, the study shows how the tax burden is divided between producers and consumers.

■ TB-24
Tuesday, 10:30-12:00 - Y307a

Sustainability in E-Commerce Delivery

Stream: Demand and Supply in Consumer Goods and Retail
Invited session
Chair: *Heinrich Kuhn*
Chair: *Pedro Amorim*

1 - A literature review for Green Smart Home Delivery Problem in urban environments
Haifa Jammeli, Jerome Verny

Due to growing urbanization, changing climatic, and lifestyles, Green logistics has become a global concern. Traditionally, the objective of a logistics operation has been to achieve customer service goals by minimizing costs and maximizing profits. In recent years, more and more companies want to proactively add sustainability objectives, reduce their carbon footprint and support the ongoing efforts to prevent climate change. The future of transportation will be largely influenced by this consideration. This paper aims to overview the operational research models that were developed to solve the Green Smart Home Delivery Problem. We start with a general overview of green home delivery optimization. Therefore, we provide a summary of the literature on smart home delivery optimization. Finally, in the Home Delivery challenge, we focus on the combination of Smart and green ideas

2 - On the Consumer Implications of Delivery Consolidation in Online Retail
Pedro Amorim

A retailer who receives an online order comprising several products spread across various warehouses may be obliged to ship multiple parcels from different locations and these may reach the customer's doorstep one by one. Receiving the products sequentially instead of all together at once, we conjecture, affects a consumer's reaction to her purchases, possibly changing her decision to return some as well as her overall service satisfaction. We use two-year granular data of an online fashion marketplace to test this hypothesis and characterize the consumers' behavioral response to delivery consolidation and how it impacts the supply chain. To obtain causal inference, we exploit the fact that the marketplace supply chain consolidates some deliveries unintentionally and quasi-randomly, and construct a balanced sample of matched twin orders that are akin in all aspects except their delivery:

split vs consolidated. We find that delivery consolidation is beneficial for the marketplace and all its suppliers: by removing the otherwise mental tension of split deliveries, consolidation pacifies consumers needing closure, who return fewer products across the board and become more satisfied. Delivering all products of an order in one fell swoop, even if later, lowers the probability of a return and is hence a win-win-win for consumers, suppliers, and marketplaces—and for the planet.

3 - Last mile deliveries with some-day option for more sustainability in e-commerce
Markus Frank, Heinrich Kuhn

E-commerce retailers face the challenge of acting cost-efficient and becoming more sustainable at the same time, especially on the last mile, as the success of online retailers is strongly dependent on an efficient delivery to the customer. Retailers therefore offer a range of delivery options that differ in terms of speed. While the trend is moving in the direction of same-day and instant delivery, a new concept already adopted by Amazon is to offer a slow delivery option, too. Faster delivery modes increase total costs and emissions by leaving less time for efficient planning and limit consolidation possibilities on the last mile. Slowing down the delivery process offers the opportunity to increase shipment consolidation and thus save costs and take greater care of environmental demands simultaneously. The so-called "Some-Day-Delivery" option significantly increases flexibility in tour planning. We formulate the stochastic-dynamic some-day delivery problem (SDDP) that considers delivery deadlines as well as routing and capacity constraints in a multi-period planning environment. Our numerical study shows that forecasting future customer orders and their associated delivery options is critical to finding feasible routes, balancing capacity, and realizing consolidation opportunities.

4 - Solution methods for a combined inner city vehicle routing and commercial parking bay location problem under sustainability aspects
Niels-Fabian Baur, Julia Rieck, Maik Trott

The international market for courier, express, and parcel services has grown significantly and traffic volumes in inner cities are rising. This leads to increased air pollution and congestion. A potential concept to ensure favourable living and operating conditions for urban stakeholders is the introduction of commercial parking bays for delivery vehicles, from which the surrounding houses are supplied. This reduces second-row parking, what can avoid congestion and emissions, but can also lead to longer delivery times. We evaluate the potential advantages and disadvantages of these parking bays in terms of environmental, economic, and social sustainability aspects. For this purpose, we have adopted a combined approach of simulation and mathematical optimization, allowing to evaluate the concept efficiently and reliably. The mixed-integer model is a specific vehicle routing problem with hourly based speed factors. Moreover, the locations of the parking bays are not known in advance. Accordingly, the objective is to determine the locations for the parking bays and, on this basis, to establish routes for the vehicles with minimal emissions and delivery times. In order to solve large instances in acceptable time, a tabu search method is also applied and embedded into an agent-based simulation to evaluate the impact of parking bays under realistic conditions. Data from one of the largest German service providers is used to create a realistic case study for the city of Hannover.

■ TB-25

Tuesday, 10:30-12:00 - Y308

Emerging Research on Education, Competences and Labor Markets

Stream: Emerging Research and Specific Applications of OR
Invited session
Chair: *Magdalena Graczyk-Kucharska*
Chair: *Milagros Baldemor*

1 - Game theoretic approach to school inspections
Abhishek Bhatnagar, Diptangshu Sen, Nomesh Bolia

India has a large government school network that aspires to provide quality education. Student scores and school pass percentage are quantifiable and well accepted measures of school performance. A key factor that influences school performance is school inspections that provide an independent verification whether the school meets the professional standards. In this work, we study the periodic inspections and formulate school inspection process using the principles of game theory. The problem consists of an inspector and n schools. The inspector action set consists of whether or not to inspect a school in a given period, whereas the school has a choice to violate or not to violate. The inspector incurs a cost to inspect and earns a revenue if a violation is caught. The schools incur less operational costs if they choose to violate, and therefore, have an incentive to violate. We formulate the inspection game and find the mixed strategy Nash Equilibrium. We obtain results for various values of costs and number of schools in the network to understand its effects on probability of inspection and violations. The results indicate that the probability of violation increases with the school size and number of schools in the network. The results have several policy implications: (i) for the size and scale of the school network and (ii) for inspectors to help them determine their inspection schedule.

2 - Flexible employee recruitment and retention models via flexible work plans: A bi-level optimization approach
Iris Forma, Hila Chalutz Ben-Gal, Gonen Singer

The growing practice of flexible work following the COVID-19 pandemic is likely to have a significant impact on management and human resource (HR) practices. In this research, we propose a novel bi-level mathematical programming model that can serve as a decision support tool for firms in real-life settings to improve recruitment and retention via hybrid and flexible work plans. The first proposed model for recruitment is composed of two levels: the first level reflects the company's goal of maximizing profitability by offering competitive salaries to candidates. The second level reflects the candidate's goal of minimizing the gap between their desired salary and the perceived benefits of a preferred flexible plan. We show that the model provides an exact solution based on a mixed integer formulation and we present a computational analysis based on changing candidate behaviors in response to firm's strategy. Results indicate that introducing a flexible work plan leads to an improvement of up to 59 percent in the firm's profitability. We apply the optimal solution of the bi-level model to a real-world case study which demonstrates its applicability to a real-world dataset. Then, we propose an extension of the model to address employee retention challenges in a firm and we present initial results. This research advances knowledge by proposing novel bi-level models for effective recruitment, retention and compensation decisions in real-world flexible workforce settings.

3 - Employment Analysis of the EU Regions from the Spatial Econometric Perspective
Michaela Chocholatá, Andrea Furková

The paper deals with the regional employment analysis of the European Union (EU) regions. The aim of the paper was twofold. Firstly, the spatial instability (spatial heterogeneity) of the relationship between the employment rate and the opted explanatory variables was examined. Secondly, the problem of spatial autocorrelation was also treated. We supposed, that the spatial dependencies among the EU regions, i.e., spatial location of the region is an inevitable determinant of employment rate levels. As methodological tools, the spatial econometric and spatial regime models were chosen for analysis. Following the results of the Explanatory Spatial Data Analysis, two spatial regimes were identified. Both, the spatial instability of estimated parameters and spatial regional linkages were indicated. In addition, spatial spillovers of all employment determinants under consideration were calculated and pointed to strong importance of these effects. Overall, the results suggest that the tools and goals of regional labour market policies should be performed in a more heterogeneous way.

4 - The application of quantitative modeling approaches in higher-education institutions (HEIs)
Aghdas Badiee, Mohammad Moshtari

Higher-education institutions (HEIs) have recently been challenged by funding cuts, austerity measures in both developed and developing countries. Moreover, governmental budgets allotted to HEIs have decreased, reducing investment in research and facilities. Simultaneously, societies and governments expect HEIs to become more deeply engaged in solving local and national socioeconomic problems and revise their educational programs to teach students the skills and competencies that various industries require. Stakeholders have also pressured them to be more economically and socially accountable by delivering value and positively influencing society on local, regional, national, and even international levels. This growing interest in improving HEIs' service effectiveness and efficiency including reducing operational costs, increasing educational and research quality, and boosting social impact provides a significant opportunity to promote the use of quantitative decision-making modeling tools. We have reviewed papers published in quality journals that used quantitative modeling approaches of industrial engineering and management (i.e., mathematical programming, operations research, optimization, data mining, simulation, etc.) in the higher education setting. Our aim is to highlight the potential of quantitative decision-making tools to improve the performance of HEIs and other knowledge-intensive institutions to encourage future research to contribute to this important field.

■ TB-26

Tuesday, 10:30-12:00 - Y309b

Responsible Humanitarian Supply and Operations Management

Stream: EWG HOpe, EURO working group on Humanitarian Operations
Invited session
Chair: *Gerald Reiner*
Chair: *Martin Hrusovsky*

1 - Revisiting Gini for equitable humanitarian logistics
Aakil Caunhye, Douglas Alem, Alfredo Moreno

Modeling equity in the allocation of scarce resources is a fast-growing concern in the humanitarian logistics field. The Gini coefficient is one of the most widely recognized measures of inequity and it was originally characterized by means of the Lorenz curve, which is a mathematical function that links the cumulative share of income to rank-ordered groups in a population. So far, humanitarian logistics models that have approached equity using the Gini coefficient do not actually optimize its original formulation, but use alternative definitions that do not necessarily replicate that original Gini measure. In this paper, we derive the original Gini coefficient via the Lorenz curve to optimize the effectiveness-equity trade-off in a humanitarian location-allocation problem. We also propose new valid inequalities based on a bounding Lorenz curve to tighten the linear relaxation of our model and develop a clustering-based construction of the Lorenz curve that requires fewer additional constraints and variables than the original one. The computational study, based on the floods and landslides in Rio de Janeiro state, Brazil, reveals that while alternative Gini definitions have interesting properties, they can generate vastly different decisions compared to the original Gini coefficient. In addition, viewed from the perspective of the original Gini coefficient, these decisions can be significantly less equitable.

2 - Location and capacity allocation for emergency contact points in large-scale power outages
Christian Truden, Christian Wankmüller, Dominik Zehetner, Margaretha Gansterer

Nowadays, a secure electricity supply is essential for the industry and for individuals. A large-scale power outage, commonly known as "blackout", caused by natural disasters, cyber-attacks, technical failure, or human errors, can cause a variety of severe consequences. The far-reaching dynamics of blackouts can even result in the collapse of critical public service infrastructure reliant on electricity (e.g., communication, water supply, medical services, public safety). Especially the loss of information and communication infrastructure, used to report medical emergencies, and the collapse of the drinking water supply are two critical stressors for the population to cope with. One attempt to tackle this situation is installing temporary emergency contacts points (ECPs) in existing infrastructure. These can be used by inhabitants to communicate with healthcare workers and to receive drinking water. Maintaining ECPs is highly dependent on the limited resource availability of professional personnel. Our study presents an integer linear program for optimal spatial allocation of ECPs such that multiple types of human resources required for operating such locations can be efficiently utilized. A comprehensive case study, based on empirical data of Vienna, Austria, demonstrates how to reduce the walking distance of inhabitants while resource allocation efficiency for involved organizations is increased.

3 - Decision support system for the anticipative rail freight fleet planning
Martin Hrusovsky, Vera Hemmelmayr, Georg Schett, Alexandra Birkmaier

Despite the support for rail as sustainable transport mode from the literature as well as from the EU and other organisations, its share on modal split is rather stagnating. Whereas this might be caused by external reasons, such as changing demand patterns and responsive logistics systems with small deliveries, one important factor is also the low flexibility and high complexity of the multi-stage planning processes in the railway freight transport that are partly done manually. One necessary planning step is to find the optimal fleet size so that there are sufficient railcars available to cover the expected demand but at the same time the size of the railcar fleet is minimized to reduce the costs. Whereas the demand for railcars can change in a relatively short time, changes in railcar supply belong to mid-term decisions due to long delivery times and long lifetime of railcars. In order to support the fleet planning, we present a decision support system combining two models: a fleet sizing optimization model, determining the necessary number of railcars based on the demand and the available fleet, and a fleet management model, identifying overstocks and understocks for different railcar types and supporting measures for increasing and decreasing their inventory. The system considers various factors, such as customer preferences, substitutability of railcars or transitions between months, and is applied to a real-world case study illustrating the advantages of our approach.

■ TB-27

Tuesday, 10:30-12:00 - Y313

Challenging Problems in Economy

Stream: Splitting and ADMM Methods
Invited session
Chair: *Dimitri Papadimitriou*

1 - Threshold phenomena in optimal control problems
Andrea Seidl, Gustav Feichtinger, Dieter Grass, Richard Hartl, Peter Kort

In many interesting economic applications of optimal control multiple optimal solutions can occur. In the present talk we take a closer look at so-called Stalling equilibria which serve as threshold between two different long run outcomes. The key feature of a Stalling equilibrium is that it is impossible to increase the state value beyond this point which is usually due to the underlying state dynamics in combination with a control constraint.

In the present talk, we will discuss how different parameter values lead to the occurrence of threshold points, indifference points and Stalling equilibria in context of an optimal control problem. We derive conditions for the occurrence of abnormal solutions and discuss their economic implications.

2 - Optimality of Base Stock Policy under Unknown Demand Distributions: New Results and a New Method
Suresh Sethi

This paper advances significantly the literature on the optimality of the base stock policy by generalizing the demand distribution and prior belief to be updated as demands, assumed to be continuous i.i.d. random variables, are observed over time. As the value function depends on the belief, the functional Bellman equation is infinite- dimensional. More importantly, we derive a functional equation for the derivative of the value function with respect to the inventory level and this equation provides a direct approach to obtain the optimal base stock. We characterize the way the base stock depends on the belief and implement it in two important cases. In the case of conjugate probabilities, the infinite-dimensional state reduces to a finite-dimensional sufficient statistic allowing us to solve numerically an example of Weibull demand. The second case considers the demand to come from one of two possible distributions, but we do not know which. This gives a functional equation in one hyperparameter expressing the ratio of the weights assigned to the two distributions. We develop an approximation scheme to solve it, obtain the formulas for the base stock, and show numerically that the procedure converges.

3 - A PDE-constrained optimisation approach towards an optimal harvesting yield
Kit Daniel Searle

In this presentation, the maximal sustainable pro-rata density-dependent harvest rate of a hypothetical population on the spatial boundary of its habitat, which is otherwise a protected zone (i.e. no harvesting of the species is allowed in the interior of its habitat), is determined analytically. This is achieved by analysing an abstract mathematical model for the spatio-temporal evolution of the species density over its habitat if it is subjected to a continuum of potential pro-rata density-dependent harvest distribution functions on the spatial boundary. The model takes the form of an initial-boundary value problem involving a reaction-diffusion equation, equipped with a Robin boundary condition, in which the reaction term is a concave function of the population density. A long-time asymptotic analysis of the population density is undertaken in order to establish a sufficient condition on the pro-rata density-dependent harvest distribution function for the existence of a strictly positive equilibrium attractor of model solutions. Thereafter, the problem of finding a pro-rata harvest distribution function which maximises the total profit derived from harvesting the population is addressed. This is achieved by formulating the problem as a Partial Differential Equation (PDE)-constrained optimisation problem. The solution to this problem is a pro-rata harvest distribution function and equilibrium population distribution which maximises the total profit at equilibrium.

4 - Nonconvex Semi-Infinite Programming for Robust Supply Chain Problems
Tom Savage, Antonio del Rio Chanona

Supply chain problems commonly contain aspects of uncertainty, and often must be solved for all realisations of uncertain parameters such as consumer demand or transport times. Typically, these robust optimization (RO) problems are linear, or convex in the decision variables as well as uncertain parameters enabling reformulation into a tractable robust counterpart. When relationships between uncertain parameters are nonconvex, alternative approaches must be sought. Semi-infinite programming is an area concerned with the solution of optimization problems whereby a solution must satisfy a parameterised constraint for all possible parameter realisations. All formal RO problems are SIPs and therefore many existing approaches may be transferable. However, the RO community has been slow to investigate existing methods developed for nonconvex SIPs. In this work we apply an interval-based SIP method for the solution of a robust nonconvex biomass facility planning problem. The method produces an upper and lower bound which is refined through a branch-and-bound procedure and ensures a globally optimal solution. We compare our method with standard RO approaches and find increased reliability, demonstrating that SIP methods can successfully be applied to difficult, applied RO problems. Future work includes the adaptation of the method for use with alternative uncertainty sets such as ellipses and polygons, as well as improving performance in higher dimensions.

■ TB-28

Tuesday, 10:30-12:00 - Y405

Data Science and Analytics Applications 4

Stream: Data science and Analytics (contributed)
Contributed session
Chair: *Léon Sobrie*

1 - Major ML-based password guessing techniques analysis
Andrius Chazevskas

Password guessing is essential for forensic encrypted data examination since the data must be decrypted first. The most common password guessing attacks are dictionary and brute-force. The main drawback of a brute-force attack is the size of a set of all possible password candidates. It grows exponentially with the length of the password. The ability of digital forensics laboratories to rely on brute-force attacks depends on the availability of hardware resources (how many guesses attempts can be made per second) and is limited. The analysis of leaked password databases shows that users tend to use easy-to-remember passwords. It means that a large proportion of passwords usually exhibits a logical structure - they are not just random character sets. Forensic information technology experts exploit this defect using modern automated password guessing strategies relying on machine learning and natural language processing. This presentation offers a survey of the major password guessing methods (rules-based, Markov, Probabilistic Context-Free Grammar, Neural networks) and strategies applied in password guessing techniques based on leaked user data from Lithuanian social websites.

2 - Meta-ranking of technology and innovation management journals in a global landscape
Grigory Pishchulov, Rudolf R. Sinkovics, Heinz Tüselmann

A significant volume of academic research is focusing on the measurement of reputation and influence of academic journals. For interdisciplinary areas such as technology and innovation management (TIM), this is particularly relevant. While several TIM journal rankings have been developed, they are restricted to either opinion-based or citation-based analyses. More recent meta-ranking studies fail to treat the TIM area holistically and within a broader context of related disciplines. Our study aims to fill this gap. We construct a rich data set from a variety of reputable journal lists and citation indices that comprises 3,784 journals and thus represents, to the best of our knowledge, the most comprehensive data set of journal reputation and influence in business, management, and economics to date. We propose a novel approach for automated subject area classification across the data set and employ a meta-ranking approach to deliver a balanced view on the reputational standing of 2,639 journals, of which 66 represent the TIM area. We find notable changes in the relative standing of core TIM journals compared to previous studies. Our findings also reveal that the TIM area fares well in various tiers of the ranking, except for the top and the bottom of the list. We provide recommendations for improving the TIM standing among the related disciplines.

3 - Deep Learning-Based Prevention of Insider Threats Using User Behavioral Keystroke Biometrics
Arnoldas Budžys, Olga Kurasova, Viktor Medvedev

Cybersecurity is becoming one of the most important topics in today's critical infrastructures, therefore, the connection between the administrator and the session needs to be strengthened. A compromised administrator password can cause significant damage to the critical infrastructure or its institutions. Threats posed by insiders are responsible for 60% of cyber-attacks and are extremely difficult to detect. Most of them remain undetected for months or years, which is why cybersecurity specialists need to be able to quickly detect and identify the insider. A deep learning-based methodology for authenticating users of critical infrastructure systems has been proposed. The proposed approach offers two authentication levels: static and continuous authentication. Timestamps of user behavioral keystroke biometrics are extracted from raw data and used in the proposed methodology. In order to verify the effectiveness of the proposed methodology, experimental studies were carried out using state-of-the-art deep learning methods (e.g., LSTM, Transformers, RNN). Once logged in, the keystroke biometrics of the user behavior continues to be monitored to determine whether the user who authenticated at the static stage continues to use the session. In case of doubts about the user authenticity, the proposed method initiates an operating system lockout, and the user has to re-authenticate in the static phase. Preliminary results were obtained using public datasets.

4 - Real-time employee workload analytics in digital control rooms
Léon Sobrie, Marijn Verschelde, Bart Roets

Previous research has pointed out how employee workload is connected to job satisfaction, well-being, and the quality of their performance. Recent research argues that there is a need for workload predictions in real-time. Moreover, workload management is becoming increasingly important. We fill these gaps by providing tailored analytics for managers in digital traffic control rooms based on real-time workload predictions. For this paper, we work in close collaboration with Infrabel, the Belgian national railway infrastructure company, to construct real-time workload predictions leveraging their rich data sources on the performed control room activities. We divide the workload into six operational task categories that represent the task load of the operators. The advocated methodology is a multi-output sequence-to-sequence machine learning model that predicts the next 30 minutes of workload for every workload category per workstation in all control rooms. This machine learning model uses fully anonymized controller and control room characteristics and spatial, temporal, and operational influences. We investigate the additional predictive accuracy of dividing the workload into different task categories. The results confirm this added value and dive deeper into the importance of the feature groups. Furthermore, the predictions are implemented in a decision support tool that provides real-time analytics for the control room managers.

■ TB-29

Tuesday, 10:30-12:00 - M1

Industry 4.0

Stream: Industrial Production, Planning and Inventory Management
Invited session
Chair: Francisco Maia

1 - Towards the Additive Manufacturing Evolution: determination of time sensitive factors
Maria Koltsaki, Maria Mavri

Additive manufacturing - commonly known as 3D printing- is gradually improving fabrication processes, causing a real revolution in the fields of product design, process planning, and supply chain management. The manufacturing process is transformed, as the final product can be directly built, via a CAD model or a 3D scanner output. According to the literature, there is limited research on the classification of AM technologies and additionally, there is no reference about the correlation between the different AM typologies and their evolution over time. Different taxonomies have already been proposed, usually getting as criteria the material and the fabrication method. However, these criteria are not effective classification inputs, as they do not significantly affect the evolution of AM technologies. To provide a holistic view, this study explores new systematic classification criteria, examining if the deposition mechanism, the post-process requirements, the feedstock format, and the material type are influenced and in which way by the time factor. The goal of this study is to determine how 3D printing technology is being evolved to become more accessible and accurate and which are the key factors that attract the scientific interest in expanding the AM concept. To achieve the latter, this study proposes a new multi-level classification model and examines if the suggested categories participate in the AM evolution over time.

2 - A Data-driven Approach to Enhance Worker Productivity by Optimizing Facility Layout
Mahdi Ghorashi Khalilabadi, Debjit Roy, René de Koster

The facility layout problem (FLP) is the problem of determining non-overlapping positions of departments on the shop floor to minimize material handling costs. Traditional methods for solving FLPs consider pairwise (from-to) flows to optimize layouts. This study shows that these traditional methods underestimate the total travel distance of a layout when departments have more than a single input/output point and some flows consist of visits to more than two departments. To accurately calculate the traveled distances, the actual routes of the workers and transporters (connected movements) in the system need to be determined. The connected movements of the workers in a facility can be captured using the Internet of Things network. We propose a mixed-integer non-linear programming model for the FLP that minimizes the total travel distance based on the connected movements. A biased random key genetic algorithm is used to find the layout. To ensure the validity of the method, a case study is carried out at a fertilizer production company that implemented an Internet of Things network to minimize worker productivity loss via an improved layout. By using these connected movements, the best layout for the case company is found. The results of the proposed data-driven optimization method indicate that leveraging connected movements can reduce the total travel distance by 10.6% compared to the best possible layout generated by the traditional pairwise method in the case study.

3 - Industry 4.0 on Supply Chain Functions and classification of technologies: An overview
Marios Vasileiou, Vasileios Zeimpekis

Industry 4.0 stands for the contemporary trend of automation and digitalization technologies in industry and it is typified on services and manufacturing by highly sophisticated electronics and IT. Academic researchers focalize on the comprehension and definition of this idea and endeavor to develop contiguous systems, business models and respective methodologies, while industry diverts its attention on the development of the industrial hardware and intelligent systems along with future clients. The automation and digitalization of the operations must be implemented throughout the supply chain regarding optimization of its functions. The aim of this paper is to probe the impact of Industry 4.0 technologies on the Supply Chain Functions (SCF) classifying them depending on their utilization. To attain that, the Systematic Literature Review (SLR) approach was used which has a three-phase step review with multiple publications and manifold criteria to identify the related research. In this overview we have distinguished nine trending technologies that are transforming the SCF enabling the industry 4.0 to redefine businesses to the new era. These technologies are Additive Manufacturing, Artificial Intelligence, Augmented Reality, Big Data & Analytics, Blockchain, Cyber-Physical Systems, Internet of Things, Robotics and Automation, and Simulation. The reviewed publications were classified based on these technologies related to supply chains and Industry 4.0.

4 - Hybrid Machine Learning/Simulation Approaches applied to Logistics Systems
Francisco Maia

Nowadays, we are witnessing an abrupt growth and evolution of industry, mirrored in the high level of complexity and intelligence that the current production systems present. One of the main purposes of industrial environments is the elimination of idle activities. Hence, Material Handling and Job-Shop Scheduling, considered two of the most in vogue dynamic problems, are addressed by this paper. The manufacturing plant follows a job-shop layout, characterized by its high flexibility, in which the workstations (WS) are arranged by specialized areas. Our setting is composed of 7 WS, a supply warehouse with unlimited capacity, a set of 5 different part types with their own WS sequence, as well as an Automated Guided Vehicle with unitary capacity. Beyond the simulation model, the major goal stands in the implementation of decision rules to be applied to this vehicle, in order to increase the productivity for a time horizon. Given that Machine Learning has been so successful in other technological areas, the challenge of introducing Neural Networks stands out, through the creation of a new entity called Agent, responsible for the decision process, and following a Reinforcement Learning approach. The Reinforcement Learning-based approach provided the best productivity results for specific time horizons. In addition, these models proved to be robust in terms of their flexibility when subject to different production mixes and processing times.

■ TB-30

Tuesday, 10:30-12:00 - M237

Scheduling with Maintenance

Stream: Project Management and Scheduling
Invited session
Chair: *Jussi Leppinen*

1 - A Dynamic Optimization Model for Maintenance Scheduling of a Multi-Component System

Jussi Leppinen, Antti Punkka, Tommi Ekholm

Many multi-component systems require maintenance to operate reliably. The cost of maintaining a set of components is not necessarily additive over some component-specific maintenance costs, but rather depends on the specific maintenance action portfolio of components to be maintained. Moreover, not all such portfolios are necessarily feasible because structural dependencies can require simultaneous maintenance of some other component(s), or the system must operate with high enough probability.

We develop a model to solve optimal maintenance scheduling policy of a multi-component system with economic and structural dependencies that are described with a directed graph. Component lifetimes are random, and the system operates only if every component operates. Component replacements are only possible at pre-defined maintenance instances, which are separated by constant maintenance intervals. The problem is modeled as a discrete time Markov Decision Process, where the system state depends on the components' ages and failure states. System-level risk is managed by introducing a reliability threshold. The optimal long-term maintenance action portfolios are solved with policy-iteration.

We illustrate the model with a system of 4 components. Our approach has potential in creating cost savings across different maintenance intervals and reliability thresholds compared to simple heuristic policies. It also provides decision support for the specification of those parameter values.

2 - Just-In-Time Scheduling with a Flexible Maintenance Activity

Gur Mosheiov

We study single machine scheduling problems. A flexible (but mandatory) maintenance activity needs to be performed, and must be completed prior to a given upper bound. The objective function is that of maximizing the number of jobs completed exactly at their due-dates. Extensions to the weighted case and to the setting of job-dependent due-windows are also studied. The basic setting (with no weights), the weighted case and the setting of job-dependent due-windows with identical job processing times are shown to have polynomial time solutions. The case of general due-windows is strongly NP-hard. Solution algorithms for all the problems are introduced and tested numerically.

3 - Robust scheduling in SNCF railway maintenance centers

Rahman Torba, Stéphane Dauzere-Peres, Claude Yugma, Cédric Gallais, Juliette Pouzet

The French railway company, SNCF, carries out the heavy maintenance of its rolling stock units in ten different maintenance centers. The renovation and modernization of rolling stock units are done to increase their lifecycle, to reduce costs and the environmental impact of the railway industry. To schedule maintenance activities, we propose a MILP model with different industrial constraints. As each rolling stock unit is considered as a project and since resources have multiple skills, our problem corresponds to the multi-skill resource-constrained multi-project scheduling problem (MSRCMPSP). To solve very large industrial instances, several priority rules were first implemented. The initial solutions are then improved using a simulated annealing algorithm. An original contribution of this work is that our objective function, which minimizes the weighted sum of the durations of the projects, is a non-regular criterion as the start and end dates of projects are flexible. To the best of our knowledge, this objective has never been considered in the literature. As the maintenance centers face many uncertainties, our main perspective is to consider the stochastic version of the problem. Exploring the flexibility of start and end dates of projects can improve the schedule robustness. How to measure solution robustness is also discussed.

4 - Shift Scheduling in Interdependent Multi-stage Systems with Reallocation of Workforce

Seyed Mohammad Zenouzzadeh, Raik Stolletz

Many manufacturing and logistic systems (e.g., distribution centers) consist of serially organized stages. In each of these stages, a process is performed on each item of the demand (e.g., picking, consolidation/packing, and shipping in a distribution center). The number of items to be processed at each stage depends on the demand pattern, and the assigned capacity to the predecessor stages. Hence, the capacity decisions for the stages are interdependent in such systems. We model the shift scheduling problem in systems with serially organized stages. We consider a daily planning horizon with multi-skilled workforce who can be reallocated multiple times during their shifts. Each reallocation between stages results in a loss of capacity at the destination stage. The objective is to minimize the total workforce costs. We propose a column-generation algorithm to solve the problem. We solve various realistic instances to test the effectiveness of the proposed algorithm. Our results show that scheduling the shifts independently for stages will either result in suboptimal or infeasible solutions. We also show that taking into account the interdependency among the stages helps better utilize the reallocation flexibility.

■ TB-31

Tuesday, 10:30-12:00 - M240

Methodological and practical contributions of Soft OR/PSMs to Policy Making - B

Stream: Problem structuring and soft OR
Invited session
Chair: *Irene Pluchinotta*
Chair: *Ine Steenmans*

1 - An integrated soft OR approach for understanding perspectives on agricultural transition in Scotland
Matthew Hutcheson

The need to balance agricultural productivity with measures to address the climate and biodiversity crises enhances the challenges of both farm management and policy-making in the farming sector. Different perspectives on the way in which objectives in agriculture are achieved adds further complexity to the issue. Soft OR offers a selection of tools for structuring and making sense of such problems. This research integrates causal mapping and critical systems heuristics to explore perspectives on agricultural transition in Scotland, with a specific focus on agroecology. Boundary critique provides a theoretical framework to facilitate learning about a system by explicit consideration of judgements relating to motivation, control, knowledge, and legitimacy. Exploring the way in which value judgements inform farmers' perspectives, coupled with causal mapping of the system elements, can aid in understanding how agroecological and conventional farmers translate their objectives into practice. In employing a structured approach to learning about farm-level transitions, this study aims to provide insights to support policy-makers in the implementation of necessary changes in agriculture to meet our present-day challenges.

2 - Meaningful, useful and legitimate decision support
Alexis Tsoukias, Yves Meinard

The paper extends and specifies the notions of valid and legitimate decision support model with specific emphasis to public policy making decision processes. We provide formal definitions of the three concepts and potential tools for checking them.

3 - Systems mapping for policy: diversity and plurality in its practice
Ine Steenmans

A significant influence of OR on UK public policy involves the current internal promotion of 'systems mapping' for scoping and designing policy.

Diversity and plurality characterise how such 'systems mapping' are operationalised in practice. Diverse methods are used. Each approach epistemologically foregrounds knowledge about specific policy aspects: some projects use causal loop diagrams to identify feedback loops changing resource availability; others use cognitive mapping to explore divergence of expert views on policy issues; others generate stakeholder maps with overlayed policy agendas; etc.

Feedback from those involved in developing systems maps suggests such ambiguity around what 'systems mapping' is, and the diversity of what it can be, is confusing. When making sense of the ontological plurality of systems maps, they ask: what exists that can be mapped for a policy system? How are plural meanings of the same issue to different stakeholders handled? How does this inform selection of a systems mapping method? What does that selection mean in terms of the possible uses of the resultant systems map outputs for policy decisions?

There is little overview of the ways these questions of diversity and plurality play out in practice. This paper contributes a comparative overview of the implications of different ontological and epistemological assumptions using data from 6 UK civil service systems mapping projects (2019-2022).

■ TB-32

Tuesday, 10:30-12:00 - F101

Sustainable Development

Stream: Sustainable Development and Green Technologies
Invited session
Chair: Veronika Mitkova

1 - Extracting patterns of ecological footprint in the world: single valued neutrosophic sets based machine learning approach
Sevgi Abdalla

Reducing the ecological footprint is a vital issue for sustainable world. For this purpose, countries have been developing new strategies and applying to create livable countries. The question arises whether all these individual efforts of countries are sufficient. From this point of view, in this study, it is aimed to put forward a world projection by grouping the countries according to their similarities in terms of important factors such as carbon footprint, human development index, bio capacity, bio deficit, population, green energy investments and some related indices. However, some factors have more significant impact on ecological footprint. For this reason, those critical factors are determined via triangular single valued neutrosophic random forest algorithm. Then, Triangular single valued neutrosophic clustering analysis is utilized by using unsupervised machine learning algorithms to categorize the worldwide countries into optimal clusters. Hence, country clusters are created according to their similarities in terms of various sustainability indicators. Finally, the proposed approach offers effective and valuable mapping of the countries to reflect the sustainability performance of countries.

2 - Formalising an Assessment Based Roadmap Towards Urban Sustainability
Sadiye Eylul Sadanoglu

Performance evaluation of urban sustainability has a vital impact on improving urban well-being, while also balancing the demands of urban social, economic development, natural resource consumption and environmental pollution. Moreover, majority of the urban sustainability performance evaluation methods focused on environmental sustainability and other two pillars: economic and social aspects are neglected. Hence, the first phase of this paper will introduce a novel performance assessment framework to identify the best practices of and the lessons learned by the borough councils. Given the performance measures representing both desirable and undesirable outputs and dynamic changes, the Malmquist-Luenberger Index (MLI) approach is applied. In the second phase of this research, in-depth exploratory studies took place and the results led us to take a novel approach in studying urban sustainability at the borough level to determine how local authorities contribute to overall urban sustainability. As a result, a detailed operational insight is provided, sustainable operations strategy and a detailed strategic road map is developed to help decision makers enhance sustainable development at the local level.

3 - The bioeconomy and its promise of climate change reduction - A linear optimization approach for the use of lignocellulosic biomass in Germany
Sebastian Lubjuhn, Sandra Venghaus

The concept of a sustainable bioeconomy has become a new economic leitmotif for reducing greenhouse gas (GHG) emissions. Its central narrative rests on the idea of replacing fossil resources by bio-based ones for a broad spectrum of products including, e.g., heat, electricity, fuels, plastics, or chemicals. Yet, the amount of available bio-resources is limited, rendering the success of some technologies, while leaving behind others. Lignocellulosic biomass is a key resource already used on a large scale, e.g., for heating purposes or electricity production and increasingly also for the production of chemicals and bioplastics. Because market mechanisms do not necessarily drive a cost-optimal use with respect to its GHG-reduction potential, a linear optimization model under long-term scenarios was developed for Germany accounting also for competition with non-biobased technologies. It consists of two sub-models connected by a shared amount of biomass residues. The first is a detailed model for the heat sector that aims to fit the heat demand cost optimally, whereas the second model aims to maximize profits in the non-heat applications. First results indicate that lignocellulosic biomass is most cost-efficiently used in the high-temperature industry to reduce emissions in the heating sector, whereas in private housing heat pumps are expected to dominate. The use of lignocellulosic biomass for non-heating purposes will become competitive on a large scale after 2030.

4 - The CGE Analysis of the European Green Deal - Is There a Chance to Meet the Objectives in Targeted Industries by 2030?
Veronika Mitkova, Mirka Janosova

One of the European Commission's goals is to establish Europe as the first climate-neutral continent. The European Green Deal sets various policies to reduce the net greenhouse gas emissions by at least 55% by 2030, compared to 1990. The paper deals with nine key energy-environmental indicators associated with air pollution (black carbon, carbon monoxide, ammonia, non-methane volatile organic compound, nitrogen oxides, organic carbon, particulate matter with a diameter of 10 'm or less and 2.5 'm or less and sulphur dioxide), three types of emissions (nitrous oxide, methane, and fluorinated gases) for eight aggregated industries (agriculture, coal mining, crude oil, natural gas extraction, refined oil products, electricity, energy-intensive industries - minerals not elsewhere classified, chemical, basic pharmaceutical, rubber, plastic, mineral products, and ferrous materials, and aggregated other industries and services) in the European Union with a special emphasis on the Slovak Republic and the Netherlands. In the first part, the development of the air pollution and emissions indicators in the period from 2004 till 2014 were observed. In the second part, the static computable general equilibrium model based on 2014 data was used to estimate the effects of the European Green Deal instruments on the set of prices, welfare, and the terms of trade of various regional groups.

■ TB-33

Tuesday, 10:30-12:00 - F102

Game Theory and Operations Management 4

Stream: Game Theory and Operations Management
Invited session
Chair: Behzad Hezarkhani

1 - Dynamic Competition for Buyer Loyalty on Product Availability
Myron Benioudakis, Michalis Deligiannis, George Liberopoulos

The purpose of this work is to study the effect of a buyer's availability-driven loyalty on the suppliers' competitive and cooperative inventory policy. To this end, we consider a stylized multi-period model of a repeat buyer doing business with two heterogeneous make-to-stock suppliers. To enjoy the best availability advantage, the buyer plays one supplier against the other by rewarding availability with repurchase in the next period and punishing stockouts with switching in the next period. Under this behavior, the optimal ordering policy of each supplier is a basestock policy with a positive basestock level when the supplier has the buyer's loyalty and a zero basestock level when she doesn't. If the suppliers compete, the optimal positive basestock level of each supplier is greater than her myopic basestock level and is an increasing response function in the other supplier's positive basestock level. The basestock levels of both suppliers comprise at least one pure strategy Nash equilibrium, which is unique under conditions. If the suppliers cooperate, the optimal positive basestock level of one supplier is greater than or equal to her myopic basestock level, while the optimal positive basestock level of the other supplier is smaller than or equal to her myopic basestock level and can even be to zero. To get a more concrete apprehension of their implications, we apply them to the case where the buyer's demand is exponentially distributed.

2 - Contingent Renewal Contracts in High-tech Manufacturing with Oligopolistic Suppliers
Mirjam Meijer, Willem van Jaarsveld, Ton de Kok

High-tech manufacturers (OEMs) often produce multiple generations of high-tech end-products. For each generation an OEM has to source complex components from a few oligopolistic suppliers. Due to the high shortage costs for missing components, resulting from costly delays in production of the end-product, it is important to align incentives between OEMs and suppliers of these components that are often single-sourced. We formulate an infinite horizon perfect information game with two possible suppliers where the payoffs in the current generation and transition probabilities for the next generation depend on the capacity investment of the current supplier. We express the suppliers' optimal capacity investment as a function of the wholesale price paid by the OEM and the capacity investment decision of the alternative supplier. We show that for every wholesale price there exists an equilibrium where neither supplier has incentive to adjust their capacity decision. Additionally, we show that the wholesale price for which in equilibrium the supply chain optimal capacity decision is made is lower than the coordinating wholesale price when only a single supplier is present, but higher than in case there is an unlimited number of suppliers that have the required capabilities.

3 - Global Agricultural Supply Chains under Tariff-Rate Quotas
Behzad Hezarkhani, Sobhan Asian, Afshin Mansouri

The tariff-rate quota (TRQ) is a market-access instrument that is widely used in global agricultural supply chains. A TRQ allows a pre-determined quantity of a product to be imported at lower import duty rates (in-quota tariff) than the duty rate normally applied to that product (over-quota tariff). Considering the importance of logistics and operational factors in international trade, this paper investigates how the design and execution of TRQ systems impact the competition among importers. We study the two most common quota administration systems, namely, licensing and 'first-come, first-served' (FCFS). A dual TRQ system is also formulated, wherein both licensing and FCFS elements are active. For each TRQ system, we analyze the strategies (i.e., import quantity, logistics channel, and warehousing) of importers, who have limited knowledge about the quota fill statistics due to long lead times and a lack of real-time information. We develop solution algorithms that obtain Nash equilibria and compare the performance of alternative TRQ systems in terms of their fill rates.

■ TB-34

Tuesday, 10:30-12:00 - T003

Sharing and collaboration in vehicle routing

Stream: Smart Mobility and Logistics
Invited session
Chair: Yannick Scherr

1 - Collaborative Vehicle Routing: Computational and Game Theoretical Aspects
Margaretha Gansterer, Richard Hartl

The concept of shared transportation resources, also denoted as collaborative vehicle routing, is one of the hot topics in transportation and logistics. A collaboration can be described as a partnership between two or more companies to optimize operations by making joint decisions and sharing information, resources, or profits. While the willingness to enter coalitions does exist, the success of collaborations strongly depends on mutual trust and behavior of participants. Hence, proper mechanism designs, where carriers do not have incentives to deviate from jointly established rules, are needed. In this talk, we elaborate horizontal collaborations, where logistics providers share resources with their competitors through the exchange of selected transportation requests. The aim is to increase the overall efficiency of the transport industry, by avoiding costly and pollutive empty trips. We focus on decentralized exchange mechanisms, which are based on the assumption that no fully informed decision maker exists. In such mechanisms, efficient solution methods for complex routing problems have to be tackled, while game theoretical aspects have to be taken into account. The talk gives insights on auction-based systems, where several strongly related decision problems have to be integrated. We analyze, for instance, whether carriers face a Prisoner's Dilemma when selecting requests for trading. Recent findings as well as promising future research directions are presented.

2 - Generating attractive bundles of customers for last-mile delivery with in-store occasional drivers

Simona Mancini, Margaretha Gansterer

Exploiting a mixed fleet of committed and occasional drivers in last-mile delivery has been shown to be profitable for companies involved in last-mile delivery operations. In this work we focus on the particular case in which occasional drivers (ODs) are in-store customers willing to perform one or more deliveries on their way back home for a small compensation. The investigated system generates attractive bundles of customers, which are then offered to ODs. Based on submitted bids, the system suggests which bids to accept and provides a routing plan for committed drivers, in order to minimize the total delivery cost. The latter is expressed as the sum of compensations paid to ODs and routing costs. We provide an innovative bundle generation method based on the idea of generating geometrical corridors starting from the depot. We compare this approach against a more classical clustering-based technique. Computational results show the huge benefit of using the corridors-based approach. To solve the whole system optimization problem, we provide a mathematical formulation and an effective Large Neighborhood Search matheuristic, exploiting both classical and ad-hoc neighborhoods. In an extensive computational study, the matheuristic shows excellent performance. Furthermore, we also investigate the dynamic version of the problem, where OD's bids are not known in advance, but are revealed dynamically at multiple fixed points in time.

3 - Customer Acceptance for Collaborative Time-Window Based Home Deliveries

Steffen Elting, Jan Fabian Ehmke, Margaretha Gansterer

This presentation focuses on the opportunities of horizontal carrier collaboration for Attended Home Deliveries (AHD). Before vehicles start their route, customers dynamically request a delivery from one of the carriers in the collaboration network. Upon request disclosure, the carrier offers a set of delivery time windows to the customer. Once a time window has been agreed upon, the order cannot be canceled in favor of another order that is requested later. After the order arrival phase, an auction-based framework permits collaborating carriers to buy and sell delivery requests without disclosing business information. Every carrier submits a fraction of its accepted requests to a shared auction pool. A limited number of attractive request bundles are centrally assembled from that pool, and all participating carriers submit their corresponding marginal delivery cost as the bid price for each of these bundles. The solution to the Winner Determination Problem defines the new allocation of orders to carriers. We quantify the collaboration gain of this network by solving the underlying problems for dynamic customer acceptance, vehicle routing, and the combinatorial auction. We investigate the general impact of delivery time windows on network-wide travel durations. We will tailor specific parts of the auction mechanism to include time window information and deploy strategic procedures of dynamic customer acceptance to study the potential of request exchanges for AHD.

4 - Dynamic decision making for a collaborative pickup and delivery problem

Yannick Scherr, Margaretha Gansterer, Richard Hartl

We consider the problem setting of a less-than-truckload carrier that receives stochastic customer requests with pickup location, delivery location, volume, and revenue. Each request must be answered dynamically by accepting or rejecting it immediately. On the next day, the accepted requests are served within routes by a set of vehicles, each with limited load capacity and route duration. After the request acceptance phase and before the requests must be served, multiple carriers participate in a combinatorial auction to exchange a subset of requests among each other. After carriers place bids on bundles of requests, an auctioneer allocates the bundles to carriers in a cost-minimizing way. We model the carrier's optimization problem of maximizing its profit as a Markov decision process that depicts the sequential decisions in all different phases. Heuristic approaches are used for solving a dynamic version of the vehicle routing problem with pickups and deliveries. We develop request acceptance policies that recognize the outsourcing and acquisition options provided by the auction. In a computational study, we compare different policies and assess the profitability of entering collaborations. Results show that carriers can achieve considerable collaboration gains that are impacted by their request acceptance decisions in this dynamic setting.

■ TB-35

Tuesday, 10:30-12:00 - T004

Freight transportation and logistic III

Stream: Transportation
Invited session
Chair: Anass Kajji

1 - Green cyclic inventory routing with fleet sizing

Anass Kajji, Tarik Aouam, Asmae ElMokrini, Birger Raa

This paper presents a novel model and solution approach for planning cyclic distribution from a single depot to multiple customers with constant, deterministic demand rates. The objective is to minimize the overall cost rate, consisting of fleet, operational and emission costs of the distribution as well as inventory holding costs at the customers. The operational cost includes vehicle loading and dispatching, unloading at the customers, the driver wage, and energy consumption. The energy and emissions costs are affected by numerous factors such as vehicle load, speed, and travel distance. We present a powerful metaheuristic solution approach that integrates speed and cycle time optimization within the route and fleet design. When designing vehicle routes in a first phase, the speed levels and route cycle times are chosen such that not only the operational, emissions and inventory holding costs are minimized, but also a schedule is constructed such that the fleet cost is reduced. Then, in a second phase, the routes remain unchanged, but their speed levels and cycle times are adjusted to further reduce the required number of vehicles. Computational experiments show that the solution framework outperforms existing solution approaches and that it adequately balances total customer holding costs, fixed and variable routing costs, with energy consumption and emissions cost.

2 - Integrating production scheduling and vehicle routing with limited storage capacity

Leon Lan, Joost Berkhout, Rob van der Mei, Sandjai Bhulai

With the rise of mass customization, many manufacturing industries are shifting from make-to-stock production to make-to-order production. As a result, the storage capacity becomes an increasingly limiting factor in the supply chain. This is especially the case in production facilities that were traditionally built for stock production and where products cannot be stored together due to contamination issues (e.g., food and agriculture). Consequently, a more coordinated approach between production and distribution is required.

In this work, we present an integrated production scheduling and vehicle routing problem with limited storage (PSVRP-LS). The PSVRP-LS is based on the supply chain of a Dutch compound feed manufacturer. We consider a single production facility with unrelated parallel machines and a finite number of end-product silos. All products are unique and require an individual silo for storage after production. The routing problem includes attributes such as time windows, multi-compartment loading and multiple trips. The goal is to minimize transportation costs, including penalties for late delivery. We propose an adaptive large neighborhood search metaheuristic to solve the problem. To show the improvement in operational efficiency as a result of integration, we compare between an uncoordinated approach, where we independently solve the production and routing problem, and the integrated approach. The results are evaluated using data provided by the company.

3 - A new multi-period mathematical model for locating long-haul autonomous transportation enablers
Ebrahim Mohammadi, Rob Zuidwijk, Marie Schmidt

Autonomous Transportation (AT) has been deemed by many as a game-changer in the transportation and logistics industry. It is expected to result in cost savings in transportation, address driver shortages, reduce traffic congestion, improve road safety, and have a positive impact on the environment. Facilitating AT by providing the required services and infrastructure is crucial to exploiting the potential benefits of AT. In this paper, we propose a new multi-period mathematical model to locate various service stations and enablers required for long-haul autonomous transportation over multiple periods. This study tries to integrate the location decisions of multiple enablers with different operational characteristics such as refuelling stations, emergency maintenance stations, transfer hubs etc. Furthermore, because the investment budget and completion time of facility installations are both expected to be time dependent, it is critical to consider the time dimension. The necessity of developing an integrated model is more evident for AT as they will require all of them upon their initial deployment. To ensure model accuracy, the model is implemented numerically, and sensitivity analyses for critical parameters are provided. Additionally, the findings indicate several managerial insights, such as the amount of investment required to achieve a particular outcome.

4 - Rail freight transport in the age of decarbonization and autonomous driving
Stefan Voss, Joachim R. Daduna

For many years, there have been increasing claims in the EU to strengthen rail freight transport with the objective to promote ecologically-oriented transport services. Interest groups are agitating for subsidies of many billions of euros for the infrastructure expansion and a politically supported prioritization of this transport mode. However, if we look at the development of the modal split in recent years, we see a continuous decline in market share due to a lack of competitiveness.

The reasons for this are the goods-structure effect, changed production structures with increasing facility dislocation, and the transition to on-demand-based additive manufacturing. This results in a transport demand with low order volumes and flexible service, which predominantly covers a distance range of less than 150 km. From an economic and operational point of view, however, this market segment cannot be served by rail freight transport, not even by bi-modal transport.

Due to the politically forced decarbonization of road transport, the repeatedly propagated ecological advantages of rail freight transport can no longer be justified in the future. The use of autonomous trucks with e-drives will lead to decisive changes, as a result of which the freight transport market will be even more clearly dominated by road transport. The actual developments are explained in detail and in this context also the subsidy policy in the area of the EU is discussed.

■ TB-36

Tuesday, 10:30-12:00 - U006

Appointment Planning

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: Sebastian Kraul

1 - Customer-Driven Robust Appointment Scheduling
Carolin Bauerhenne, Rainer Kolisch

Appointment scheduling under uncertainty encounters a fundamental trade-off between maximizing capacity utilization and minimizing customer waiting times. Most existing approaches to appointment scheduling tackle this trade-off using a weighted sum approach, resulting in a low consideration of individual customer waiting times and thus of customer satisfaction. In contrast, we study how to maximize capacity utilization while guaranteeing acceptable waiting times for all customers. Therefore, we derive a mixed-integer linear model in a robust optimization framework with box uncertainty sets. We prove NP-hardness of the general problem and present optimal polynomial-time scheduling and sequencing rules for special cases. These rules generalize the well-known Bailey-Welch rules and the least variance rules to consider not only but in particular maximum waiting times. Furthermore, our case study with real data from a radiology department of a large hospital demonstrates that our approach not only guarantees acceptable waiting times but, compared to existing robust approaches, also reduces costs incurred by idle time, for the worst-case and on average.

2 - Acute Care Rehabilitation Therapy Scheduling Considering Appointment Priority, Continuity of Care and Therapist Preferences
Sebastian Kling, Sebastian Kraul, Jens Brunner

Physical therapy in acute care hospitals plays an important role in the rehabilitation of patients. Like nursing, the profession often has to deal with staff shortages due to a lack of potential employees and absenteeism caused by the stressful work environment. As a result of therapist shortages, the department is unable to fulfill all daily appointments. Furthermore, continuity of care with the same therapist, highly important for the quality of care as well as an influencing factor on employee stress, cannot be guaranteed for individual patients. This project presents a novel multi-criteria model for the daily therapy appointment-scheduling problem. The primary objective is to minimize the number of unscheduled appointments according to their importance to the hospital. In order to improve therapist satisfaction as well as the patient outcome, we integrate continuity of care and therapist preference as a secondary objective. The developed integer program cannot provide schedules for real-world sized problems, so a Greedy Randomized Adaptive Search Procedure (GRASP) with six innovative neighborhoods is developed. We show that the metaheuristic can provide high-quality schedules for various problem sizes in short runtimes. Comparisons with the optimal solutions for small problem instances show high-quality results of the GRASP with a similar number of scheduled appointments and good adherence to continuity of care and therapist preference requirements.

3 - Digitally assisted decision making in psychotherapy planning
Alexander Scherrer, Friedrich Duge, Hauke Felix Wiegand, Karl-Heinz Kuefer, Klaus Lieb

Mental disorders like depression or anxiety are widespread in the population. Patients suffer from a considerably limited quality of life and performance. There are various options for therapy of mental disorders with high success rates. Their individualized application requires precise knowledge of the treatment standards and great professional expertise. However, mental disorders are often treated by general practitioners with the risk of limited quality of care. This research work presents a solution approach for digitally assisted treatment planning for mental disorders. A data model with crucial parameters allows a precise case documentation. This assures solid data for good decision making. A knowledge base provides the contents of therapy standards as a rule-based system. This provides the expert information required for qualified decisions. A logic interpreter allows for an evaluation of the knowledge on a case. This facilitates an efficient search for medically indicated therapy options. With a decision support system, treatment planning can be addressed as a multi-criteria evaluation problem. This allows for a targeted selection of individually best-suited therapy options. Case modifications trigger new search runs for therapy options in the sense of sequential decision making. This guarantees therapy decisions on demand for the entire duration of treatment. The solution approach is implemented as prototypical web service and evaluated on exemplary patient cases.

■ TB-37

Tuesday, 10:30-12:00 - V001

Exact and Matheuristic Algorithms for Vehicle Routing Problems

Stream: Vehicle Routing and Logistics
Invited session
Chair: Juan José Salazar González

1 - An adaptive memory matheuristic for the Set Orienteering Problem
Michael Dontas, Georgios Sideris, Eleftherios Manousakis, Emmanouil Zachariadis

In this talk, we deal with the Set Orienteering Problem (SOP), a generalization of the well-known Orienteering Problem (OP). SOP considers that customers are partitioned into mutually disjoint sets with a predetermined profit that is enjoyed if this set is served. To serve a set, a single customer of this set must be visited. SOP calls for the maximization of the collected profit subject to a maximum route duration. The proposed framework consists of a matheuristic algorithm with the following basic features: local search operators are employed for simple set relocations, insertions, deletions and swaps. In addition, a richer operator is periodically applied that performs multiple set insertions and deletions by solving a MILP model. It also solves a suitably defined Shortest Path problem for selecting the best customer nodes for the served sets, and a Traveling Salesman Problem (TSP) for the selected customers. Moreover, an Adaptive Memory structure is employed for constructing promising solution from high-quality set sequences. The matheuristic algorithm was tested on 612 SOP benchmark instances, where it matched or improved the best-known solution scores for 98.2% of the test cases. Furthermore, a new set of large-scale instances is introduced by appropriately modifying Generalized TSP test problems. The algorithm consistently generated scores very close to the upper bounds determined by the corresponding best-known Generalized TSP solutions for these new problems.

2 - Branching on clustered VRP instances
Eduardo Uchoa, João Marcos Silva

The customer positioning in typical real-world VRPs is far from random, they are often concentrated in clusters corresponding to more populated areas. We observed that the performance of Branch-Cut-and-Price VRPs algorithms was much worse on some highly clustered instances. The problem was that the traditional branching on edges/arcs or branching on sets was ineffective, even using aggressive strong branching, leading to large search trees. We propose a new branching scheme where first a cluster analysis is performed, looking for sets of customers that are well separated from other customers. Then, we may perform branching on the aggregation of edges/arcs between clusters. The approach was tested over instances of the Capacitated VRP (CVRP), Distance-Constrained VRP (DCVRP) and VRP with Time Windows (VRPTW) and could solve several hard instances for the first time. Interestingly, the method showed positive results even on some instances with random customer positioning. We also comment on the significance of those findings for general MIPs, showing that there are models where branching over individual variables, even with the best possible strong branching, is ineffective; but branching over well chosen aggregations of variables can be effective.

3 - The Consistent Travelling Salesman Problem
Juan José Salazar González, Daniel Díaz-Ríos, Inmaculada Rodríguez Martín

The consistent travelling salesman problem looks for a minimum-cost set of Hamiltonian routes, one for every day of a given time period. When a customer requires service in several days, the service times must differ in no more than a given threshold (for example, one hour). We analyze three variants of the problem, depending whether the vehicle is allowed to wait or not at a customer location before start been served. There are three mathematical models in the literature for the problem without waiting times, and this talk will describe a new one appropriated to be solved with a branch-and-cut algorithm. There were no mathematical models in the literature for the other variants, and we adapt the four formulations to them. We analyze computational results of the formulations on instances from the literature.

■ TB-38

Tuesday, 10:30-12:00 - V002

Humanitarian Logistics

Stream: Humanitarian and Healthcare applications (contributed)
Contributed session
Chair: Christine Currie

1 - Cost of the Diet Linear Program: Finding Distinct Solutions with close to Optimal Cost
Romée Geelen, Melissa Koenen, Marleen Balvert

The Cost of the Diet (CotD) is a tool developed by Save the Children that applies Linear Programming (LP) to select a diet that meets the energy and nutrient requirements for a given individual at the lowest possible cost citepdeptford2017cost. The aim of this thesis is to find nearly optimal solutions for the CotD formulation: solutions that are as distinct from the optimal solution (and each other) as possible, but comparable in costs. Data from Indonesia was used to find such solutions, regarding 64 food items citepaliassusenas. The optimal diet for an example household including eight individuals was analysed. From these diets the limiting nutrients were distinguished for each individual. Several techniques have been applied to find nearly optimal solutions. The results showed that against a slight increase in costs, many nearly optimal solutions can be generated in the feasible area. Yet, a large part of the basis of most solutions corresponds to the optimal solution. Hence, the optimal basis appears to be quite robust as several optimal food items need to be contained in the basis in order to keep the cost of the diet within a reasonable range. In case disruptions occur within this area, only a few good items can be considered as a proper substitute within its price range. Thus, assuring availability of the items in the optimal food basket (and the possible substitute items) should be the main priority.

■ TB-39

Tuesday, 10:30-12:00 - U8

MAI: Show don't tell; prove don't claim

Stream: Making an Impact
Invited session
Chair: Vladimir Fux

1 - Show don't tell: Quick Interactive prototypes to elevate communication with users
Vladimir Fux

In the early stage of the project, concise communications with your users is crucial. As Operation Research specialists, we need to understand and challenge what our users request. This includes presenting potential solutions and approaches beyond their requests, circumventing limitations of current products. In this session, we show how to build a simple interactive prototype. It visualises complicated concepts to gather valuable feedback early on.

2 - Prove, don't claim: Harden your OR models by hypothesis testing
Torsten Gellert

Convincing yourself that your OR model is theoretically correct and implemented flawlessly is no trivial task. In the worst case, it might break in production and cause high losses. Manually curated test cases are cumbersome, exhaustive and hard to maintain. In this session we present how to leverage property-based testing with the python framework Hypothesis. By defining data generators and formulating hypotheses your understanding of the model deepens and bugs hiding in overlooked corners are spotted.

Tuesday, 12:30-14:00

■ TC-01

Tuesday, 12:30-14:00 - A

Grit Walther

Stream: Keynotes
Keynote session
Chair: *Ana Paula Barbosa-Póvoa*

1 - Interdisciplinary perspectives on the transformation of our energy, industrial, and mobility systems
Grit Walther

Realizing concepts like circular economy, bioeconomy, and climate-neutrality invokes a paradigm shift for our economy as their implementation requires a fundamental transformation of our energy, industrial, and mobility systems. Herein, complex planning tasks arise as we can no longer focus only on the economic objectives of one specific task of a single company or supply chain. Instead, we have to develop intersectoral models that also account for technological development, environmental criteria, social benefit measures, or acceptance of technologies and infrastructure by the public. This requires enriching Operations Research models with interdisciplinary objectives and constraints, e.g., from engineering and environmental or social sciences. This talk gives examples on how OR models benefit from multidisciplinary cooperation and vice versa, how such cooperation benefit from OR results. For instance, we discuss how integrating results of process engineering, energy system analysis, and social studies can improve decision making for the design of alternative fuel supply chains, and how cooperation with policy makers, industry, and environmental think tanks can enhance planning models for future CO2 transport and sequestration.

■ TC-03

Tuesday, 12:30-14:00 - C

Machine Learning and Mathematical Optimization in Banking and Finance

Stream: Machine Learning and Mathematical Optimization
Invited session
Chair: *Yujia Chen*
Chair: *Belen Martin Barragan*

1 - Machine learning approaches to forecasting cryptocurrency volatility: considering internal and external determinants
Yijun Wang, Galina Andreeva, Belen Martin Barragan

The cryptocurrency market is extremely complex and risky, but it is still regarded as an alternative investment instrument because of the unique characteristic of high return and highly volatile nature. At the same time, the key determinants of cryptocurrency price volatility and forecasting models are still poorly explored and identified. Therefore, this study mainly focuses on exploring the role of internal factors(such as lagged volatility; moving average volatility, and trading volume) and external factors (such as Block-chain Technology factor; Financial factor, and Policy Uncertainty factor) in forecasting cryptocurrency volatility using traditional time-series models and different machine learning (ML) techniques. We applied GARCH as the baseline model, and we applied the most powerful ensemble models including Random Forests (RF) and deep learning techniques model including

Long short-term memory (LSTM). After forecasting, we applied two machine learning Interpretability models including SHapley Additive exPlanations (SHAP) and Local interpretable model-agnostic explanations (LIME) model to interpret the determinants. The results verify the applicability of the ML techniques for forecasting cryptocurrency price volatility, especially ABC-LSTM achieved the best prediction performance. Besides, the results provide strong evidence that lagged volatility is the key-driven for forecasting volatility compared to external factors.

2 - Interpretable machine learning for imbalanced credit scoring datasets
Yujia Chen, Belen Martin Barragan, Raffaella Calabrese

The class imbalance problem is common in the credit scoring domain, as the number of defaulters is usually much less than the number of non-defaulters. To date, research on investigating the class imbalance problem has mainly focused on indicating and reducing the adverse effect of the class imbalance on the predictive accuracy of machine learning techniques, while the impact of that on machine learning interpretability has never been studied in the literature. This paper fills this gap by analysing how the stability of Local Interpretable Model-agnostic Explanations (LIME) and SHapley Additive exPlanations (SHAP), two popular interpretation methods in the credit scoring context, are affected by the class imbalance. Our experiments use UK residential mortgage data collected from European Datawarehouse. We evaluate the stability of LIME and SHAP on datasets of progressively increased class imbalance. The results show that interpretations generated from LIME and SHAP are less stable as the class imbalance increases, which indicates that the class imbalance does have an adverse effect on machine learning interpretability.

3 - Clustering-based optimization in fraud detection classifier training
Dalia Breskuvienė, Gintautas Dzemyda

Fraud detection is an essential problem in the bank industry. It can create the loss of money and can do massive harm to the reputation of financial institutions. Therefore, in real-world examples, fraud comes as a prevalent and influential research area. The goal is to train the transactions classifier of two classes: fraudulent and regular transactions. Fraudulent transactions are a rare event that leads to very imbalanced data. Therefore, the imbalanced data set faces unsolved issues when used for classifier training. Let us have a data set of transactions. We suggest splitting the classification process into several ones. The training data set is clustered, and different sub-classifiers are trained on the clustered data. We chose XGBoost as the classifier of transactions. When testing the classification, the decision is made by a sub-classifier whose training set center is the closest to the particular point from the training set. In our case, the proper criterion of classification is the F1 score because it is a harmonic mean of precision and recall. For the experimental evaluation of the suggested strategy, We use the credit card transaction database (https://data.world/ealtman/synthetic-credit-card-transactions) representing actual transactions of the credit card users living in the United States. The experiments show that we succeed in the significant increase of F1 score as compared with the case without clustering.

4 - Fairness of ML in the context of credit scoring
Darie Moldovan

The fairness of Machine Learning has received a multitude of definitions during recent years. These attempts show several ways to approach this issue and emphasize the difficulty in creating a standardized framework for evaluating it. Due to its impactful nature, credit scoring has often been used as support for demonstrating the utility of different fairness metrics in the literature, by evaluating the possible discrimination caused by ML algorithms.While the laws prohibit the use of some features that may be subject to discrimination, such as gender, race or nationality, other unrestricted information may cause discrimination for vulnerable groups. As our research shows, the credit scoring process has several specific features making some of these fairness metrics unsuitable. In a profit-driven environment, eliminating discrimination in the loan approval mechanism can be very difficult as a strong inverse proportionality between fairness and profitability exists. We use two real-world datasets as testbeds for different mechanisms to increase fairness in credit scoring. We use the interest rate as an adjustable feature in the context of creditworthiness evaluation, creating a risk-based pricing framework as a solution for reducing discrimination for vulnerable groups. The effects of applying fairness criteria should be observed over time and adjusted, as implications for both borrowers and lenders are not yet charted and are only subject to simulation.

■ TC-04
Tuesday, 12:30-14:00 - D

Machine Learning and Mathematical Optimization: challenges and real-world applications

Stream: Machine Learning and Mathematical Optimization
Invited session
Chair: M. Asuncion Jimenez-Cordero

1 - Minimax Classification with 0-1 Loss and Performance Guarantees
Santiago Mazuelas

Supervised classification techniques use training samples to find classification rules with small expected 0-1 loss. Conventional methods achieve efficient learning and out-of-sample generalization by minimizing surrogate losses over specific families of rules. This talk presents minimax risk classifiers (MRCs) that do not rely on a choice of surrogate loss and family of rules. MRCs achieve efficient learning and out-of-sample generalization by minimizing worst-case expected 0-1 loss w.r.t. uncertainty sets that are defined by linear constraints and include the true underlying distribution. In addition, MRCs' learning stage provides performance guarantees as lower and upper tight bounds for expected 0-1 loss. We also present MRCs' finite-sample generalization bounds in terms of training size and smallest minimax risk, and show their competitive classification performance w.r.t. state-of-the-art techniques using benchmark datasets

2 - A Rule Generation Framework for Learning
Tabea E. Röber, Ilker Birbil, M.Hakan Akyuz

We introduce a new rule-based optimization method for classification and regression. The proposed method takes advantage of linear programming and column generation, and hence, is scalable to large datasets. Moreover, the method returns a set of rules along with their optimal weights indicating the importance of each rule for learning. Through assigning cost coefficients to the rules and introducing additional constraints, we show that one can also consider interpretability and fairness of the results. We test the performance of the proposed method on a collection of datasets and present a case study to elaborate its different aspects. Our results show that a good compromise between interpretability and fairness on the one side, and accuracy on the other side, can be obtained by the proposed rule-based learning method.

3 - Embedding machine learning models in the scheduling problem of pumped hydro energy storage
Pietro Favaro, Jean-François Toubeau, François Vallée

In order to efficiently hedge against uncertainties from renewable generation, power systems are subject to a growing need of flexibility that can be provided by Pumped Hydro Energy Storage (PHES) plants. However, accurately modeling the PHES operation is a challenging problem, arising from the fact that their operation inherently couples electrical and water constraints through a non-convex and non-concave relationship. In this work, we leverage regression-based supervised machine learning to learn this intricate function. The resulting (convex) model is then integrated into an optimization tool aiming at improving the PHES economic benefits. Outcomes reveal that the method can reduce modeling approximations (and thus improve ex-post profits), while keeping adequate computation times.

4 - A novel machine-learning-aided approach for warm-starting constraint generation methods in MILPs
M. Asuncion Jimenez-Cordero, Juan Miguel Morales, Salvador Pineda Morente

Mixed Integer Linear Programs (MILP) are well known to be NP-hard problems. Although pure optimization-based methods, such as constraint generation (CG), guarantee to provide an optimal solution if enough time is given, their use in online applications is still a great challenge. To alleviate it, some machine learning (ML) tools have been proposed in the literature, using the information provided by previously solved MILP instances. Unfortunately, these techniques report a non-negligible percentage of infeasible or suboptimal solutions. By linking mathematical optimization and ML, this talk proposes an approach that speeds up the traditional CG method, preserving feasibility and optimality guarantees. Particularly, we warm-start the CG algorithm with an invariant constraint set. This way, the computational burden to solve online each MILP problem is significantly diminished. The performance of the proposed approach is quantified through synthetic and real-life MILP applications.

■ TC-05

Tuesday, 12:30-14:00 - E

Optimization Models for Machine Learning

Stream: Data Science Meets Optimization
Invited session
Chair: *Dimitri Papadimitriou*

1 - Rolling Look-Ahead Approaches for Optimal Classification Trees
Zeynel Batuhan Organ, Enis Kayis, Taghi Khaniyev

Decision Trees are one of the most popular algorithms for prediction tasks in a wide range of applications due to their simplicity and interpretability. The most popular implementations of decision trees are myopic which employs heuristics to find the best tree. Hence, despite being very fast, they could not guarantee finding the globally optimum trees. Due to significant improvements in the computational efficiency of optimization solvers, researchers began to tackle the problem of finding optimal classification trees. However, existing approaches do not scale well with the number of sample points and the number of features. We present a novel approach for binary classification trees that runs in a rolling-horizon manner and tries to locally optimize trees by using a two-step look ahead approach (instead of the one-step look ahead approach employed in CART-like algorithms). This approach enables us to find a good trade-off between the computational time and the accuracy of the resulting trees. Moreover, we offer new formulations to handle hard versus soft clustering approaches. We conduct extensive computational experiments on benchmark instances with varying levels of difficulty and compare our results with the state-of-the-art methods with respect to both out-of-sample accuracy and computational time.

2 - A Novel Optimization Based Hyperbox Approach for Multi-Class Data Classification Problem
Fatih Rahim

Multi-class data classification is a supervised machine learning problem that involves assigning data to multiple groups. Among Mixed-Integer Linear Programming based methods (MILP), hyperbox learning is computationally expensive and applicable on datasets with certain size. We check separability of class set pairs along any axis and construct an undirected graph that represents the separability information of the datasets. We decompose the main MILP using the connected components of the graphs and any separable class pairs provides reduced models by eliminating redundant decision variables. Moreover, we check separability of groups via hyperplanes and we introduce hyperboxes with cuts. Linear separability based information provides us with sparser graphs with more reduction and decomposition opportunity. We evaluated our approach on benchmark problems and present our findings for axis splits and hyperboxes with cuts.

3 - Photovoltaic self-consumption optimization for Home Microgrid: A Deep Reinforcement Learning approach
Mohamed Saâd El Harrab, Michel Nakhla

Increasing penetration of renewable energy sources (PV, Wind) due to environmental constraints, impose several technical challenges to power system operation. The fluctuating and intermittent nature of wind and solar energy requires constant supply-demand balance for electric grid stability purposes.

Self-consumption is a regulatory framework intended to promote local consumption over export. Thus, self-consumption will raise the profit of PV electricity from grid-connected residential systems and lower the stress on the electricity distribution grid.

This work presents a novel Deep Reinforcement Learning (DRL) Based Energy Management System (EMS) to control a Home Microgrid system powered by renewable energy sources (PV arrays) and equipped with an energy storage system. An optimal energy scheduling is carried out to maximize the benefits of available renewable resources through self-consumption. A DRL approach is used to make optimal decisions and generate the optimal management strategies.

4 - Using industrial data to enhance a solution approach for a multi-objective real-time railway rescheduling problem
Hugo Belhomme, Stéphane Dauzere-Peres, Mathieu Gagnon, François Ramond

Dense railway systems (eg. Paris) are subject to daily disturbances, and the management of these disturbances is a complex multi-objective real-time rescheduling problem. In previous works, a solution approach has been designed that couples optimization and simulation with satisfying results. As this rescheduling problem has been manually solved by decision makers for years, we were able to obtain a history of their decisions (several years of manual rescheduling decisions). This presentation introduces how this historical data has been used to enhance our solution process, and in particular how the data is used to complement our optimization approach and to evaluate the performances of our algorithms. A graph neural network is proposed to predict the quality of solutions and to limit the size of the solution space. Additional hybridization of our solution approach with machine learning approaches will be discussed in the presentation.

■ TC-06

Tuesday, 12:30-14:00 - U1

Novel Models and Optimization Approaches in Manufacturing

Stream: Combinatorial Optimization
Invited session
Chair: *Alena Otto*
Chair: *Erwin Pesch*
Chair: *Dorothea Calmels*

1 - A Large Neighborhood Search Approach for the Collaborative Batching Problem in Multi-Site Additive Manufacturing
Dominik Zehetner, Margaretha Gansterer

Due to the recent trend of mass customization, consumers are striving for individualized products while they continue to be price sensitive. Such requirements create immense pressure on supply chains to fulfill customers' demands. Collaborative production (CP) could be a powerful tool to manage these upcoming challenges by decreasing production costs while increasing the supply chain's flexibility. Additive Manufacturing (AM) is a promising technology in combination with CP. It has been proven that such a combination can decrease the operational costs considerably. Moreover, it has been shown that efficiency increases with the size of the collaborating networks. However, suitable planning algorithms are not yet applicable to real-world problems due to computational limitations. Within this study, we propose an algorithm that is able to solve large scale instances of the collaborative batching problem in multi-site additive manufacturing. We propose a linear formulation of an existing quadratic model. Furthermore, we devise an efficient algorithm based on Large Neighborhood Search (LNS) in which selective neighbourhoods are optimized iteratively. We compare the proposed LNS to an existing benchmark algorithm in an extensive computational study. Our experiments prove that our approach outperforms the benchmark in terms of computational times and solvable instance size. Furthermore, we demonstrate that CP is particularly efficient in large manufacturing networks.

2 - Dynamic Reconfigurations of Matrix Assembly Layouts
Baturhan Bayraktar, Martin Grunow, Rainer Kolisch

Due to increasing customization and volatility in demand (e.g., trend in e-vehicles), traditional assembly lines become less efficient. Assembly systems in which automated guided vehicles move products between the workstations arranged in a matrix layout gain popularity. One advantage of such systems is that they can be easily reconfigured. In this work, we develop a methodology for the configurations and reconfigurations of matrix assembly layouts under changing demand. In a multiperiod planning horizon, the decisions to be made for each period are the stations to be active, the task assignments to stations, and the product flows. We formulate a lexicographic multiobjective mixed-integer linear programming model for this problem. The three objective functions minimize the number of active stations, the number of reconfigurations, and the total flow distance. We develop an exact solution approach using period- and layout-based decompositions. We adopt Benders decomposition for the subproblems and solve them with the L-shaped method. For our numerical tests, we adapt standard instances from the literature. In terms of computational performance, our approach is on average 89.9% faster than the commercial solver. Our insights reveal that matrix layouts with dynamic reconfigurations enhance station utilization by 9.1% and reduce flow distances by 7.6% on average, compared to static layouts.

3 - Parallel Branch-and-Price Algorithms for the Single Machine Total Weighted Tardiness Scheduling Problem with Sequence-Dependent Setup Times
Philipp Speckenmeyer, Guido Schryen

Scheduling problems occur in a broad range of real-world application fields and have attracted a substantial amount of research articles. In relation to the overall number of published papers on this topic, however, there is only little research on exact algorithms for scheduling problems, many of which are NP-hard in the strong sense. To address this matter, we investigate the problem on a single machine with a total weighted tardiness objective function and sequence dependent setup times between jobs. First, we adopt a serial branch-and-bound algorithm from the literature where lower bounds are computed by column generation (pricing), present a modified branching strategy and develop a primal heuristic to enhance the frequency and quality of generated upper bounds. Second, we use the potential of parallel computing architectures provided by the broad availability of multi-core processor technologies and present two parallel versions of the branch-and-price algorithm. Here, in contrast to the traditional approach of solving multiple subproblems concurrently, we apply parallelization to the solution of the pricing problem. Third, we conduct extensive computational experiments to show that our parallelization approaches provide substantial parallel speedups on well-known benchmark instances from the literature.

■ TC-07
Tuesday, 12:30-14:00 - U3

Fintech and market dynamics

Stream: Financial Risk Measurement and Management
Invited session
Chair: Bertrand Tavin

1 - Revisiting Informational Efficiency: a Long-memory Oriented System for Bitcoin Cross-market Disparity
Jinqiang Ye, Jeremy Cheah, Tapas Mishra, Ming-Chien Sung, Johnnie Johnson, Zhuang Zhang

By revisiting informational inefficiency, this research exhibits episodes of long memory in Bitcoin cross-market price dynamics. We argue price behaviour of Bitcoin is in line with adaptive market theory by (Lo 2004; 2005; 2017) and hypothesise the adaptive learning patterns can be governed by a long-memory process. To set up the model for examination, we propose to characterise Bitcoin cross-market convergence patterns via the framework of fractional co-integrated vector auto-regression (FCVAR). Bitcoin trading in five developed markets is of considered and the examination of long memory phenomena covers two aspects, i.e., the individual markets' convergence behaviour and the cross-market interdependence patterns (co-integration). In addition, we exhibit sentimental factor fear indicator can be a driver for relationships among information across five developed markets.

2 - Need for Speed, but How Much Does It Cost? Unpacking the Fee-Speed Relationship in Bitcoin Transactions
Guangzhi Shang

The growing popularity of blockchain-based cryptocurrencies is driven by the flexibility in transaction fee offerings, among other factors. To achieve service-level differentiation among their users, many cryptocurrencies allow users to "name your own price", giving rise to a large variation in fee offerings and hence, variation in confirmation times. Yet, the time it takes a cryptocurrency transaction to be confirmed in the blockchain is not only affected by the fee offered, but also by the contemporaneous congestion level and the inherent randomness in the verification process. Although it is generally expected that higher fees lead to quicker confirmation, the uniqueness of the cryptocurrency setting adds important nuances to the fee-speed relationship. Using Bitcoin - the original and most heavily used cryptocurrency by far - as our empirical context, we stylize the transaction confirmation processes, propose a theoretical framework that maps the causal path from fee to speed, and estimate this framework using Bitcoin transaction data under periods of high volatility. Our results show strong evidence for two characteristics of fee's impact: congestion dependence and tail shrinkage. Our finding that the speed acceleration effect of fee is particularly strong on the tail of the confirmation time distribution motivates a target service level approach to fee recommendation.

3 - Which cryptocurrency is leading the market? Evidence from dynamic networks
Barbara Będowska-Sójka, Piotr Wójcik

The cryptocurrency market is growing rapidly and the growth rate of cryptocurrencies is staggering, with the number of cryptocurrencies doubling in 2021 and now said to be over 12,000. Although Bitcoin, the first decentralized digital currency, seems to maintain its leadership position, competing cryptocurrencies have emerged in the market. Recently, the cryptocurrency market has matured, reduced its volatility and improved liquidity. The number of trading platforms and exchanges with a high degree of automation has also increased. The purpose of this paper is to identify the leading cryptocurrencies and their clusters that shape the development of the overall market. We use an approach based on unsupervised machine learning and similarity measures observed in the cryptocurrency returns. This allows us to examine the coins' network hubs and check the stability of the network structure over time. To verify this structure, partial contemporary correlations and partial directed correlations are obtained. We also construct the network of volatility spillovers between the main cryptocurrencies.

4 - BRICS stock markets, cryptocurrencies, and stablecoins: Asymmetry and quantile dependency
Mariem Brahim

We examine the long- and short-term asymmetry and quantile dependency in the relationships between BRICS stock indices and four cryptocurrencies, including two traditional cryptocurrencies (Bitcoin, Ethereum) and two stablecoins (Tether, TrueUSD). Ethereum is the most influential cryptocurrencies and exerts an asymmetric influence across various quantiles and investment horizons, whereas Bitcoin exhibits only a partiallysignificant effect. Tether and TrueUSD affect Indian and Chinese stock indices, mainly in the short-term. The pandemic influenced this asymmetric dependence more prominently in Russia, India and Brazil.

The findings are important for decision making among investors and policy making regarding the potential adoption of cryptocurrencies.

■ TC-08

Tuesday, 12:30-14:00 - U4

Discrete-continuous or stochastic optimization and control in transportation and design (space-time) II

Stream: Combinatorial Optimization
Invited session
Chair: Gerhard-Wilhelm Weber

1 - Solving the problem of batch deletion and insertion members in the Logical Key Hierarchy structure by a DC Programming approach
Thi Tuyet Trinh Nguyen, Hoai An Le Thi

In secure group communications, users of a group share a common group key to prevent eavesdropping and protect the exchange content. A key server distributes the group key as well as performs group rekeying whenever the membership changes dynamically. Instead of rekeying after each join or leave request, we use batch rekeying to alleviate the out-of-sync problem and improve the efficiency. In this paper, we propose an optimization approach to the problem of updating group key in the Logical Key Hierarchy (LKH) structure with batch rekeying. A subtree of new nodes can be appended below a leaf node or is replaced the position of leaving node on the binary key tree. The latter has a lower updating key cost than the former since when a member leaves, all the keys on the path from the root to the deletion node must be updated anyway. We aim to minimize the total rekeying cost, which is the cost of deletion and insertion members while keeping the tree as balanced as possible. The mentioned problem is represented by a unified (deterministic) optimization model whose objective function contains discontinuous step functions with binary variables. Thanks to an exact penalty technique, the problem is equivalently reformulated as a standard DC (Difference of Convex functions) program that can be solved efficiently by DCA (DC algorithm). Numerical experiments have been studied intensively to justify the merit of our proposed approach as well as the corresponding DCA.

2 - Multi-period facility location and capacity expansion with modular capacities and convex short-term costs for hydrogen production in Norway
Šárka Štádlerová, Peter Schütz, Asgeir Tomasgard

We present the problem of hydrogen production in Norway. The problem is formulated a multi-period facility location problem with capacity expansion. The objective is to minimize the sum of investment, expansion, production, and distribution costs while satisfying the demand. The costs structure is characterized with concave long-term costs and convex short-term costs. In our model, only one expansion during the planning horizon is allowed, and we also introduce the limits on minimum production quantities. We consider modular capacities and define the short-term production costs function for each capacity. The production quantity can differ from the installed capacity.

Due to the high complexity, the problem is hard to solve for larger instances. Therefore, we develop a solution method based on Lagrangian relaxation. The lower bound is calculated using a dynamic programming approach. To obtain a feasible solution, we develop a greedy heuristic based on the solution to Lagrangian dual.

We compare the performance of our algorithm to Gurobi for different problem sizes. With our algorithm, we outperform Gurobi in terms of computational times as we can find good solution within considerably faster run times. We can find a solution with a gap lower than 1.5% for more instances than the commercial software.

3 - Strong bounds from linearized formulations and relaxations of the Cross-dock Door Assignment Problem
M. Araceli Garin, Laureano Fernando Escudero, Aitziber Unzueta

The Cross-dock Door Assignment Problem (CDAP) deals with the optimizing of strip and stack door assignments given the shape of the cross-dock and the origin-destination volumes of goods. The CDAP includes the Generalized Assignment Problem (GAP) as a subproblem and like the GAP subproblem is NP-hard. Starting from the binary quadratic formulation of the CDAP model, different Linearized mixed Integer Programming formulations are proposed by using the Adams-Sherali RLT-k scheme for k=1 and a new type of binary variables. Being all of these formulations mathematically equivalent to the original quadratic one, two of them are based on tight models taken from the literature while one is original to this work. Given the (possibly) high dimensions of some of the instances, a Lagrangean relaxation and decomposition scheme is proposed for obtaining a (hopefully) tight lower bound of the optimal solution of the original model. On the other hand, and with the aim of getting feasible solutions quickly, and then, an upper bound of the optimal solution, we propose ad-hoc matheuristics based on local search, designed explicitly for the given formulations. It is then important to be able to come up with a quick solution together with a good bound. An extensive computational analysis on benchmark instances from the literature is carried out, to compare the effects of the different schemes over the proposed formulations.

■ TC-09

Tuesday, 12:30-14:00 - U5

MILP for multi-energy systems

Stream: Mixed Integer Linear Programming
Invited session
Chair: Paolo Paronuzzi

1 - Limits of Information Technology in Energy System Optimization Modeling
Henrik Schwaeppe, Torben Zeller, Albert Moser

Awareness of climate change and consequently the transformation of the energy system has led to the development of various models that help to plan future energy systems and to analyze optimal policies or strategies. In recent years, energy system optimization models (ESOMs) have received a major boost. They integrate bottom-up technology specifications and use linear programming techniques to minimize the cost of technology expansion and utilization. As energy system transformation has become more urgent, so has the required level of detail and resolution. Mapping a European energy system scenario at transmission grid level with demand and energy technologies in hourly resolution easily results in optimization problems with several 100 million variables and constraints. Even after reasonable reduction measures, optimization problems of this magnitude require a lot of memory. While Moore's Law has led to a steady increase in computing capacity in the past decades, a certain stagnation in memory and single-core computing power has been noticeable. So, what system size can be meaningfully calculated and what does it mean for the future of ESOMs? Using exemplary calculations, we extrapolate the required working memory and computing time in theory and practice, address further issues like numerical precision, and derive challenges for the further development of large-scale optimization solvers.

2 - Integrated planning of multi-energy systems (PlaMES): a comprehensive modelling framework and decision support tool
Matteo Pozzi, Aldo Bischi

The European Union's commitment towards a carbon-neutral economy can only be accomplished by a synergistic implementation of measures where Renewable Energy Sources expansion, integration of different energy systems and Transmission/Distribution infrastructure development are calibrated to meet future (2050) energy needs. The high complexity of the task comes from problem dimension, where future national demand and supply must be managed taking into account the interconnection between electricity, gas, heat and mobility sectors, with an hourly granularity to take into account multi-energy coupling dynamics. The Horizon 2020 project PlaMES, currently in its last year, aims to determine the optimal target system, including the investment trade-off between different technologies, infrastructure configurations and emissions reductions that minimize overall system costs. Introducing the overall business challenge, further explored in its detailed modelling and resolution strategies by the academic partners of the project during the session. Particular focus will be devoted to the decision support tool, that must handle extremely large quantities of data to provide significant scenario management capability to perspective decision makers, be them Transmission System Operators designing optimal infrastructure plans or Country Planners identifying what technology mix guarantees effective future energy systems that meet the challenges of decarbonisation.

3 - A decomposition approach for the Central Energy System planning
Paolo Paronuzzi, Silvia Anna Cordieri, Henrik Schwaeppe

The Central Energy System (CES) planning is a problem including both unit commitment problem and generation expansion planning, and it is formulated as a linear program. The system consists of a set of nodes, each one with a set of available energy production technologies, a set of time steps, and a transmission network topology. For each node and time step a demand is given, and the objective is to minimize the suom of operational and installation costs, while satisfying the demand and respecting the maximum limit on CO2 emissions. Given the scale at which the problem is treated, a heuristic algorithm exploiting the block-structure presented by the mathematical formulation of the problem has been designed. In particular, the procedure works in two distinct phases. In the first phase, the considered time-horizon is divided in a number of subperiods, each one defining a subproblem presenting the same characteristic of the original problem. Then, these subproblems are solved (possibly in parallel) and their solution are used to define the values of all the design variables (i.e., the amount of capacity for each technology installed at each node and the possible expansion of the network). After the design variables has been fixed, in the second phase of the algorithm, the same subproblems are solved again (possibly in parallel), this way operational variables are also defined and a feasible solution is found.

4 - Transmission expansion planning for future European energy grid
Antonio Punzo

PlaMES is an H2020 project aimed at developing an integrated planning tool for multi-energy systems on a European scale, taking into account both the expansion of generation and storage technologies and the related infrastructure in an integrated manner, so as to deliver to the European Union's COP21 commitments. The PlaMES architecture consists of six tools. In this talk we will introduce the module designed for solving the Transmission Expansion Planning (TEP), which aims at identifying cost-efficient expansion and congestion management measures to ensure the system security and reliability of future electrical transmission grids. Our modelling approach considers different expansion and reinforcement measures and yields to an integer linear programming formulation, which is solved by using an exact enumerative algorithm in which a Benders decomposition scheme is used to compute a dual bound. The method is enhanced by means of a metaheuristic algorithm, and is computationally tested on realistic instances of large size.

■ TC-10

Tuesday, 12:30-14:00 - U6

Optimization in Financial Markets

Stream: Financial Risk Measurement and Management
Invited session
Chair: *Audrius Kabasinskas*

1 - Active portfolio management using robust optimization
Illia Kovalenko, John Cotter, Thomas Conlon

We conduct an empirical analysis of robust out-of-sample portfolio performances, where uncertainty exists in the underlying probability distribution. This study proposes an alternative specification of the uncertainty set allowing for joint uncertainty in both probability and threshold levels for three portfolio selection approaches (expected shortfall, semi-variance and the Omega ratio). There are two cases considered where the two uncertainty sets are dependent or independent. The empirical results show that joint uncertainty with dependent sets yields superior results to other portfolios. Robust portfolios have a different correlation with common risk factors compared to non-robust portfolios. In particular, joint uncertainty with dependent sets yields portfolios with significant exposure to the momentum factor, that is, betting on stocks which were past winners. The performance of the robust Omega ratio portfolios is attributed to the combination of value and momentum factors. Furthermore, portfolios constructed using joint uncertainty also have the additional benefit of significant protection against market crashes for portfolios.

2 - A Stochastic Gordon-Shapiro Formula and the Equity Premium Puzzle Reconsidered
Andreas Loeffler, Lutz Kruschwitz

The equity premium puzzle is the term used to describe a glaring mismatch between the theoretical model of consumption behavior and its empirical calibration.

In this paper we will take a new look at this puzzle. We believe that the puzzle is based on a logical inconsistency in which deterministic and stochastic quantities are not precisely separated. Nevertheless, a correct distinction between certain and uncertain variables requires one to demonstrate that it is possible to develop a theory of stochastic dividend-price ratios that satisfies both the principles of no arbitrage and transversality. We are able to provide such a derivation and thus prove a stochastic version of the Gordon-Shapiro formula.

Attempting to incorporate this stochastic dividend-price ratio into the Lucas model is somewhat more difficult. Our idea of attributing uncertainty to heterogeneous investors and partial participation in trading is valid. However, if we calibrate this extended model with realistic data, the equity premium puzzle does not vanish. Although the absolute level of risk aversion is reasonable, its variation is not sufficient to explain the observed variation in the dividend-price ratio.

3 - On the development of stochastic dominance based tracking index
Kristina Sutiene, Milos Kopa, Audrius Kabasinskas

The role of regulators is playing an increasingly important role as new mechanisms are implemented to protect stakeholders and promote financial stability. The benchmark could be used as the means to reference the price of financial instrument or to measure the performance of investment fund. In the study, the theory of stochastic dominance, serving as the basis for the research methodology, is used to estimate the pension fund's performance in respect to the benchmark. Specifically, we focus on the application of almost stochastic dominance, which is an extension of stochastic dominance. Almost stochastic dominance is applied in pairwise comparison of pension fund and the benchmark, which is established by the pension fund manager to track its performance. Based on these results, the development of dominance based tracking index is under consideration with the aim to include two aspects of risk assessment, i.e. the degree of risk aversion and the fund's value deviation from the benchmark. The project has received funding from the Research Council of Lithuania (LMTLT), agreement No S-MIP-21-32.

4 - Theory of Pure Active Risk Measure
Dipankar Mondal

In active portfolio management, a portfolio manager forms portfolios with the goal of outperforming a benchmark portfolio, which could be a market index, or any other broadly diversified portfolio. The risk that occurs for attempting to beat the benchmark return is called active risk. The active risk is mainly measured by tracking error, the standard deviation of the difference between return on the portfolio and the return on the benchmark. Some variants of tracking error are also used for this purpose. For example, non-central second moment return deviation and mean absolute return deviation. However, none of them are appropriate measures of active risk. The reason is that they treat both the underperformance and the outperformance in a same way. Thus, they fail to reflect the actual purpose of measuring active risk- penalizing only the underperformance.

In this paper, we present and justify some desirable axioms for measures of active risk. The axioms are developed keeping in mind that they should have realistic economical interpretation as well as proper relevance to the active portfolio management. A risk measure satisfying these axioms is called pure active risk (PAR). We also describe some interesting properties of PAR measures. The properties can be used to construct new PAR measures (mixed measure, worst-case measure etc). In addition, we propose some examples of PAR measures and describe how different types of investment goal can be accomplished by using them.

■ TC-11

Tuesday, 12:30-14:00 - U7

MCDA applications in engineering and management

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Selin Özpeynirci*
Chair: *Ozgur Ozpeynirci*

1 - An interactive algorithm for resource allocation with balance concerns
Selin Özpeynirci, Ozgur Ozpeynirci, Vincent Mousseau

Institutions and organizations devote their resources to various projects and programs to achieve their goals. The resources required for the projects and programs that are intended to be realized are generally more than the available resources. In resource allocation problem, the decision maker has to distribute the available input to alternative projects/investments in order to obtain the portfolio with maximum output. Applications can be seen in many real life situations. In finance, analysts need to choose among investment alternatives. Military, municipalities, scientific organizations and universities often need to solve the problem of selecting the best group of project proposals for financial support. In this study, we consider the resource allocation problem where each project has a category, and define two objectives: maximizing the total benefit of the selected projects and maximizing the portfolio balance in distribution of input among categories. We develop an interactive approach that requires the decision maker to make pairwise comparisons among alternative portfolios. Computational experiments show that, in majority of the instances, the incumbent solution proposed by the algorithm is either equal or very close to the most preferred solution.

2 - Selection of age management measures to risk mitigation
Terezie Krestová

MCDM methods have long been used in various areas of management. These include strategic management, human resource management, ethics and social responsibility, and others (Leilaee and Rezaeian, 2021; Horváthová et al., 2021; Joshi et al, 2017; Staňková, 2016; Bartusková, 2015; Zhang and Zhoug, 2009). It has also been verified that the Analytic Hierarchy Process (AHP) method can be used to select appropriate age management measures. Age management is an approach that considers the age of employees in managing human resources in an organization. By adopting it, the organization eliminates the risk associated with aging population. However, a weakness was found in the application of the AHP method, which is the omission of links between the elements of the proposed model (Krestová and Kresta, 2021). Therefore, it seems more appropriate to use a method that respects these relationships. This is the analytic hierarchy process (ANP) method. In practice, it has been found useful to combine the ANP method with the DEMATEL (Nazir and Cavus, 2017; Kabak, 2013; Kashi and Franek, 2014) method to easily quantify the relationships and their strength between the elements of the model. In this paper, this hybrid DEMATE-ANP method will be used to select appropriate age management measures in the selected organization.

3 - PMM Prediction using a Hybrid "Machine Learning and Multi-Criteria Decision Analysis" Approach
Ines Ben Kraiem

The theory of project management proposes several methodologies that can be grouped into three categories: traditional, agile, and hybrid. The best-known methodologies are classified into various methods such as Waterfall, V Cycle, Scrum, SAFe, and many others. It is certain that the implementation of an inadequate methodology will not enhance but will rather lessen the chances of the project's success. Even though there is no one-size-fits-all methodology, project managers are frequently familiarized with a particular one and, thus, keep choosing it inconsiderately of other important factors. Aiming to improve this practice, this paper proposes a hybrid decision-analysis approach to help decision-makers in selecting the most suitable Project Management methodology (PMm) and Project Management Method (PMM). Our approach consists of a three steps process that is summarized as follows: (i) a conceptual modelling of the critical variables of the project determined by existing literature (ii) Multi-Criteria Decision Analyses (MCDA) to evaluate the PMm's appropriateness through quantitative assessments and collaborative decision making (iii) Machine Learning techniques to predict the PMM using as input the results obtained in the previous steps. This study sheds light on how to improve the prediction of PMM using the hybrid approach to help decision-makers in selecting the appropriate method to achieve the project's goals and objectives in an efficient way.

4 - Evaluation of the e-Government Tax Information System using Multicriteria Analysis
Nikolaos Matsatsinis, Alma Tzelai

The web-based administration system called "taxisnet" is the most well-known and widely used means of e-govenrment in Greece. It is most frequently used by accounting firms, which handle an extremely large number of taxation-related tasks for both private and corporate clients. They are the end users who handle every function and know all the positive and negative points of Taxisnet, and are therefore the most appropriate group for the evaluation of its services. In this paper we aim to have this eGov integrated tax services system evaluated by its most demanding users. We will employ a quantitative approach, by compiling and distributing an online satisfaction-measuring questionnaire. Satisfaction measurement was based on a number of criteria such as design, completeness, functionality, quality, support, etc. The analysis of responses was performed using multi-criteria decision analysis with the aim of calculating the global satisfaction, the satisfaction and the weights of each criterion, the degree of user demand, etc. Finally, conclusions are given on its strengths and weaknesses, and propose priorities actions and improvements.

■ TC-12

Tuesday, 12:30-14:00 - U9

Modeling for a Sector-Integrated Renewable Energy System

Stream: OR in Energy
Invited session
Chair: Jens Weibezahn

1 - Optimal Design of Production and Storage Facilities for Green Hydrogen under Fluctuating Electricity Prices
Endre Bjørndal, Mette Bjørndal, Raag August Sandal Rolfsen, Lars Skaugen Strømholm

Due to high cost, green hydrogen is not yet competitive with grey hydrogen, which has a much higher carbon footprint. However, decreasing capital costs, and the possibility to exploit electricity price fluctuations, could reduce its cost and make green hydrogen a competitive alternative.

We study production of hydrogen by alkaline water electrolysis. A multi-period decision model is presented to find the most cost-efficient, long-term production schedule for an on-site, grid-connected production plant, and we combine the decision model with forecasts of future electricity prices based on historical prices. We use the decision model and the price forecasts to study the levelized cost of hydrogen under various assumptions with respect to storage capacity, production capacity, and future price volatility.

We find that it is costly to exploit electricity price fluctuations to reduce hydrogen costs. In most cases, the cost of additional production and storage equipment outweighs the benefit of producing in hours with low electricity prices. However, under certain circumstances, mainly very volatile electricity prices and large-scale underground storage, the costs can be reduced through investments in excess production capacity. Additionally, we see that the profitability of capacity expansions may be substantially affected by the cost structure for grid fees.

2 - Can a Hydrogen Network Substitute Electricity Transmission Network Expansion in a Climate-Neutral Scenario for Europe?
Fabian Neumann

Electricity transmission network expansion has suffered many delays in Europe in recent decades, despite its importance for integrating renewable electricity into the energy system. But could a hydrogen network that reuses the existing fossil gas network offer a replacement for balancing variations in wind and solar energy across the continent?

We examine these questions in the high resolution (181 nodes) all-energy-sector open-source model of the European energy system, PyPSA-Eur-Sec. The model is detailed enough to capture existing bottlenecks and long time series, and has been highly optimised to run sector-coupled capacity-expansion simulations. Scenarios are run for the year 2050 assuming zero net greenhouse gas emissions, while varying the allowed expansion of the electricity and hydrogen grids respectively. A hydrogen network can take over and exceed the electricity grid in terms of the amount of energy transported over long distances, balancing renewables both in space (with the network) and time (with underground storage). The presence of the hydrogen network can reduce system costs by up to 10%. The ability to import synthetic fuels reduces the benefit of the hydrogen network.

3 - Optimal operation of a Multi-Carrier Microgrid including P2X on multiple electricity markets
Lissy Langer, Ioannis Kountouris, Rasmus Bramstoft, Marie Münster, Dogan Keles

The conversion of excess renewable electricity into hydrogen via water electrolysis as well as the synthesis of further energy carriers (e.g., liquid fuels) and other biogenic elements such as CO or CO2 creates new business opportunities and alternate revenue streams. Those energy systems known as Multi-Carrier Microgrid P2X systems (MCMG) are projected to scale up their infrastructure in a couple of years. In this study, we investigate the optimal operation of a MCMG by utilizing the flexibility of P2X and other assets (i.e., electrolyzers, battery energy and compressed hydrogen storage systems) and analyze the MCMG participating in different electricity markets such as the spot and the ancillary service market. The proposed optimization model performs a profit maximization considering the technical and physical constraints of the P2X assets given a variety of operational strategies and fulfilling the synthetic fuels demand. The model is presented and validated using a case study of the Danish industrial park GreenLab Skive. Preliminary results of the investigation underscore the benefits of exposing the renewable and P2X assets to both the spot and the ancillary service market.

4 - Network reduction methods for integrated energy systems using power grids and gas pipelines
Manuel Wetzel, Jens Schmugge, Francesco Witte

Against the background of the need for a rapid decarbonization towards a climate-neutral energy system, green hydrogen and methane are taking up an increasingly important role. Two of the driving factors are the need for seasonal energy storage solutions and the emission reduction of applications where direct electrification is difficult to achieve. To better understand challenges and solutions in the transformation of infrastructures, energy system optimization models are a useful tool. In these models, an adequate representation of the corresponding infrastructure across different spatial resolutions is a prerequisite for deriving recommendations on future network expansion. To this end, we compare different grid reduction methods for a joint network of power grid and gas pipelines. In this context, clustering methods such as k-medoids and graph partitioning methods are considered. One of the main challenges during the reduction is maintaining spatial information about key infrastructure such as import terminals, cavern storage, and optimal locations for large-scale electrolysis and gas turbines. To analyse the impact of different reduction methods on the results of the overall energy system model, in this presentation the comparison is performed for two scenarios focusing on a high share of imported energy carriers and distributed and domestic generation, respectively. Thus, a well-suited grid reduction method is identified for a wide range of future energy systems.

■ TC-13

Tuesday, 12:30-14:00 - U119

Topics in graph theory

Stream: Discrete Optimization and Algorithms (contributed)
Contributed session
Chair: Jose Brandao

1 - Preconditioning methods for the winner determination problem
Sandor Szabo, Bogdan Zavalnij

The winner determination problem in combinatorial auctioning can be reduced to a maximum weight clique search or to a zero-one linear program. It is known from the literature that the maximum clique approach is preferable to the linear programming approach in certain instances.

We propose to further strengthen the clique technique by introducing a number of preconditioning techniques. In other words, before embarking on a large scale maximum clique search we inspect the underlying weighted graph. We describe methods that may result deleting nodes or edges from the graph and consequently speeding up the search.

Qinghua Wu, Ji-Kao Hao. Solving the winner determination problem via a weighted maximum clique heuristic. Expert Systems with Applications: An International Journal Volume 42 Issue 1, January 2015 pp 355-365.

2 - Robust optimization of weighted independent sets in trees and under interval uncertainty

Robert Manger, Ana Klobučar

The maximum weighted set (MWIS) problem consists of finding a set of vertices in a graph, which are not adjacent one to another and whose sum of vertex weights is as large as possible. Such problem occurs in various real-life applications, e.g., facility location, selection of non-overlapping time slots, labelling of digital maps, etc.

This work deals with robust variants of the MWIS problem where vertex weights are uncertain. A special situation is considered where the involved graph is a tree and uncertainty of weights is represented by intervals. First, we observe that (under the considered circumstances) the max-min variant of the problem can be solved in linear time. Next, we prove that the corresponding min-max regret variant is still NP-hard. Finally, we propose two mutually related approximation algorithms for the min-max regret variant and evaluate them experimentally.

3 - Reducing transitive tournament problem to clique problem

Bogdan Zavalnij, Sandor Szabo

Finding a k-clique or a maximum clique in undirected graphs are well studied problems with several efficient algorithms available. The analogous problems of finding a maximum transitive tournament or a transitive k-tournament in directed graphs are less studied. In particular there are certainly less attempts to write a good solver to the latter. In the present talk we propose a reduction of the transitive k-tournament problem to the k-clique problem. This reduction can also be viewed as a graph transformation which assigns a undirected graph to a directed one.

The structure of the resulted undirected graph is special in the sense that it is a k-partite graph, and the goal is to decide if there is a k-clique in it. This structural property of the graph allows strong and specialized preconditioning methods. Aided with a state-of-the art clique solver this procedure is able to handle some hard problems. As an example we were able to solve some instances of a recently proposed Ramsey type problems the so called maximum 2-increasing sequences problem.

W.T. Gowers, J. Long. The length of an s-increasing sequence of r-tuples. Combinatorics, Probability and Computing. 30(5), 686-721.

L. Kiviluoto, P.R.J. Oestergaard, V.P. Vaskelainen. Algorithms for finding maximum transitive subtournaments. Journal of Combinatorial Optimization. 31 (2016), 802-814.

S. Szabo, B. Zavalnij. Clique Search in Graphs of Special Class and Job Shop Scheduling. Mathematics. 2022, 10(5) 697.

4 - A memory-based iterated local search algorithm for the multi-depot open vehicle routing problem

Jose Brandao

The problem studied is the multi-depot open vehicle routing problem, which has the following two differences in relation to the classical vehicle routing problem: there are several depots; the vehicles do not return to the depot after delivering the goods to the customers, i.e., the end of the route is not the starting point. In the literature, many practical applications are described both for variants containing a single depot as well as when the depots are multiple. Nevertheless, the vast majority of those cases refer to the open vehicle routing problem with a single depot, and, usually, they include additional constraints not considered in this study. In this paper, we present an iterated local search algorithm, in which the moves performed during the local search are recalled and this historical search information is then used to define the moves executed inside the perturbation procedures. Therefore, it is recorded the number of times that each customer is moved during the local search. Since this information is continuously updated and changes in each iteration, the search is driven to potentially better regions of the solution space, and increases the chance of avoiding cycling, even when using deterministic perturbations. The performance of this algorithm was tested using a large set of benchmark problems and was compared with other algorithms, and the results show that it is very competitive.

■ TC-14

Tuesday, 12:30-14:00 - U261

Energy policy and planning

Stream: Energy Management
Invited session
Chair: *Sezen Ece Kayacık*

1 - Electricity supply and demand dynamics in Iran considering climate change induced stresses

Behzad Zamanipour, Hesam Ghadaksaz, Ilkka Keppo, Yadollah Saboohi

The impacts of climate change such as water scarcity and air temperature increase affect the development of the electricity supply system. In this study, the electricity demand was predicted considering the effect of air temperature. Also, the water scarcity impact on the expansion of the power system was investigated. An econometric approach was employed to assess electricity demand in four sectors. TIMES as a bottom-up energy system optimization modelling platform was applied to analyze the power supply system in Iran. The developed model encompasses each power plant unit separately. Besides, the option of switching cooling technology was provided. The results show that fuel price increase alters the capacity and cooling type portfolio substantially. Renewables become more desirable under the scenarios in which the fuels and water prices, as well as the carbon taxes, are high. The emissions will increase less under the carbon tax scenarios compared to the business as usual scenario. The water withdrawal experiences a rapid decline in the high water price scenarios. It is observed that imposing carbon taxes alone will not reduce water withdrawal. Also, fuel price increase reduces emissions more than imposing low carbon tax. The sensitivity analysis of water price revealed the effect of this parameter in Iran.

2 - Market equilibria on regional flexibility markets for congestion management considering a strategic aggregator

Hannes Hobbie, Matthew Schmidt

Future decentralised energy systems require novel solutions for managing congestions in power grids. These also entail new forms of coordination between grid operators and flexibility suppliers. End-users typically own the needed flexible applications, e.g. heat-pump, electric vehicles, but have limited access to wholesale markets. Potential solutions must involve them to exploit needed flexibility potentials. In this context, regional flexibility markets and aggregators who manage the bundled energy procurement will likely play an essential role in the market-based coordination of flexibility provision between grid operators and end-users.

Besides technical challenges, aspects related to market design issues and individual stakeholders' preferences substantially impact possible design solutions. Whereas operators seek to implement congestion management measures according to the regulatory framework, end-users and regional aggregators usually endeavour to maximise their own utility or profits.

In order to consider these aspects in a modelling framework, the application of bi-level programming and complementarity systems is proposed to investigate potential design solutions for regional flexibility markets. Expected findings of this work particularly will highlight how a strategically offering aggregator may impact equilibria on regional flexibility markets and how different market design options may prevent resulting market inefficiencies.

3 - Insights on Joint Integration of Renewable Energy Sources and Hydrogen Storage into Power Networks

Sezen Ece Kayacık, Albert Schrotenboer, Evrim Ursavas, Iris F.A. Vis

The use of green hydrogen, i.e., hydrogen generated from renewable sources, is a high-potential solution to the intermittency problem of renewable energy output. It can be used to store renewable energy to mitigate supply-demand imbalances of electricity. Besides, it can be sold outside the network to satisfy increasing green hydrogen demand from different sectors such as industry, mobility, and heat. Coordination and integration of these green technologies into power grids requires optimization techniques for determining the location and power ratings of the renewables and storage systems. We aim to support decision-making for economically and environmentally efficient location and rating decisions that are resilient to the uncertainty of renewable output, electricity demand, and electricity price. For this purpose, we develop an integrated stochastic optimization model in which we jointly integrate renewables and hydrogen storage based on the operational level problem, i.e., multi-period optimal power flow. To provide globally optimal solutions to this naturally stochastic mixed-integer nonlinear optimization problem, we develop a second-order cone programming approach within a tailored Benders' decomposition framework. On a case study of the largest hydrogen valley of the European Union, we show the importance of jointly considering renewable and storage investments and the possibility of considerable operational cost-savings with small investment budgets.

■ TC-15

Tuesday, 12:30-14:00 - U262

Decision Support in Health and Disaster Planning

Stream: Decision support (contributed)
Contributed session
Chair: Mikko Nuutinen

1 - Decision Support for Companies' Disaster and Crisis Management

Markus Lüttenberg, Miriam Klein, Marcus Wiens, Frank Schultmann

To quantify investments into disaster and crisis management mitigation measures is key to companies' decision making processes. Even though there are good reasons for companies to support state disaster response, research on so-called Public-Private Emergency Collaborations (PPEC) is still rare. Companies are currently unable to assess how the population values their involvement in such PPECs. In a survey of 402 participants the perception of consumers, Corporate Social Responsibility (CSR), and the associated involvement in emergency cooperation is linked with the economic success of the company. We find that companies' involvement in PPECs is in general highly valued. In a next step, we conducted an economic experiment with over 250 participants in order to investigate to what extent the valuation and the loyalty of customers interacts with the stocking behaviour of a company. For long-term customer/company relationships, the company's valuation plays an important role. A company can build a positive valuation in "bad times" by delivering products reliably. Thus, the experiment quantifies the economic value to a company resulting from the availability of goods in times of a disaster rated by the population. Based on the examined data, we derive decision support to companies in disaster management dedicated to the question whether an investment in their reputation can be advantageous for them in the long term.

2 - Resilient control algorithms for food security in large-scale food supply networks

Sissi Bazan, Hanno Friedrich, Sebastian Albrecht, Rudolf Sollacher

National food systems are exposed to a wide range of high-impact disruptions. Each government is responsible for securing food and may introduce special support policies in crisis situations. However, without models that support the understanding of the measures' impact on food security, the effectiveness of any decision made for crisis situations is limited. We show that the implementation of three control algorithms applied to a dynamic macro-model of the national food supply can support the decision-making processes of a central organizer seeking to secure food supply during high-impact disruptions. Using a linear programming formulation, we applied model predictive control(MPC) to find strategic decisions during modeled disruptions that minimize user-defined monetary and risk-related costs. We include robust MPC to evaluate multiple scenarios with varying probabilities and impact degrees. Finally, by incorporating robust control, we search for the optimal placement and sizing of regional inventories. The algorithms are applied on a large numerical case study of the German wheat supply considering climate change-induced yield losses of different projected intensities. Our results show which governmental measures related to the required transportation, processing and storage capacities, their management, and the reduction of export increase the system's resilience depending on the relative weighting of monetary and risk-related costs in the objective function.

3 - Water main deterioration with nearby excavations

Lieke van der Heide, Bram de Jonge, Dirk Pieter Van Donk

In the upcoming decades, renewing and maintaining infrastructures will be an immense task. To maintain underground infrastructures, such as water mains and gas pipes, they need to be excavated. Research has shown that excavations nearby water mains can lead to their deterioration and failures. However, current maintenance planning research for water mains does not include this effect. In this study, we propose a maintenance planning model for water mains that does incorporate the potential increase in deterioration due to nearby excavations. We model these excavations as random shocks that affect all nearby water mains. We add these random shocks to water main deterioration models from the literature to inspect how nearby excavations can influence your maintenance scheduling decisions. Specifically, we use a Bayesian updating system to continuously update the expected effect of excavations on water mains. Failures of water mains are used to estimate the impact of excavations, which can in turn be used to improve the estimation of the deterioration of other nearby mains. We use a water main infrastructure network from a Dutch municipality to determine if our findings also hold in realistic settings. Moreover, we research the benefits of joint maintenance projects for different infrastructures. This results in more accurate estimations of the benefits of joint maintenance and allows for improved deterioration estimations and maintenance decisions in water main infrastructures.

■ TC-16

Tuesday, 12:30-14:00 - U264

Set- and Vector-Valued Models in Risk Management

Stream: Set Valued Models in Finance
Invited session
Chair: Tobias Fissler

1 - Elicitability of set-valued functionals

Jana Hlavinová, Tobias Fissler, Birgit Rudloff

Estimating various risk measures, such as Value at Risk or Expected Shortfall, is a common task in financial institutions. Assessing the quality of different estimation procedures via comparative backtests crucially hinges on the notion of elicitability. A risk measure is called elicitable if there is a strictly consistent scoring function for it. That is, a function S(x,y) of a forecast x and an observation y, such that its expectation with respect to y is uniquely minimized in x by the correct forecast. Recently, financial mathematics has witnessed a shift towards set-valued measures of risk, in particular when it comes to financial systems and portfolios. The question therefore arises what notion of elicitability is appropriate when evaluating set-valued risk measures, or set-valued functionals in general. We introduce two modes of elicitability: an exhaustive and a selective one. While in the exhaustive mode, the forecasts aim to specify the whole set, in the selective mode one is content with reporting any point within the set. We study the structural relations between these two modes and their properties, notably establishing a mutual exclusivity result between the two notions. Finally, we study several relevant examples of set-valued functionals including systemic risk measures and answer the question whether and in which sense they are elicitable.

2 - Intrinsic measures of systemic risk

Alexander Smirnow, Jana Hlavinová, Birgit Rudloff

In recent years, it has become clear that an isolated micro-prudential approach to capital adequacy requirements of individual institutions is insufficient. It can increase the homogeneity of the financial system and ultimately the cost to society. For this reason, the focus of the financial and mathematical literature has shifted towards the macro-prudential regulation of the financial network as a whole. In particular, systemic risk measures have been discussed as a risk mitigation tool. In this spirit, we adopt a general approach of multivariate, set-valued risk measures and combine it with the recently proposed notion of intrinsic risk measures. In the latter, instead of using external capital to define the risk of a financial position, we use internal capital, which is received when part of the currently held position is sold. We translate this into a systemic framework and show that intrinsic measures of systemic risk have desirable properties such as monotonicity and quasi-convexity. Furthermore, for convex acceptance sets we derive dual representations of systemic intrinsic risk measures. We combine our approach with an Eisenberg-Noe network of banks and show how risk can be mitigated by moving the network towards more stable assets.

3 - Computing systemic risk measures via mixed-integer linear programming

Cagin Ararat, Nurtai Meimanjan

Systemic risk is concerned with the instability of a financial system whose members are interdependent in the sense that the failure of a few institutions may trigger a chain of defaults throughout the system. Several systemic risk measures have been proposed in the literature that are used to determine capital requirements for the members subject to joint risk considerations. We address the problem of computing systemic risk measures for systems with a sophisticated clearing mechanism. In particular, we consider an extension of the Rogers-Veraart network model where the operating cash flows in the system are unrestricted in sign. We propose novel mixed-integer linear programming problems that can be used to compute clearing vectors for these models. Due to the binary variables in these problems, the corresponding (set-valued) systemic risk measures fail to have convex values in general. We associate nonconvex vector optimization problems to these systemic risk measures and provide theoretical results related to the weighted-sum and Pascoletti-Serafini scalarizations of these problems. We test the proposed formulations on computational examples and perform sensitivity analyses with respect to some model-specific and structural parameters.

4 - Acceptability Maximization

Gabriela Kovacova, Birgit Rudloff, Igor Cialenco

In this work, we study the optimal investment problem, where a coherent acceptability index (CAI) is used to measure portfolio performance. We call this problem the acceptability maximization. First, we study the one-period (static) case and propose a numerical algorithm that approximates the original problem by a sequence of risk minimization problems. In the second part, we investigate the acceptability maximization in a discrete-time dynamic setup. Using robust representations of dynamic CAIs in terms of a family of dynamic coherent risk measures (DCRMs), we establish an intriguing dichotomy: if the corresponding family of DCRMs is recursive (i.e. strongly time consistent) and assuming some recursive structure of the market model, then the acceptability maximization problem reduces to just a one-period problem and the maximal acceptability is constant across all states and times. On the other hand, if the family of DCRMs is not recursive, which is often the case, then the acceptability maximization problem ordinarily is a time-inconsistent stochastic control problem. For two particular dynamic CAIs - the dynamic risk-adjusted return on capital and the dynamic gain-to-loss ratio - we overcome this issue by considering related bi-objective problems and applying the set-valued Bellman's principle.

■ TC-17

Tuesday, 12:30-14:00 - U356

Modelling Tools I

Stream: Software for Optimization
Invited session
Chair: Robert Fourer

1 - 20 Years Xpress Mosel: Software design driven by application needs and technological advances

Susanne Heipcke, Yves Colombani

At the occasion of the 20th anniversary of the first commercial publication of Xpress Mosel this talk reviews the major phases of its development, stressing as the two main drivers behind its design and evolution user requirements/usage patterns and technological (hardware) advances. Phase 0 (1997-2001): during the phase preceding the first publication the fundamental questions of whether, why, and how to replace an established software had to be addressed. Design decisions were made in collaboration with a group of expert users of OR software. Phase 1 (2002-2008): new directions for modelling: making programming tools (debugger, profiler) available for a modelling language and exploiting the newly available multi-processor machines for parallelising (decomposition) algorithms and other computational tasks on the model level. Phase 2 (2009-2017): support for distributed computing: creating technology to enable working in distributed settings including cloud architectures, providing the underlying technical framework for Xpress Insight (platform for web-based apps with scenario handling based on Mosel models, first released in 2014) and a new browser-based development environment, Xpress Workbench. Phase 3 (2018-now): addressing advanced programming needs of increasingly large software development projects, including connectivity and testing systems. In recognition of its increasing use as general-purpose programming language Mosel was turned into free software.

2 - Insights into Recent Project Activities with GAMS
Robin Schuchmann

The evolution in software and hardware has a great impact in the field of mathematical optimization. Apart from obvious benefits such as increased computing power, the way software is used has also changed significantly. Whereas optimization software used to be invoked via the command line on a local computer, today many users want to log into an online service and perform their optimization on a centralized compute resource. Another tendency that has been emerging for some time is that more and more software, as well as optimization models, are being made available as open source. These and other trends do not stop at GAMS. In recent years, various new developments have been initiated to meet the changing requirements. In this talk, real-life examples are used to show what modern software solutions with GAMS can look like. Different approaches will be discussed, from the integration of a cloud-based GAMS system into existing infrastructures to entirely redesigned applications whose graphical user interface can be operated via a smartphone. We will also discuss how to organize projects in an efficient way and how to facilitate communication with the customer.

3 - Advances in Model-Based Optimization with AMPL
Robert Fourer, Gleb Belov, Filipe Brandão

The ideal of model-based optimization is to describe your problem the way you think about it, and then let the computer do the work of getting a solution. Recent enhancements aim to bring the AMPL modeling language and system closer to this ideal. Using a variety of modeling language extensions, common formulations are described more naturally, with the AMPL translator, the AMPL-solver interface, or the solver itself doing most of the needed transformations. Extensions described in this presentation include quadratic expressions, logical operators and constraints, simple near-linear and nonlinear functions, and combinations of these together with linear terms. All are supported by a new C++ AMPL-solver interface library that can be adapted to handle the multiple detection and transformation strategies required by large-scale solvers.

■ TC-18

Tuesday, 12:30-14:00 - U358

Advances in Stochastic and Robust Optimization

Stream: Stochastic and Robust Optimization
Invited session
Chair: *Francesca Maggioni*
Chair: *Johanna Burtscheidt*

1 - A Robust Optimization Model for Nonlinear Support Vector Machine
Andrea Spinelli, Francesca Maggioni

In this contribution we present a novel optimization approach for Support Vector Machine (SVM), with the aim of separating two sets of points by means of a nonlinear decision boundary. Our approach extends the deterministic and linear predictor proposed in [1] to a nonlinear classifier by including a kernel function in the model. Moreover, we consider the case in which training data are plagued by uncertainty. To tackle the problem, we formulate a robust optimization model that generalizes the technique proposed in [2] to a class of uncertainty sets bounded by a p-norm and by including a nonlinear classifier [3]. The deterministic model and its robust counterpart reduce both to linear programs which can be shown to be computationally tractable. Preliminary numerical results on real-world datasets show the performance of the proposed approach.

References [1] Liu, X., Potra, F.A., 2009. Pattern separation and prediction via linear and semidefinite programming. Stud. Inform. Control 18, 71-82. [2] Faccini, D., Maggioni, F., Potra, F.A., 2022. Robust and distributionally robust optimization models for linear support vector machine. Comput. Oper. Res., to appear. [3] Trafalis, T.B., Gilbert, R.C., 2006. Robust classification and regression using support vector machines. Eur. J. Oper. Res. 173, 893-909.

2 - A Simheuristics framework for stochastic combinatorial optimization
Joost Berkhout, Arik Berkan, Ger Koole

Ignoring uncertainty in combinatorial optimization leads to suboptimal decisions in practice. Nevertheless, the focus is often on deterministic combinatorial optimization problems, mainly because they are already challenging enough without stochasticity. To make it easier to address stochasticity in combinatorial optimization, in recent years so-called Simheuristics were developed that proved to be effective to solve stochastic combinatorial optimization problems. Simheuristics combine Monte Carlo simulations and existing efficient (meta)heuristics for deterministic combinatorial optimization problems.

In this work, a general Simheuristic framework is presented that dynamically changes the optimization focus between a deterministic and stochastic perspective based upon a statistical model. By doing so, a trade-off is made between exploration and exploitation of the solution space during the optimization. We believe that dynamically changing the optimization focus can lead to enhanced performance when solving stochastic combinatorial optimization problems. The broad applicability and effectiveness of the framework are numerically demonstrated by applying it to a production scheduling problem that originates from the cattle feed industry.

3 - On the Structure of Bilevel Stochastic Linear Problems with Integer Variables
Johanna Burtscheidt, Matthias Claus

Stochastic bilevel problems arise from the interaction between two decision makers at different levels of a hierarchy, where the lower level problem is affected by a random vector. In our context, the decision vector of the follower is additionally integer.

We present a deterministic formulation for a bilevel problem under stochastic uncertainty based on special risk measures. In particular, the structural properties of the optimal value function of this model are considered.

■ TC-19

Tuesday, 12:30-14:00 - Y228a

Novel Control Mechanisms for Queueing Systems

Stream: Performance Evaluation of Queues
Invited session
Chair: *Samuli Aalto*
Chair: *Esa Hyytiä*

1 - The Gittins Policy in the M/G/1 Queue
Ziv Scully, Mor Harchol-Balter

The Gittins policy is a highly general scheduling policy that minimizes a wide variety of mean holding cost metrics in the M/G/1 queue. Perhaps most famously, Gittins minimizes mean response time in the M/G/1 when jobs' service times are unknown to the scheduler. Gittins also minimizes weighted versions of mean response time. For example, the well-known "cμ rule", which minimizes class-weighted mean response time in the multiclass M/M/1, is a special case of Gittins.

However, despite the extensive literature on Gittins in the M/G/1, it contains no fully general proof of Gittins's optimality. This is because Gittins was originally developed for the multi-armed bandit problem. Translating arguments from the multi-armed bandit to the M/G/1 is technically demanding, so it has only been done rigorously in some special cases. The extent of Gittins's optimality in the M/G/1 is thus not entirely clear.

In this work we provide the first fully general proof of Gittins's optimality in the M/G/1. The optimality result we obtain is even more general than was previously known. For example, we show that Gittins minimizes mean slowdown in the M/G/1 with unknown or partially known service times, and we show that Gittins's optimality holds under batch arrivals. Our proof uses a novel approach that works directly with the M/G/1, avoiding the difficulties of translating from the multi-armed bandit problem.

2 - Scheduling in redundancy-systems
Elene Anton

We characterize the impact of scheduling policies on the mean response time in nested redundancy systems. We consider not only class-oblivious policies, such as FCFS and ROS, but also class-aware policies of the form P1-P2, where P1 discriminates among job classes (e.g., least-redundant-first (LRF), most-redundant-first (MRF)) and P2 discriminates among jobs of the same class. Assuming that jobs have independent and identically distributed (i.i.d.) copies, we prove the following: (i) When jobs have exponential service times, LRF policies outperform any other policy. (ii) When service times are New-Worse-than-Used (NWU), MRF-FCFS outperforms LRF-FCFS as the variability of the service time grows infinitely large. (iii) When service times are New-Better-than-Used (NBU), LRF-ROS (resp. MRF-ROS) outperforms LRF-FCFS (resp. MRF-FCFS) in a two-server system. Statement (iii) also holds when job sizes follow a general distribution and have identical copies (all the copies of a job have the same size). Moreover, we show via simulation that, for a large class of redundancy systems, class-aware policies can considerably improve the mean response time compared to class-oblivious policies.

3 - When does FCFS minimize the mean slowdown in the M/G/1 queue?
Samuli Aalto

We consider the optimal scheduling problem in the M/G/1 queue. The optimal policy depends naturally on the objective function but also on the information available to the scheduler. The scheduler is said to be non-anticipating if it knows the attained service of each job, while an anticipating scheduler knows even the remaining service times.

If the aim is to minimize the mean delay, the optimal anticipating scheduling policy is known to be SRPT. In the special case where the service times are deterministic, SRPT coincides with the ordinary FCFS policy. The optimal non-anticipating policy minimizing the mean delay, however, depends essentially on the service time distribution. For example, FCFS is optimal when the service time distribution is NBUE, which can proved, e.g., by the so-called Gittins index approach.

However, instead of mean delay, we focus in this talk on the optimal scheduling problem where the objective function is the mean slowdown. The optimal anticipating policy minimizing the mean slowdown is known to be SPTP. Recently, Scully and Harchol-Balter showed that the Gittins index approach is applicable even when minimizing the mean slowdown among the non-anticipating policies. Now the challenge is to characterize the optimal non-anticipating policy more explicitly. In this talk, we reveal the properties that the service time distribution should have in order for FCFS to be the optimal non-anticipating policy with respect to mean slowdown.

4 - A Bounded Multi-Vacation Queue Model for Multi-stage Sleep Control
Behnam Badihi, Jie Chen

To evaluate the performance of multi-stage sleep telecommunication systems, this paper presents a bounded multi-vacation queue model. The energy consumption predicted by this model, shows an average error rate of 0.0177 and the delay (predicted by the same model) shows an average error rate of 0.0655. Both error rates were calculated over 99 instances. An optimization algorithm is also proposed to minimize the energy consumption whilst not violating the delay bound. Based on the model, numerical results, which quantify the performance of current state-of-art multi-stage sleep 5G base stations, are presented.

■ TC-20

Tuesday, 12:30-14:00 - Y228b

DEA applications in Agriculture and Sustainability

Stream: Data Envelopment Analysis and Performance Measurement
Invited session
Chair: Laura Carosi

1 - Measuring DEA Conditional Efficiency in agri-food through economical and physical territorial capital: a local analysis on in-the-Consortia Firms
Chiara Colamartino, Anna Rita Dipierro, Pierluigi Toma

Firms and territories are considered extremely interrelated, especially approaching the market of agri-food products detaining the PDO (Protected Designation of Origin) and PGI (Protected Geographical Indication) label. In order to reduce their costs and simultaneously exploit potential benefits, entrepreneurial realities often collaborate through consortia. This aspect takes on a crucial relevance when considering the Italian context, widely known for its high-quality products, the vocation to cooperate, and high adaptability to insidious locations. In this light, the study uses conditional Data Envelopment Analysis (DEA) by considering, besides the traditional input and output of the production function, also mediating factors catching physical and economic territorial capital. By exploring more than 600 in-the-consortia firms in 419 municipalities within the 2011-2020 period, huge territorial disparities emerge. Accordingly, physical riskiness and attitude to cooperate are examined, in terms of their potential impact on the transformation process of inputs (i.e., the number of employees and tangible assets) into outputs (i.e. revenues) in Italian firms belonging to consortia in fresh meat and cold cuts, and dairy products industries. Practical implications arise in terms of huge support of the impulse to collaborate, in order to take additional advantages from consortia.

2 - DEA optimization approaches in a non - homogenous environment - practical study
Jakub Hanousek

Data envelopment analysis has some assumptions for the application. If some assumptions are disturbed the results are distorted or do not make sense. Homogeneous production units are one of these assumptions. This article presents some approaches how to solve non - homogeneous environments between production units. Data envelopment analysis works with production units. Production units compose of inputs and outputs. This article transforms production units and their inputs and outputs to the nodes. We find close production units by network optimization. We divide close production into a more similar cluster. Then we work with this cluster. These approaches are presented on data of quality of living in the cities in the Czech Republic. Production units are the Czech Republic cities in this article.

3 - EU municipal waste management performance evaluation: An AHP-GPSI-based composite indicator
Laura Carosi, Giovanna D'Inverno, Giulia Romano

In this paper a new composite indicator is devised by integrating the Goal Programming Synthetic Indicator (GPSI) methodology with the Analytic Hierarchy Process (AHP). The proposed approach is used to evaluate to which extent European countries fulfill the European Union (EU) requirements in terms of waste management. Taking into account the EU Waste Hierarchy, a dashboard of indicators is identified together with a set of targets that European countries are supposed to meet. By means of the Analytic Hierarchy Process two different scenarios are proposed. The first one rewards the countries with good performance in the higher level of the Waste Hierarchy, while the second one penalizes countries whose infringements are in the lower part of the Waste Hierarchy. The analysis is performed using Eurostat data on

28 European countries from 2013 to 2018. For each year, countries are assessed in terms of their ability to keep the right waste management track delineated by the Waste Hierarchy principles. Countries' ranking over time is first obtained and then interpreted in light of countries policies and achievements, deriving policy suggestions to improve waste management strategy able to reach the expected results.

■ TC-21

Tuesday, 12:30-14:00 - Y229a

Behavioural issues in preference elicitation (I)

Stream: Behavioural OR
Invited session
Chair: *Alice H. Aubert*

1 - Revisiting the prioritisation of decision objectives in public policy analysis
Gilberto Montibeller

Public policy choices are rife with conflicting societal objectives: efficiency versus fairness, technical criteria versus political goals, costs versus multiple benefits. Such choices necessarily require the prioritisation of these objectives, which can guide the definition of trade-offs. Public policy analysis has employed different analytical methods to support such difficult choices, such as cost-benefit analysis or multi-criteria decision analysis. These methods encompass the representation of trade-offs, which enable the normalisation of different impacts, benefits, and costs of policy options onto a single scale, so these options can be compared. In this paper, I revisit the prioritisation of decision objectives in public policy analysis on three main fronts. First, I identify the different ways that conflicting objectives are considered in analytical methods that aim to normalise different impacts, benefits and costs. Second, I contrast the normative standards required by these methods with the behavioural evidence related to the elicitation of value trade-offs. Third, I reflect on my experience, over almost thirty years, of explaining, teaching and eliciting trade-off judgement from decision-makers and policymakers. I conclude with some suggestions on how elicitation protocols could be refined and common pitfalls be avoided in practice.

2 - Biases in weight elicitation and opportunities for debiasing - experiences from environmental applications
Mika Marttunen

One of the key objectives of multi-criteria decision analysis (MCDA) is to improve the quality and consistency of planning and decisions through the systematic identification and evaluation of objectives and options. Due to the positive experiences, the methods are increasingly used in comprehensive assessments to support of environmental decision-making. The methods are flexible, i.e., they can be applied in various different ways to take the case specific needs of different situations into account. The flexibility is a strength, but it also poses challenges and requirements for analysts to follow good practices. Although there is a large number of different guidelines and manuals in the field, there is still a lack of clear, widely accepted protocols on how processes should be implemented to ensure their quality and to get credible results. Such protocols have been prepared, for example, for environmental economic valuation methods but not that much for MCDA. In this presentation, we focus on challenges in assigning weights to criteria and ways to reduce biases in this process on the basis of our experiences on applying MCDA in environmental projects.

3 - Risk preference elicitation for public policy? Insights from a randomized controlled experiment about urban drainage services
Lisa Scholten

The degree to which urban water management decisions represents the preferences of the general public as intended beneficiaries is not frequently studied, yet risk aversion is often deemed appropriate. Assessing public preferences would require reliable methods to elicit stable preferences from large samples, which remains a challenge in policy making and decision support more widely. I will present a randomized controlled experiment which studied risk preferences elicitation for five wastewater management outcomes. It also traced preference instability and choice blindness as indicators of preference (un)reliability along with six predictors. Reasonable importance rankings of service outcomes were obtained along with moderately stable risk attitudes, suggesting that coherent preferences had been obtained. However, the great majority of participants were choice blind and no coincidence with preference stability was observed. Likewise, the randomly assigned stimuli presenting the same risk information split respondents into risk-seeking and risk-averse. This defies the idea that any valid, inherent preferences were obtained. This poses important methodological, philosophical, and ethical questions considering the use of preference elicitation to inform and legitimize public policy such as for urban drainage services.

4 - Can online weight elicitation surveys facilitate learning for decision-making?
Alice H. Aubert, Judit Lienert

Decision-making about complex problems that affect citizens is often not participatory. Consulting citizens using online surveys could alleviate this problem. Such surveys can inform the decision-makers about the trade-offs between achieving objectives that citizens are ready to make. Our first attempts of citizen participation using online surveys for preference elicitation were promising but also revealed critical issues. We addressed these in recent experiments, applied to a decision on wastewater management in rural Switzerland. In this talk, we present the evaluation of four tools for online weight elicitation from laypeople. In a 2 x 2 experiment, we tested the effect of two varying factors: the presence/absence of learning loops based on consistency checks and the presence/absence of game elements in the survey. 834 respondents, representative of the Swiss population, answered one of our four surveys. We evaluated the online surveys using a value-focused approach. The surveys should enable three types of learning for decision-making, namely factual learning about wastewater management, preference construction, and process understanding. We collected data in pre- and post-questionnaires to evaluate quantitatively (performance tests and self-reporting questions) and qualitatively the three types of learning. The overall evaluations are positive, with some nuances between the tools. We will reflect on lessons learnt from these online preference elicitation surveys.

■ TC-22

Tuesday, 12:30-14:00 - Y229c

Coordination and Contracting in Sustainable Supply Chains

Stream: Sustainable Supply Chains
Invited session
Chair: *Bruna Mota*

1 - Closed-Loop Supply Chain Coordination with Contracts: a Literature Review
Nazanin Nami, Grigory Pishchulov, Joao Quariguasi Frota Net

Closed-loop supply chains (CLSCs) are regarded as a key approach to mitigating environmental depletion and pollution. Such systems require collaboration among several parties with different perspectives and interests that are not always well-aligned. Supply chain coordination mechanisms offer a tool to consider all CLSC parties' interests and optimise the overall supply-chain performance. Therefore, in recent years, a growing body of literature on CLSC coordination has emerged. This study conducts a framework-development systematic literature review on CLSC coordination with contracts, and the criteria of our proposed framework are CLSC configuration, CLSC modelling, specific issues, and coordination, with ten sub-criteria. We focus in particular on addressing the shortcomings in the reviewed studies and providing insights for scholars and future research directions.

2 - Closed-loop supply chain coordination contracts with price-dependent stochastic demand
Petr Fiala, Renata Majovska

Supply chain is a decentralized system where material, financial, information and decision flows connect members. When a supply chain coordinates the backward flows with the forward flows, the system is called the closed-loop supply chain. Contracts are used to provide some incentives to adjust the relationship of supply chain partners to coordinate the closed-loop supply chain, i.e., the total profit of the decentralized supply system is equal to that achieved under a centralized system. Double marginalization is a well-known cause of supply system inefficiency and the problem occurs whenever the supply chain's profits are divided among more members and at least one of the members influences price-dependent demand. The aim of this paper is to analyze contracts for the combined problem of closed-loop supply chain coordination with price-dependent stochastic demand.

3 - Production allocation for global manufacturing under import quota restriction and uncertainty
Yue Wu, Lin Zhu

Production allocation, as a vital part of supply chain management, has inevitably been affected by the rapid development of globalization. Many domestic companies are facing greater competition from international companies than before. As a result, some governments provide some policies to protect their domestic companies, such as import quotas that is discussed in this research. Import quotas are extensively employed by various governments as a means of addressing perceived trade imbalances. With today's increasingly competitive environment, many international companies, whose markets are located in Europe and North America, for example, decide to manufacture their products in developing countries, such as Vietnam, mainland China and Thailand. Their sales departments collect market information, which is continually changing, and their headquarters allocate production among their manufacturing plants in different regions and countries. Additionally, not all information for production allocation is known in advance makes decision-making more complicated. The headquarters have to allocate production among their manufacturing companies under uncertain demand and quota limitation. In this research, a robust model is developed for global production allocation under demand uncertainty and quota limitation. Numerical results and tests are carried out to demonstrate the effectiveness of the robust model.

4 - Design and planning of symbiotic supply chains: a case study in pulp and paper and construction industries
Margarida Espadinha, Bruna Mota

Industrial symbiosis (IS) is a Circular Economy business model defined by collaboration between two or more businesses or organizations, focusing on the valorisation of materials, energy, water, knowledge, infrastructures, and expertise. From the standpoint of supply chain management, IS creates a collaborative supply chain network between previously unconnected organizations and establishes new supplier-buyer partnerships. The goal of this work is to identify critical modelling features for the development of a decision support tool to design and plan symbiotic supply chains. Given the difficulty of transitioning to circularity and the European Commission's goal of making Europe an impact neutral continent by 2050, this research also identifies the primary barriers and, as a result, the most important incentives to support and guide the progress of circularity. Descriptive research methods are applied for an in-depth characterization of a case study that explores symbiotic relationships between the Portuguese pulp and paper industry and the construction industry at different development stages. In particular, the case of paper sludge ashes produced in the fluidized bed boilers of the pulp and paper facilities is detailed. Semi-structured interviews supported by literature and available technical and regulatory information are carried out with stakeholders such as suppliers, buyers, facilitators, regulators, and academics, to capture the different involved perspectives.

■ TC-23

Tuesday, 12:30-14:00 - Y307

OR in Sports 3

Stream: OR in Sports
Invited session
Chair: Ali Hassanzadeh

1 - Optimizing the selection of a soccer team in Fantasy Premier League
Lennert Claerhout, Jens Goemaere, Jan Goedgebeur

Fantasy Premier League is a game where a player acts as a soccer team manager. Points can be scored based on real-life performances of the selected team. Specific game chips can be used to boost points. For example, one of those chips allows the player to perform free transfers during one week. This study aims to create a model that predicts the performance of players to select for the team. The model will also educate the player on when to use the game chips. The first part of this study describes a mixed integer programming model of the game. On the one hand, this mathematical model can be used to extract interesting statistics from previous seasons. On the other hand, it is used as a benchmark for the prediction model. This prediction model uses a Recurrent Graph Evolution Neural Network (ReGENN) to predict the points of each player based on past performances. The ReGENN architecture combines the information of multiple performance statistics of every player recorded every gameweek over past seasons. We use these scores together with a mathematical model to select our starting team and to predict when we should perform transfers in our team. To predict whether we want to use a game chip in a specific week, we refer to a variant of the Secretary Problem from the field of optimal stopping. Results of the model are validated by testing the performance using actual data of a past Premier League season.

2 - Concluding a Suspended Sports League
Ali Hassanzadeh

Professional sports leagues may be suspended due to various reasons such as the recent COVID-19 pandemic. A critical question the league must address when re-opening is how to appropriately select a subset of the remaining games to conclude the season in a shortened time frame. Despite the rich literature on scheduling an entire season starting from a blank slate, concluding an existing season is quite different. Our approach attempts to achieve team rankings similar to that which would have resulted had the season been played out in full. We propose a data-driven model which exploits predictive and prescriptive analytics to produce a schedule for the remainder of the season comprised of a subset of originally-scheduled games. Our model introduces novel rankings-based objectives within a stochastic optimization model, whose parameters are first estimated using a predictive model. We present simulation-based numerical experiments from previous National Basketball Association (NBA) seasons 2004-2019, and show that our models are computationally efficient, outperform a greedy benchmark that approximates a non-rankings-based scheduling policy, and produce interpretable results. Our data-driven decision-making framework may be used to produce a shortened season with 25-50 % fewer games while still producing an end-of-season ranking similar to that of the full season, had it been played.

3 - Integrating the grouping and timetabling of multi-league sports competitions
Miao Li, Dries Goossens

The multi-league grouping and timetabling problem is an integration of the sport team grouping problem and the multi-league sports scheduling problem which consists of grouping a number of teams from a set of clubs to play multiple round robin tournaments, and determining the schedule for each league. The objective is the minimization of two components: the distance travelled and the venue capacity violations, which can conflict when the leagues have different sizes. We formulate a bi-objective mathematical model and design a two-phase two-layer constructive method aimed at efficiently producing adequate approximations of the Pareto set, which is validated by the epsilon-constraints method. The algorithm uses simulated annealing on the outer-layer and integer programming on the inner-layer. The first phase explores an initial set of Pareto solutions and the second phase improves the distribution of solution points. We further develop a speed-up version in which the inner-layer is solved heuristically. By using multi-objective assessment metrics, we compare the performance of the algorithms. Finally, fuzzy-logic approach is used to help decision-makers select the preferred option among the obtained Pareto solutions. As an illustration, our decision-making framework is applied to realistic data from the Royal Belgium Football Association.

■ TC-24

Tuesday, 12:30-14:00 - Y307a

Avoiding Food Waste

Stream: Demand and Supply in Consumer Goods and Retail
Invited session
Chair: *Susana Relvas*

1 - Agent-based decision support to integrate demand and shelf life-based inventory management in grocery operations
Christian Fikar, Andreas Mild, Gerald Reiner, Martin Waitz

Customers' picking behavior is a major cause for food waste. In most cases, items with long remaining shelf lives are preferred, resulting in various challenges for grocery providers. This work develops an agent-based decision support system to investigate this point within an omni-channel context. Customers can either choose to buy food in a store or get it delivered to their premises, whereas in the latter case, the delivered quality of the items is unknown. Based on collected preference data of more than 450 customers for fresh milk, different inventory and pricing decisions of a grocery provider are simulated to study effects on food waste, customer utility and revenue. Results highlight the immense potential of both integrating shelf live and demand data in inventory management systems to facilitate more sustainable grocery operations in the future.

2 - Optimizing assortments with age-dependent inventory
Alexander Hübner, Lena Riesenegger, Manuel Ostermeier

Determining the assortment and inventory levels based on their shelf life is essential for retailers to maximize profits while avoiding food waste. Assortment and inventory decisions are interrelated by the limited shelf space. A joint approach is needed that defines the assortment size and the maximum possible inventory levels while considering product ages. We develop the first multi-period approach to integrate product shelf life and product outdating.

3 - Minimizing waste under an aggregate service constraint for retailers with periodic review inventory systems for perishables
Rob Broekmeulen, Karel van Donselaar

We investigate the potential reduction in waste and/or reduction in lost sales for perishables by differentiating the service levels for the different items in the fixed assortment of a store while satisfying an aggregate service constraint and a minimum service level for each item. We use a greedy heuristic to find the optimal reorder levels. The relevant KPI's such as expected waste are based on approximations. We test the approach using empirical data from three large European retailers, which supplied detailed data on 27 stores. Based on our dataset, the potential reduction is 50% in waste (or 60% in lost sales). We show that these results also hold in situations with out-of-stock substitution.

4 - Consumer behavior regarding the remaining shelf life of perishable products
Mariana Sousa, Pedro Amorim, Sara Martins, Maria João Martins dos Santos

Reducing food waste is a widely shared concern among retailers. Products that are aged or past their shelf life are significant causes of waste in organisations. While such products may not be unfit for consumption, consumers feel unsafe to buy them, given the perception of lower quality. Policies that encourage the purchase of perishable products, before they reach a damaged state or become outdated, have the potential to significantly reduce waste of resources. Thus, great efforts have been made in this regard, with one of the strategies often used being the implementation of discounts on products close to obsolescence. However, there remains a gap in understanding the price elasticities of demand for different products under different shelf life. In fact, the policies implemented have been mostly indiscriminate, ignoring product specificities. To help clarify consumer behavior vis-à-vis the shelf life and price dichotomy, this study proposes the development of a discrete choice model using yogurt sales data from a Portuguese retailer. The design of such model carries out a prior study of the consumers' purchase profile to validate the assumptions to be used; the delineation of alternative discrete choice models; and the selection of the model that best captures consumer behavior. Hence, it is expected to determine the willingness to pay according to different product attributes, for subsequent incorporation of the acquired knowledge into production management policies.

■ TC-25

Tuesday, 12:30-14:00 - Y308

OR Meets Computation

Stream: Emerging Research and Specific Applications of OR
Invited session
Chair: *Burcu Gürbüz*
Chair: *James Cochran*
Chair: *Gerhard-Wilhelm Weber*

1 - Maximal Brain Tumor Resection with Minimal Disruption to Network Efficiency
Taghi Khaniyev, Kaan Cakiroglu, Asli Sena Bozkurt, Sahin Hanalioglu

Connectome is the representation of the structural and functional connectivity of an organism's nervous system as a mathematical network (a set of nodes and the connections between them). Recent advances in medical imaging technologies that can probe the neural circuitry of human brains allowed the construction of connectivity networks from fiber (white matter) densities between different regions of interest (ROIs) in the human brain. One of the clinical areas where network neuroscience has contributed significantly is the analysis of the impact of damages to the brain regions. Assume we are given the connectome of a human subject's brain where a number of regions (nodes) are marked as "tumorous". Our goal is to identify a maximal subset of contiguous tumorous regions whose removal will cause less than a predetermined magnitude of disruption in the network's global efficiency. Due to the intricate nature of the networks, it is not realistic to assume that the impact of removing multiple nodes from the network together will be equal to the sum of the marginal impacts of removing them individually. This problem is a combinatorial optimization problem in nature and can be formulated as a mixed-integer linear programming problem, which is closely linked to the critical node/edge problem in the literature. The main challenge, after formulating the problem, is to solve real-life size problem instances with thousands of nodes for which we propose algorithmic approaches.

2 - Approximation of the Double Traveling Salesman Problem with Multiple Stacks
Laurent Alfandari, Sophie Toulouse

The Double Traveling Salesman Problem with Multiple Stacks (DTSPMS), deals with the collect and delivery of n commodities in two distinct cities, where the pickup and the delivery tours are related by LIFO constraints. During the pickup tour, commodities are loaded into a container of k rows, or stacks, with capacity c. This paper focuses on computational aspects of this NP-hard problem. We first review the complexity of two critical subproblems: deciding whether a given pair of pickup and delivery tours is feasible and, given a loading plan, finding an optimal pair of pickup and delivery tours, are both polynomial under some conditions on k and c. We then prove a standard approximation of 3k/2 for the Min Metric DTSPMS with k stacks, where k is a universal constant, and other approximation results for various versions. We finally present a matching-based heuristic for the problem with 2 stacks. This yields a 1/2, 3/4 and 3/2 standard approximation ratio for Max 2DTSPMS, Max 2DTSPMS(1,2) and Min 2DTSPMS(1,2) where distances are either 1 or 2, and a 1/2 differential approximation for Min or Max 2DTSPMS.

3 - Priority Management for On-Demand Service Platforms with Waiting Time Differentiation
Thomas De Munck, Philippe Chevalier, Jean-Sébastien Tancrez

Motivated by recent applications, we consider the problem of an on-demand service platform (e.g., Uber, Deliveroo) that provides two service options to two customer classes with distinct willingness to wait and to pay. Upon arrival, customers can be admitted or rejected to the system, and, at each moment, service providers can be allocated to admitted customers or reserved for future high-priority customers. We formulate this problem as a continuous-time Markov decision process and use it to find an optimal policy on customer admission and service provider allocation. Exploiting structural properties of the value function, we analytically show that the optimal policy is described by state-dependent admission thresholds for the two customers classes. In a numerical study, we then compare the performance of the optimal policy with several simpler policies. We find that jointly controlling the customer admissions and the service provider allocation enables the system to reach lower costs and operate optimally over an extensive range of system parameters. In addition, the optimal policy also improves customer welfare.

■ TC-26

Tuesday, 12:30-14:00 - Y309b

Models for resource allocation

Stream: EWG HOpe, EURO working group on Humanitarian Operations
Invited session
Chair: *Patricia Rogetzer*

1 - Unsolicited bilateral donations from international aid - a two-stage distribution model
Adhurim Imeri, Gerald Reiner

Disaster response funding typology is fundamentally consisting of monetary and in-kind donations. The latter represents the goods and services collected and distributed to the disaster affected area. Even though batches of in-kind donations, also referred to as unsolicited bilateral donations (UBDs), are oftentimes organized at a fast pace, they impose challenges in the emergency supply program. Unannounced or very-short notice upon arrival, erroneous paperwork, non-standard items, and incorrect packaging are a few burdens imposed by UBDs for organizing response supply flows. By considering this setting, this work presents a modeling framework to optimize operations that address UBDs from surrounding and distant countries to the people affected by the disaster. A stochastic program that models a two-stage distribution setting is presented. In the first stage, goods and services are screened and sorted based on applicable nomenclature guidelines developed in the commercial industries. Further on, consolidation and delivery packages are planned in the second stage. Related operational parameters are varied to assess the screening and sorting time sensitiveness in the overall response planning. The model serves as a managerial decision supporter, especially for clustered humanitarian organizations and logistic service providers that program a donation operation. Additionally, this work evaluates the current service request types of such programming clusters.

2 - The Food Bank Supply Chain Model: Optimizing resource allocation and investments
Frans Cruijssen, Meike Reusken, Hein Fleuren

We address the problem of reallocating donated food products to the community in need of food assistance, contributing to the global interest of reducing food waste and improving food security. In this paper we study a food bank supply chain consisting of a national organization, depots and local organizations, where foods are distributed to the beneficiary in the form of food packages. To provide such voluntary organizations with tools to deal with their operational complexities, a mixed integer linear program is presented to find the optimal resource allocations and investment decisions. Allocation decisions include effectively and equitably distributing food donations throughout the food bank supply chain, while shortages in storage capacity, transport capacity and supplied donations are resolved by investment decisions. As an objective, we seek to maximize the number of households that can be served within a fixed supply chain setup. Computations are performed on real data from the Dutch Food Banks.

3 - Effective and equitable location-allocation of long-lasting insecticidal nets in malaria control
Douglas Alem, Fabiola Negreiros, Fabricio Oliveira, Adriana Leiras

The most effective strategy to prevent malaria is based on the use of long-lasting insecticidal nets (LLINs) among people at risk for malaria. A critical challenge in public health is to ensure that LLINs are effectively and equitably allocated to those that need them the most. In this talk, we show some promising mathematical programming approaches to find out practical solutions for this problem based on the endemic of Malaria in Brazil.

4 - Medical resource allocation after mass-casualty incidents and evaluation of disaster simulation exercises
Patricia Rogetzer, Gelbrich Holsbrink, Derya Demirtas, Nancy ter Bogt

When mass-casualty incidents (MCIs) happen, treatment capabilities of regional hospitals are overwhelmed with patients. In the Netherlands, emergency care networks prepare their regions for an MCI by organizing analog disaster simulation exercises, also called Emergo Train System (ETS) exercises. In 2019, two emergency medical teams simulated the allocation process of casualties to ambulances and hospitals during an MCI in the Netherlands using ETS. The results of these two teams differed significantly. Although the ETS exercises are worldwide in use, the optimal solutions are not known. In this research, we propose an Integer Linear Programming (ILP) model that allocates each casualty of an MCI to an ambulance and a hospital. We demonstrate the effectiveness of our model by comparing its results to the performance measures of the ETS exercises and providing sensitivity analyses.

■ TC-27

Tuesday, 12:30-14:00 - Y313

Optimization methods with inexact evaluations

Stream: Numerical Optimization Methods with Inexact Evaluations of Objective Functions and/or Derivatives
Invited session
Chair: Stefania Bellavia

1 - A stochastic Levenberg-Marquardt method using random models with complexity results
El Houcine Bergou, Youssef Diouane, Vyacheslav Kungurtsev, Clément Royer

Globally convergent variants of the Gauss-Newton algorithm are often the methods of choice to tackle nonlinear least-squares problems. Among such frameworks, Levenberg-Marquardt and trust-region methods are two well-established, similar paradigms. Both schemes have been studied when the Gauss-Newton model is replaced by a random model that is only accurate with a given probability. Trust-region schemes have also been applied to problems where the objective value is subject to noise: this setting is of particular interest in fields such as data assimilation, where efficient methods that can adapt to noise are needed to account for the intrinsic uncertainty in the input data. In this work, we describe a stochastic Levenberg-Marquardt algorithm that handles noisy objective function values and random models, provided sufficient accuracy is achieved in probability. Our method relies on a specific scaling of the regularization parameter, that allows us to leverage existing results for trust-region algorithms. Moreover, we exploit the structure of our objective through the use of a family of stationarity criteria tailored to least-squares problems. Provided the probability of accurate function estimates and models is sufficiently large, we bound the expected number of iterations needed to reach an approximate stationary point, which generalizes results based on using deterministic models or noiseless function values.

2 - An inexact restoration trust-region method with subsampling for finite-sum minimization
Simone Rebegoldi, Stefania Bellavia, Natasa Krejic, Benedetta Morini

We propose a novel stochastic first-order trust-region method with function and gradient approximations for solving finite-sum minimization problems. At each iteration, the proposed method approximates the function and the gradient by sampling, employing adaptive sample sizes that may vary from one iteration to the other. The function sample size is computed using a deterministic rule inspired by the inexact restoration method, whereas the gradient sample size can be smaller than the sample size employed in function approximations. The trust-region step is computed by minimizing the corresponding approximate linear model, and it is accepted or rejected according to whether a sufficient decrease condition on a suitable merit function holds or not. We investigate the convergence in probability of this method under some appropriate probabilistic requirements on the gradient estimates. Furthermore, we provide some worst-case complexity results to achieve a certain accuracy in the gradient norm. We also report numerical results on nonconvex binary classification problems, which confirm that the proposed algorithm achieves an adequate accuracy way before the maximum sample size is reached, and without requiring a problem-dependent tuning of the involved parameters.

3 - A line search based proximal stochastic gradient algorithm with dynamical variance reduction
Giorgia Franchini

Many optimization problems arising from machine learning applications can be cast as the minimization of the sum of two functions: the first one is the empirical risk, and the other one imposes a priori information on the solution. Since in general the first term is differentiable and the second one is convex, proximal gradient methods are very well suited to face such optimization problems. However, when dealing with large-scale machine learning issues, the computation of the full gradient of the differentiable term can be prohibitively expensive by making these algorithms unsuitable. For this reason, proximal stochastic gradient methods have been extensively studied in the optimization area in the last decades. In this work we develop a proximal stochastic gradient algorithm which is based on two main ingredients. We indeed combine a proper technique to dynamically reduce the variance of the stochastic gradients along the iterative process with a descent condition in expectation for the objective function, aimed to fix the value for the steplength parameter at each iteration. The practical implementation does not need neither the computation of the exact gradient of the empirical risk during the iterations nor the tuning of an optimal value for the steplength. An extensive numerical experimentation highlights that the proposed approach appears robust with respect to the setting of the hyperparameters and competitive compared to state-of-the-art methods.

4 - On the role of regularization and inexactness in Interior Point Methods: a Proximal Point Perspective
Stefano Cipolla, Jacek Gondzio
Computational evidence suggests that the Primal-Dual Regularization for Interior Point Methods (IPMs) is a successful technique able to stabilize and to speed-up the linear algebra used in IPM implementations. On the other hand, many issues remain open when IPMs are used in their primal-dual regularized form and, in particular, to the best of our knowledge, the known convergence theory requires strong assumptions on the uniform boundedness of the Newton directions. Recently, the study of the interaction of primal-dual regularized IPMs with the Augmented Lagrangian Method and the Proximal Point Algorithm has permitted to prove the convergence when the regularization parameter is driven to zero at a suitable speed. In this talk, we will show that it is possible to naturally frame the primal-dual regularized IPMs in the context of the Proximal Point Algorithm. Among the benefits of the proposed approach, we will show how convergence can be guaranteed without any supplementary assumptions and how the rate of convergence can be explicitly estimated in relation to (fixed) regularization parameters. Moreover, we will show how regularization could be exploited in order to devise suitable preconditioners of the Newton system which are required to be re-computed only in a fraction of the total number of IPM iterations.

■ TC-28

Tuesday, 12:30-14:00 - Y405

Stochastic Models and Optimal Learning

Stream: Stochastic Dynamic Programming and Learning Policies
Invited session
Chair: Flora Spieksma

1 - Addressing the trade-off between optimal cumulative reward and unbiased estimation in sequential experiments
Amin Yarahmadi, Peter Jacko
The standard equal fixed randomisation procedure in the design of experiments leads to unbiased Maximum Likelihood Estimator (MLE) but results in a heavily suboptimal cumulative reward. The standard allocation procedure in the design of sequential experiments obtained by optimisation of the Bayesian multi-armed bandit problem using dynamic programming (DP) achieves the Bayes-optimal cumulative reward, but leads to severely biased MLE. Since the MLE is often applied post-mortem to data obtained from sequential experiments to evaluate the efficacy of interventions, we consider modifications of the multi-armed bandit problem in order to bring the bias of the MLE to zero or to practically acceptable levels. For concreteness, we consider the MLE to estimate the success probabilities from data collected from a finite-horizon Bayesian Beta-Bernoulli two-armed bandit problem with binary responses. We introduce two novel allocation procedures

that mitigate the bias induced by the DP procedure:(i) DP using an augmented estimator, which adds a number of pseudo-successes to the worse-performing intervention, (ii) randomised DP procedure, which perturbs the Bayes-optimal allocation decision with a given probability. Several variants using different values of the tuning parameters in both procedures have been evaluated. The results illustrate the trade-off between reducing the bias in the estimation of efficacy using the MLE and increasing the suboptimality in terms of cumulative reward.

2 - Optimal data driven policies under constrained multi-armed bandit observations
Odysseas Kanavetas, Apostolos Burnetas, Michael Katehakis

After a brief review of the multi-armed bandit (MAB) problem and its online machine learning applications, we present our work on the model with side constraints. The constraints represent circumstances in which bandit activations are restricted by the availability of certain resources that are replenished at a constant rate. We consider the class of feasible uniformly fast (f-UF) convergent policies, that satisfy sample path wise the constraints. We first establish a necessary asymptotic lower bound for the rate of increase of the regret (i.e., loss due to the need to estimate unknown parameters) function of f-UF policies. Then, under pertinent conditions, we establish the existence of asymptotically optimal policies by constructing a class of f-UF policies that achieve this lower bound. We provide the explicit form of such policies for cases in which the unknown distributions are a) Normal with unknown means and known variances, b) Normal distributions with unknown means and unknown variances and c) arbitrary discrete distributions with finite support.

3 - Approximate Dynamic Programming with Adaptive Multivariate Simplex Splines
Maike de Jongh, Richard Boucherie, Aleida Braaksma

Large-scale Markov decision processes (MDPs) typically suffer from the curse of dimensionality, which renders exact solution methods intractable. For such problems, we rely upon approximate dynamic programming (ADP) techniques. A fundamental element of approximate dynamic programming is value function approximation. This research presents a value function approximation architecture that is based on adaptive multivariate simplex splines. Their linearity in the parameters and the fact that they are easily evaluated and adapted on a local basis renders these functions suitable candidates for our purpose. The approximation power of a multivariate simplex spline depends to a great extent on the triangulation on which it is defined. Our main contribution is a procedure that adaptively refines this triangulation in regions of the state space that require a more accurate value function approximation. This procedure is integrated into an ADP framework. The result is a method that can be applied to any MDP with a continuous (or large discrete) state space and finite discrete action space without the need of any preadjustment of the splines based on problem-specific knowledge. The method is tested on two benchmarking problems in the field of approximate dynamic programming. The results indicate that multivariate simplex splines have high potential as value function approximators in an ADP context.

4 - Markov decision processes with a special lumpable structure: server farm optimisation
Flora Spieksma

In this talk we consider a Markov decision process, that can be modelled as a controlled quasi-birth-death process with the following special lumpable structure: the level sets of the quasi-birth-death process each contain one state that is both the entrance state and the exit state of the level set. If the level sets are finite, this structure can be exploited to derive an efficient algorithm that at each iteration computes the optimal policy per level, both for the discounted and average cost optimality criteria.

We will apply this to a server farm optimisation problem, derive some numerical results and discuss some possible extensions.

■ TC-29

Tuesday, 12:30-14:00 - M1

Maintenance

Stream: Industrial Production, Planning and Inventory Management
Invited session
Chair: Halit Metehan Dilaver

1 - An enhanced Bayesian Condition-Based Maintenance policy for industrial equipment subject to non-exponential deterioration.
Dimitris Kampitsis, Sofia Panagiotidou

This study presents a Condition-Based Monitoring and Maintenance (CBM) policy for a single-unit system subject to gradual degradation and catastrophic failures. We adopt a three-state process which is characterized by two different operational states (healthy and unhealthy) and a non-operational state (failure state). The deterioration mechanism is non-Markovian with generally distributed transition times between states. Non-observable shifts to the unhealthy state may randomly occur resulting in lower production revenues and higher proneness to failure. Moreover, failures are self-announced and render the equipment non-operational and, thus, corrective maintenance is directly performed. A Bayesian monitoring scheme is implemented utilizing all available data concerning: (a) the operating state and (b) the equipment's age, in order to re-evaluate the condition of the system, schedule inspections and/or maintenance actions and avoid costly failures. The operation of the system is analytically modeled and the design parameters are economically optimized. An extended numerical investigation is performed to assess the economic effectiveness of the proposed policy and demonstrate its superiority against non-Bayesian approaches.

2 - Planning of rotor blade maintenance processes on onshore wind turbines
Martin Klingebiel, Carolin Kellenbrink

The planning of rotor blade maintenance processes on onshore wind turbines is part of the tactical pre-planning of a maintenance season. The problem is motivated by the case of an international operating onshore wind turbine manufacturer. The aim is to select and schedule the service teams of the service providers and internal teams for the maintenance of rotor blades such that the total costs are minimized and all services are covered. The sequence of the maintenance processes should be planned so that the capacities of the maintenance teams in particular are used in the best possible way, considering the legal, logistical and technical conditions. However, planning such a maintenance season is very challenging. For this reason, we present both a model and a heuristic solution approach for the routing and scheduling of service teams to perform maintenance activities at different locations with minimum total costs. Using real-world data from an onshore wind turbine manufacturer we systematically generated instances and then conducted numerical studies to evaluate and compare the performance of our proposed model and heuristic.

3 - Data Driven Condition Based Maintenance
Ruud Teunter

We consider a deteriorating system of which the level of deterioration is monitored at discrete times. A condition based maintenance (CBM) strategy is applied that maintains the system when the observed level is above some threshold. The objective is to find the threshold that minimizes the expected maintenance cost per time unit, where a corrective maintenance action (after failure) is more expensive than a preventive one. We first present an optimality condition for the threshold under the assumption of complete information on the deterioration process and level. Inspired by that condition, we develop a data driven approach for much more realistic situations without such information, where decisions are directly based on previous observations of the deterioration level and failure occurrences. The results are very encouraging in that the data driven approach quickly converges to the optimal threshold decision even for limited amounts of data.

4 - Integrated Planning of Asset-Use and Dry-Docking for a Fleet of Maritime Assets
Halit Metehan Dilaver, Alp Akcay, Geert-Jan van Houtum
Maritime assets are subject to obligatory inspections that are based on calendar time. These inspections consist of exhaustive operations that need the assets to be towed into specialized facilities referred to as dry-docks. In addition, there are maintenance operations that need to be carried out as a result of usage-related deterioration of the assets, also requiring the assets to be dry-docked. In practice, a common approach is to synchronize these inspection and maintenance operations to avoid unnecessary dry-dockings. However, when and how these operations should be synchronized, and whether synchronizing them is always optimal remain as important questions. Since how an asset is used influences when it requires maintenance, answering these questions requires solving an integrated planning problem that combines the planning of asset-use and the planning of dry-docking for maintenance and calendar-based inspections. Operational constraints such as the locations of assets (i.e. the existence of dedicated assets that must be used at a particular location and flexible assets that can be used in multiple locations), limited dry-docking capacity, and the requirement to meet the demand for asset-use in each location make the problem even more challenging. We formulate this real-life problem as a Mixed Integer Linear Programming model. The resulting optimal policy is compared with a benchmark approach from industry to quantify the benefit of integrated planning.

■ TC-30

Tuesday, 12:30-14:00 - M237

ROADEF/EURO challenge 2022

Stream: ROADEF/EURO Challenge 2022
Invited session
Chair: *Eric Bourreau*

1 - ROADEF/EURO challenge 2022
Eric Bourreau, Safia Kedad-Sidhoum, Alan NGuyen, Mohamed Amine Khatouf, Christian Serrano
The French Operational Research and Decision Support Society (ROADEF) organizes jointly with EURO the ROADEF/EURO challenge 2022. This year the subject is dedicated to "Truck Loading optimization" in collaboration with Renault Group, one of the world's leading car manufacturers. Renault supply chain spans over 40 plants in 17 countries and 1500 suppliers. Every week 6000 trucks deliver parts to the plants where the filling rate of these trucks is critical. The objectives of this challenge is to regroup a set of items into stacks and to pack the stacks into trucks, in order to minimize the number of trucks used and the total inventory cost induced by early deliveries at the destination plants. During this presentation, we will describe competition rules, the optimization problem with its industrial context and constraints. We will also answer questions from the audience. After the presentation, a detailed subject, realistic instances, a solution checker and a 3D solution visualizer will be available online at challenge.roadef.org. An overall amount of 30.000 EUR will be distributed to the best contributions during the competition. Registration is possible until December 2022.

■ TC-31

Tuesday, 12:30-14:00 - M240

Variational analysis and subdifferential calculus

Stream: Variational analysis and optimization
Invited session
Chair: *Marco A. López-Cerdá*
Chair: *Abderrahim Hantoute*

1 - Optimality conditions in convex optimization. An approach based on the subdifferential of the supremum function
Marco A. López-Cerdá

In this talk, different optimality conditions are presented for the convex optimization problem posed in a locally convex space and with an arbitrary number of constraints. One possible approach is to replace the set of constraints by a single constraint involving the function supreme, and appeal to different characterizations of its subdifferential. With a view to this goal, we extend to infinite convex systems two constraint qualifications that are crucial in semi-infinite linear programming. The first, called the Farkas-Minkowski property, is global in nature, while the other is a local property, which is known as the local Farkas-Minkowski property. Different Karush-Kuhn-Tucker (KKT) optimality conditions are then deduced for our optimization problem, both exact and asymptotic in nature, under progressively weaker constraint qualifications.

2 - Closedness under addition for families of quasimonotone operators
Yboon Garcia Ramos

In the last two decades, quasimonotonicity, and more precisely notions between that and monotonicity, have received a great attention by researchers from many areas including mathematical economics, with the goal to develop new tools applicable in convex analysis and related topics. This paper puts in perspective all the notions that are extensions of monotoniticity but not beyond quasimonotonicity like pseudomonotonicity, semistrict quasimonotonicity, strict quasimonotonicity and proper quasimonotonicity, and discusses sistematically when the sum of two operators satisfying one of those notions inherits such a property. We also show some examples showing the optimality in some sense of our results.

3 - Existence results for stochastic optimization problems with decision dependent uncertainty
Anton Svensson, David Salas

We provide existence results for stochastic optimization problems with decision-dependent uncertainty, namely, the minimization of an expected value with respect to distributions that depend on the decision variable. The key property in the analysis is a certain notion of continuity of the set-valued map where the distributions concentrate. We apply our results for the so-called Bayesian approach for bilevel problems.

■ TC-32

Tuesday, 12:30-14:00 - F101

Data Science and Optimisation

Stream: YoungWomen4OR
Invited session
Chair: *Paula Carroll*

1 - Computational methods to deal with complex data
M. Remedios Sillero-Denamiel

Contemporary data are characterized by many variables, different types of variables (quantitative, categorical, clustered), dependence structures among the variables or extreme values (heavy-tailed data). Also, datasets can be characterized by asymmetric conditions (non-identical population classes size, different misclassification costs) where different errors may have different consequences (as happens in the context of medical diagnosis). Complexities can also be caused by the hierarchical structure of the data when, for instance, national statistics need to work with the partition of the country into regions, provinces, municipalities or neighbourhoods; or when a retailing company aims to group their products to be able to predict at the aggregate level. Recently, the complexity of the raw data in addition to new requests posed by practitioners (interpretable models, fair models or models which are efficient in terms of running times or memory demand for prediction) entail a challenge from a scientific and technological perspective. My research bridges the disciplines of Operations Research and Statistics to develop novel computational methods for the extraction of knowledge from the above-mentioned complex data. The main contributions are encompassed in three different research frameworks: Regression, Classification and Bayesian inference.

2 - Optimal Randomized Classification and Regression Trees
Cristina Molero-Río

The impressive advances in hardware and software in the last decades have allowed the development of more powerful versions of classification and regression trees. In this talk, we propose Continuous Optimization formulations and numerical solutions approaches to build optimal classification and regression trees that scale up well with the size of the training sample and are competitive in terms of prediction accuracy against benchmarks. We illustrate how these powerful formulations enhance the flexibility of tree models, being better suited to incorporate desirable properties such as sparsity, cost-sensitivity, explainability, and fairness, and to deal with complex data, such as functional data.

3 - New models and methods for data science via mathematical optimization
Sandra Benítez-Peña

In this talk we present a brief review of new models and methods we have developed to face different data science challenges, focusing particularly in the tasks of Classification, Regression and Benchmarking. With such a purpose, we make use of Optimization and Statistical tools. In order to address the different problems and be able to obtain knowledge from data, we combine instruments from both disciplines. Regarding the task of Classification, we have modelled novel Support Vector Machines (SVM) classifiers capable of managing with different misclassification costs, in which a Feature Selection (FS) can be embedded and that provides probabilistic outputs. From the Regression perspective, we handle specifically the problem of data linkage, since information can be obtained from many sources that contain the same individuals but there is a lack of information about how to merge them. Finally, we move to Benchmarking, in which the main objective is to compare different entities through an efficiency score. Here, our aim is to perform FS, improving interpretability and comprehension of the obtained model and efficiencies. The reported numerical experience on real-world datasets demonstrates that our models overcome those existing ones.

■ TC-33

Tuesday, 12:30-14:00 - F102

Game Theory, Solutions and Structures I

Stream: Game Theory, Solutions and Structures
Invited session
Chair: *Encarnación Algaba*

1 - A characterization of the family of Weighted Priority values
Philippe Solal

We introduce a new family of values for TU-games with a priority structure. This family both contains the Priority value recently introduced by Béal et al. (2021) and the Weighted Shapley values (Kalai Samet, 1987). We provide an axiomatic characterization of the family of the Weighted Shapley values without the additivity axiom. To this end, we borrow the Priority agent out axiom from Béal et al. (2021), which is used to axiomatize the Priority value. We also reuse, in our domain, the principle of Super weak differential marginality introduced by Casajus (2018) to axiomatize the positively weighted Shapley values. We add a new axiom of Independence of null agent position which indicates that the position of a null agent in the partial order does not affect the payoff of the other agents. Together with Efficiency, the above axioms characterize the Weighted Shapley values. Finally, we show that this axiomatic characterization holds on the subdomain where the partial order is structured by levels. From this follows an alternative characterization of the Weighted Shapley values.

2 - Ewens distribution, potential, and value for games with externalities
André Casajus, Yukihiko Funaki, Frank Huettner

We show that the potential of the Shapley value for TU games is the expected worth of a unique conditionally independent random partition, the Ewens distribution (with mutation rate 1). The same expected worth is a natural candidate for a generalization of the potential to cooperative games with externalities (TUX games). Indeed, there exists a restriction operator (that is, a notion of how to derive subgames in the presence of externalities) such that the aforementioned candidate actually is a potential for TUX games. This restriction operator is unique if it preserves null games. A player's contribution to this potential turns out to be the average Shapley value introduced by Macho-Stadler et al. (2007, J. Econ. Theory 135, 339-356). All in all, the average Shapley value is the only generalization of the Shapley value to TUX games that derives naturally from a potential that equals the expected worth of a conditionally independent random partition.

3 - TU-Games with Utility: The Core
Miklós Pintér, Zsófia Dornai

A generalization of the core - the u-core - can be defined by using the so-called utility function on the excesses and the coalitions. A special case for this is the per-capita core, where the utility function is the function which divides the excess by the cardinality of the coalition. We provide a Bondareva-Shapley theorem for u-core, that is, we introduce the notion of u-balancedness, and show that the u-core of a game is not empty if and only if the game is u-balanced.

4 - On cycle-free communication networks
Encarnación Algaba, Rene van den Brink

Communication networks are well known in the literature, we analyze the properties which characterize them, in fact, the feature of communication plays an important role in real-world networks. Namely, we pay special attention to the class of cycle-free communication networks.

■ TC-34

Tuesday, 12:30-14:00 - T003

Transportation and Logistics

Stream: Smart Mobility and Logistics
Invited session
Chair: *Ozge Safak*

1 - How to manage e-grocery demand through greener solutions
Nursen Aydin, Gokce Kahvecioglu, Merve Keskin

The COVID-19 crisis has fundamentally changed how, when, and where consumers shop and what they buy. Online shopping has become more important than ever, including grocery shopping. The growth in e-grocery market increases transport related problems such as air pollution and congestion. Due to the complexity of the service, uncoordinated vehicles can visit the same area several times, increasing the delivery costs as well as the negative impact on the environment. In this study, we focus on the vehicle routing problem in e-grocery setting considering the environmental impact. Our goal is to quantify the environmental footprint of grocery home delivery services given the growth of this sector.

2 - A simulation-optimisation model for COVID-19 vaccine supply
Ramez Kian, Sander De Leeuw, Saeed Taheri, Gunes Erdogan

In this study we investigate the COVID-19 vaccine dispatch and distribution in a periodic basis. One of the operational challenges of vaccination is its inventory level which depend on number of people register and show up in different vaccine centres. The stochastic nature of demand especially for walk-in centres necessitates a periodic replenishment programme which encompasses a logistics operation. Thus, we use a simulation-optimisation model to optimise the cost and waste. The simulation part tackles the effect of policies and prioritisations on demand, while the optimisation part deals with the routing. A numerical study is provided to compare different scenarios.

3 - Smart locker sharing model for e-commerce logistics service providers
Anthony Pang

With the vigorous development of the economy and Internet, more and more consumers choose to shop online, and people's demand for e-commerce activities increases. Logistics companies are focusing on enhancing the operations efficiency of their last-mile delivery. It is said that being efficient in last-mile delivery by using the smart locker will bring different functional, emotional, social, and financial customer values. The use of a smart locker provides flexibility to customers on the pickup time of their ordered items because they might not be available to receive the items by door-to-door service. Also, the logistics companies can save the operating cost by delivering multiple items to one location of the smart lockers instead of delivering to multiple customer locations for their door to door service.

In this research, we develop a smart locker sharing model in which the market has two logistics companies providing delivery services for e-commerce orders. One company owns some smart lockers for their delivery service, while the other has no assets. Without sharing, the latter company has to provide the door-to-door service with higher logistics costs. This model determines the locker rental price and rental quantity agreeable by these two companies. As a result, both companies will benefit, and the total supply chain profit could be maximized. Results show that sharing resources among two competing logistics companies would offer mutual benefits to both parties;

4 - A two-stage decision dependent stochastic approach for airline flight network expansion
Ozge Safak, Ozlem Cavus, Selim Aktürk M.

Airlines need to expand their flight networks with developing new routes and introducing more flights to increase their market share. In this work, we propose a two-stage stochastic mixed integer nonlinear program (MINLP), which expands an existing flight schedule by operating new flights either with existing fleet resources or a leased aircraft while considering the impact of departure time decisions on the probability distribution of random demand. Moreover, our study helps an airline to link a strategic decision of leasing an aircraft to the tactical aircraft assignment decisions by considering fuel efficiency and seat capacity of the aircraft alternatives in response to new passenger demand. However, the large number of scenarios, nonlinear fuel burn function and nonlinearities due to the decision dependent probabilities become main challenges of solving the problem. In order to deal with the computational requirements of a two-stage stochastic MINLP with decision dependent probabilities, we propose strong conic quadratic and McCormick inequalities, and an exact scenario group wise decomposition algorithm along with a new bounding method. In our computational results, we clearly demonstrate the effectiveness of proposed decomposition algorithm and the strength of the reformulations.

■ TC-35

Tuesday, 12:30-14:00 - T004

Impacts of future mobility trends

Stream: Transportation
Invited session
Chair: *Flore Vancompernolle Vromman*

1 - Operations for free floating bike sharing systems - A literature review
Flore Vancompernolle Vromman, Jean-Sébastien Tancrez, Mathieu Van Vyve

In line with the rise of the sharing economy as well as sustainability concerns, new means of collaborative transportation have emerged. Among them, bike sharing systems offer a convenient way to realize last-mile trips. At first, the station-based bike sharing system (SBBSS) appeared. With SBBSS, several stations are spread within the city where users can pick up and drop bikes. Recently, the free-floating bike sharing system (FFBSS) has been developed thanks to the built-in Global Positioning System allowing to track bikes in real-time. Users can find the closest bike available in the city thanks to an app on their phones, rent it, realize their trip, and lock the bike where they want in the city. FFBSS offers more flexibility to users but brings some operational challenges, such as disorderly parking and the need for frequent redistribution of bikes.

We review the literature on the operations of FFBSS by tackling three main subjects. The first one focuses on discretizing the bike locations by dividing the geographical area where a FFBSS is active into zones. This operation is necessary because the number of bike locations is higher with FFBSS than SBBSS. The second subject consists in forecasting the rentals' demand in each zone. The last topic focuses on redistribution models, consisting in maintaining a desired quantity of bikes at each zone by moving bikes from one place to another. Based on this literature review, we suggest future research about FFBSS operations.

2 - An exact solution approach for an electric bus dispatch problem
Mathias Klapp, Matías Alvo, Gustavo Angulo

We study how to efficiently plan a bus dispatch operation within a public transport terminal working with a mixed fleet of electric and diesel buses and a restricted number of chargers. To meet the daily trip demand, the terminal dispatcher has to assign a trip schedule and a battery charge plan to each bus and also feasibly sequence charging tasks at each charger. We model this problem as an extension of the Vehicle Scheduling Problem, which we later reformulate via a Benders' type decomposition approach into two sub–problems; (1) a master problem assigning bus trip schedules and (2) a satellite problem sequencing charging tasks for a given set of bus trip schedules. Our exact decomposition approach dynamically injects feasibility cuts into the branch–and–bound tree to remove bus trip schedules leading to an infeasible bus charging operation. We assess the effectiveness of our approach and its advantage over a single–stage model in computational experiments inspired by a bus operator from Santiago, Chile. Finally, we provide several managerial insights for planners such as the marginal benefit per additional charger or electric bus and the value added by a mixed fleet compared to a pure electric one.

3 - Powertrain hybridization of a vessel that visits Chilean scientific bases located on the Antarctic Ocean
Dagoberto Cifuentes, Lorena Pradenas

The Antarctic Treaty, signed in 1959, promotes the use of Antarctica for scientific research and cooperation between different countries. Scientific research in Antarctica plays an important role in the study of several disciplines, including biotechnology, geosciences, climate change, human behavior, social sciences, among others. Chile owns 10 scientific bases on the Antarctic territory, managed by the Chilean Antarctic Institute (INACH). INACH also manages a laboratory vessel (named Karpuj) that visits these bases; carrying researchers, supplies, and scientific equipment. However, the main drawback is that Karpuj is powered by diesel, potentially dangerous to the fragile Antarctic environment. During the last few decades, researchers and manufacturers have been developing hybrid powertrains for ships, attempting to increase their efficiency and reduce carbon emissions. These hybrid powertrains use an internal combustion engine that uses fossil fuels, and an electric motor powered by renewable energy sources, such as biofuels, hydrogen, solar, and wind power. We propose a hybridization of Karpuj's powertrain; thus reducing the need for diesel, and propelling the vessel with an electric motor powered solely with renewable energy sources. We also propose an algorithm based on Dynamic Programming, for the energy management optimization of the powertrain. Minimizing the recharging time of the electric energy storage in the bases by increasing the operating range.

4 - A Robust Optimisation Model for Integrated Vehicle and Crew Scheduling Based on the Uncertainty in the Main Inputs
Liping Ge, Abtin Nourmohammadzadeh, Stefan Voss, Lin Xie

Integrated vehicle and crew scheduling has attracted considerable interest in the last decades especially in the airline industry and in public transport. Mathematical programming approaches have been provided being able to incorporate various types of richness. In this work, while focusing on public transport, we assume that the input data of the problem is not deterministic, and a set of scenarios is considered for their values. One of the uncertain inputs gaining importance, especially when considering electric buses, is the number of available vehicles (depending on the battery, driving skills, temperature etc.). A (robust) mathematical optimisation model is presented accordingly. Two types of uncertainty arise, i.e., we assume uncertain input data being reflected in a given objective function as well as uncertainty in the number of available vehicles reflected as parameter on the right-hand side of the model. The practical importance comes from the fact that we do not yet know enough about the use of electric vehicles and their impact in scheduling problems. The theoretical importance comes from the discussion whether uncertainty sets regarding right-hand-side parameters are meaningful and can contribute towards model richness. Finally, our modelling attempts also shed lights on various aspects of revisiting mathematical models with extended tools and computing infrastructure.

■ TC-36

Tuesday, 12:30-14:00 - U006

Covid19 - Containment measures

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: Andrea Seidl

1 - A flexible rolling regression framework for the identification of time-varying SIRD models
Javier Rubio-Herrero, Yuchen Wang

Based on a time-varying susceptible-infected-recovered-deceased (SIRD) model, we introduce the problem of identifying the dynamics of an epidemic as a mixed integer nonlinear bilevel optimization problem in which a series of rolling regressions is embedded. The system identification takes place using existing data and we use our framework to determine the time series of the parameters of the SIRD model as well as the proportion of undetected infected, recovered, and deceased, such that this identification is as accurate as possible.

Our framework is tested with 2020 COVID-19 data from Minnesota (USA) and our results are analyzed under the light of previous research. Opportunities for improvement are also discussed.

2 - Reducing disease spread through optimization: Limiting mixture of the population is more important than limiting group sizes
Rowan Hoogervorst, Niels-Christian Bagger, Evelien van der Hurk, David Pisinger

One of the most efficient tools for limiting the disease spread during a pandemic is to limit the contacts between people. However, too strict restrictions may seriously affect the economy, health, education, and well-being of people. Hence, we will study in this talk the use of individualized strategies instead of uniform restrictions for the organisation of activities that include close contacts. Concretely, we will look at how to schedule a set of activities where the participants meet, and hence can spread infection. Those could be classroom teaching, sports activities, work shifts, etc. Formulating the contacts resulting from the assignment of participants to scheduled activities as a graph, we propose to search for graph structures that limit the disease spread. We develop a mathematical algorithm for identifying such favourable graphs by limiting the distinct contacts the individuals meet during an activity. The quality of a contact graph is evaluated using an agent-based model where individual disease progress is defined according to the so-called SEIR (Susceptible, Exposed, Infectious or Removed) model. We will explore the ability of this algorithm to limit the spread of a disease under several realistic setups by means of a computational study targeted towards the re-opening of physical lecturing at a major university, using real-life data from a course database.

3 - Allocating tests and lockdowns to contain pandemic spread and medical overload within a network
Michael Freiberger, Dieter Grass, Michael Kuhn, Andrea Seidl, Stefan Wrzaczek

During the COVID-19 pandemic countries invested significant amounts of resources into its containment. In early stages of the pandemic most of the (non-pharmaceutical) interventions can be classified into two groups: (i) testing and identification of infected individuals, (ii) social distancing measures to reduce the transmission probabilities. Furthermore, both groups of measures may, in principle, be targeted at certain sub-groups of a networked population. To study such a problem, we propose an extension of the SIR model with additional compartments for quarantine and different courses of the disease across several network nodes. We develop the structure of the optimal allocation and study a numerical example of three symmetric regions that are subject to an asymmetric progression of the disease (starting from an initial hotspot). Key findings include that (i) for our calibrations policies are chosen in a "flattening-the-curve", avoiding hospital congestion; (ii) policies shift from containing spillovers from the hotspot initially to establishing a symmetric pattern of the disease; and (iii) testing that can be effectively targeted allows to reduce substantially the duration of the disease, hospital congestion and the total cost, both in terms of lives lost and economic costs.

■ TC-37

Tuesday, 12:30-14:00 - V001

Green Vehicle Routing

Stream: Vehicle Routing and Logistics
Invited session
Chair: Emrah Demir

1 - A Two-echelon Time-dependent Green Location-Routing Problem
Saba Siadati, Virginie Lurkin, Tom van Woensel

In a location-routing problem, the interdependency of facility location and vehicle routing is considered, and consequently, it avoids sub-optimal solutions to the logistics and transportation design and planning. In this study, we formulate and solve a two-echelon time-dependent green location-routing problem (2E-TDGLRP) in which the optimal location of intermediate hubs within a set of candidate locations, as well as the routing of vehicles, are to be determined simultaneously by minimizing the economic and environmental costs. We consider the economic cost as the investment cost of facilities and vehicles and the drivers' wage in this problem. The environmental cost is deemed based on the GHGs emitted by the delivery vehicles, which is calculated using a comprehensive modal emission model (CMEM). Another novelty of our model lies in explicitly considering the effect of traffic congestion on travel times by assuming time-dependent speed functions. We develop a mixed-integer linear programming formulation of 2E-TDGLRP. We solve the problem exactly using the Gurobi solver for several small instances. We then present an efficient heuristic algorithm to solve larger instances. Our results show the validity of our mathematical model and allow us to analyze the effect of considering time-dependent travel times in the green location-routing problem.

2 - The Pollution-Routing Problem with Speed Optimization and Uneven Topography
David Lai, Yasel Costa, Emrah Demir, Alexandre Florio, Tom van Woensel

This paper considers a joint pollution-routing with time windows and speed optimization problem (PRP-SO) where fuel costs and CO2e emissions depend on the vehicle speed, arc payloads, and road grades. We present two methods, one approximate and one exact, for solving the PRP-SO. The approximate strategy solves large-scale instances of the problem with a tabu search-based metaheuristic coupled with an efficient fixed-sequence speed optimization algorithm. The second strategy consists of a tailored branch-and-price (BP) algorithm in which speed optimization is managed within the pricing problem. We test both methods on modified Solomon benchmarks and newly constructed real-life instance sets. Our BP algorithm solves most instances with up to 50 customers and many instances with 75 and 100 customers. The heuristic is able to find near-optimal solutions to all instances and requires less than one minute of computational time per instance. Results on real-world instances suggest several managerial insights. First, fuel savings of up to 53% are realized when explicitly taking into account arc payloads and road grades. Second, fuel savings and emissions reduction are also achieved by scheduling uphill customers later along the routes. Lastly, we show that ignoring elevation information when planning routes leads to highly inaccurate fuel consumption estimates.

3 - The adoption of autonomous assistants in route optimization
Emrah Demir, Cheng Chen

Last mile logistics is an essential service for people of all ages. As e-commerce activities and number of online buyers are growing rapidly in urban areas, logistics service providers (LSPs) need to consider alternative and greener delivery solutions to cope with the demand. Thanks to developments in automation and robotic technologies, LSPs can promote autonomous technologies (i.e., drones and delivery robots) in their daily operations. This research investigates how autonomous technologies, compared with the traditional delivery van service, can help LSPs to make their last mile operations more efficient, and greener.

Based on the concept that small autonomous delivery assistants are used with delivery vans, several related routing problems have already been investigated in the literature. We extend the standard vehicle routing problem arising in the delivery operations using integrated vehicles for more general conditions. We define a new vehicle routing problem with autonomous assistants and propose a hybrid metaheuristic algorithm. The proposed hybrid algorithm combines the well-known genetic algorithm and large neighborhood search algorithm for the newly introduced routing problem. Extensive computational results compare different technologies and provide useful insights for the logistics industry.

■ TC-38
Tuesday, 12:30-14:00 - V002

Shared Mobility I

Stream: Shared Mobility
Invited session
Chair: Masoud Golalikhani

1 - Pricing strategy for ridesharing services
Wee Meng Yeo

This paper focuses on pricing for a novel demand responsive transport model, designed to tackle lack of transportation access in big towns and small cities within UK. Our work is based on understanding the willingness-to-pay for services of an innovative partnership-driven business model. We tested price sensitivities of drivers and non-drivers in both sample populations to determine at what price point would a new service model be of interest to enough users to generate revenue for the operator.

2 - Block Now or Relocate Later? Availability Control of Short-Term Rentals in Shared Mobility Systems Considering Long-Term Rental Reservations
Matthias Soppert, Armin Wagemann, Claudius Steinhardt

Shared mobility system providers traditionally offer spontaneous and flexible short-term rentals of vehicles such as cars or bikes. However, most recently, Europe's largest free-floating car sharing provider Share Now started to extend the mobility service portfolio by offering customers to reserve long-term rentals several days in advance, including the choice of departure location and time. For the customer, these reservations now allow to plan trips with a reliable vehicle availability guarantee. For the provider, this comes along with novel challenges regarding the operational control. To ensure the vehicle availability at a reservation's desired location and time, the provider has two options in principle: Either, a suitable available vehicle which is located adequately can be blocked before the required time such that it becomes unavailable for spontaneous short-term rentals, or, a vehicle is relocated on short-notice to the required location. The first option can cause lost profits due to missed short-term rentals while the second causes relocation cost. We formulate the provider's profit maximizing dynamic problem of controlling vehicle availability for short-term rentals under the consideration of given long-term rental reservations. Based on analytical thoughts that reveal parallels to classical overbooking problems, we derive the optimal policy as well as two heuristics that require fewer parameters regarding the dynamics of the system.

3 - Attraction model for designing fare structures in public transport
Reena Urban, Philine Schiewe, Anita Schöbel

When designing a fare structure for public transport, often the revenue is considered as it is relevant for covering the costs. Also, based on the concept of sustainability, the objective of attracting demand and increasing the share of sustainable transport modes is becoming more and more important. Combining these ideas, we propose a new model with two groups of passengers: those that rely on public transport (captive passengers) and those that have other options like a car (choice passengers). Based on the specified price, people use or do not use public transport. We consider the bi-objective optimization problem of determining a fare structure maximizing both the revenue and the number of attracted passengers. As a starting point, we determine a price for every origin-destination pair. We show NP-completeness of the proposed tariff attraction model. Further, we examine the set of efficient solutions depending on the input data. We determine a finite dominating set for the efficient solutions and analyze the structure of the Pareto front. We use the results to provide algorithms for finding efficient solutions.

4 - Optimizing realistic pricing plans for one-way carsharing systems
Masoud Golalikhani, Beatriz Brito Oliveira, José Fernando Oliveira, Maria Antónia Carravilla

In the one-way carsharing systems, users can access a fleet of shared cars on a short-term, as-needed basis and are not required to return cars to their origins. The carsharing operators (CSOs) usually offer several pricing plans with different attributes (e.g., registration, travel distance, and rental time fees), and customers must choose one of the plans to become a user of the system. Despite the attractiveness of one-way services, the uneven nature of users' demand may lead to complexities affecting system performance. To tackle this, pricing decisions can be used as a promising means of controlling the interactions between demand and supply to increase the CSOs' profitability. However, to our knowledge, no study has been conducted to design realistic plans with different attributes that can be applied in a business environment. Moreover, most works assume that each CSO offers a single plan for homogeneous users, while in reality, heterogeneous groups of customers use the system and differ in their preferences for various types of plans according to their travel patterns. Hence, we aim to develop a model to design the optimal combination of plans with realistic attributes competing to capture those segments of customers that maximize CSOs' profit. To this end, we analyze customers' travel patterns and spatial-temporal factors that may affect the demand and identify specific customer segments whose preferences are incorporated in the model through discrete choice methods.

■ TC-39
Tuesday, 12:30-14:00 - U8

MAI: Ethical challenges in everyday practice

Stream: Making an Impact
Invited session
Chair: Alec Morton
Chair: Ruth Kaufman

1 - Our moral compass: integrating ethics into everyday OR practice
Ruth Kaufman, Alec Morton

"Practising ethically" means knowing what is the right thing to do, and doing it. This is easy to say, and much of the time it is easy to apply. But in the hurly-burly of every-day professional life, we are continually making compromises between 'the best' and 'the feasible'. Sooner or later we come up against grey areas where we may disagree with colleagues about what is right, or where our personal ethical values conflict with each other, or where we realise too late that we should have made a different choice. The purpose of this session is to enable participants to reflect on ethical challenges in their own professional life; to learn from the ethical challenges experienced by others and how others have dealt with them; and to think about whether and how a code of conduct and/or other support/training mechanisms might be useful to them and their teams.

The session will start with a brief discussion of practical situations where ethical challenges occur. This will be followed by a summary of previous work on ethics in OR, a review of the codes of ethics that different organisations have introduced, and discussion of how ethics codes might benefit OR professionals. We will then break into small groups to discuss actual experiences of ethical dilemmas, before returning to plenary to review. Note: this session will not explore the ethics of choosing particular application areas of OR, but focus on ethical practice whatever the application area (within the law).

Tuesday, 14:30-16:00

■ TD-01
Tuesday, 14:30-16:00 - A

Martin Schmidt

Stream: Keynotes
Keynote session
Chair: Arie Koster

1 - Recent algorithmic advances in bilevel optimization
Martin Schmidt

Bilevel optimization is a wonderful area of mathematical optimization. There are at least two reasons. First, bilevel optimization problems today serve as a powerful modeling tool to formalize hierarchical decision making processes. This leads to an enormous amount of applications ranging from energy markets or machine learning over pricing problems in revenue management to critical infrastructure defense or anti-poaching problems. Second, bilevel problems are inherently nonconvex and thus hard to solve both in theory and practice. What might sound as a disadvantage of the field at a first glance, in the end lead to a growing number of researchers that study theoretical well-posedness issues, equivalent reformulations, or effective solution methods.

The increasing number of applications also lead to more and more challenging classes of bilevel problems that emerged over the last years and decades. Without any specific chronological order, these challenges are given by mixed-integer aspects, continuous but nonlinear nonconvexities, or even black-box constraints that all particularly increase the hardness of the overall bilevel problem if they are part of the lower level.

In this talk, we give an overview of the developments of the area with a focus both on the above mentioned challenges as well on the algorithmic advancements in the corresponding fields. In particular, we focus on mixed-integer and continuous but nonlinear aspects.

■ TD-03
Tuesday, 14:30-16:00 - C

Synergies: Learning for and with Optimization

Stream: Machine Learning and Mathematical Optimization
Invited session
Chair: Gabriele Iommazzo
Chair: Andrea Lodi

1 - Deep Neural Networks pruning via the Structured Perspective Regularization
Matteo Cacciola, Antonio Frangioni, Andrea Lodi

In Machine Learning, Artificial Neural Networks (ANNs) are a very powerful tool, broadly used in many applications. Often, the selected (deep) architectures include many layers, and therefore a large amount of parameters, which makes training, storage and inference expensive. This motivated a stream of research about compressing the original networks into smaller ones without excessively sacrificing performances. Among the many proposed compression approaches, one of the most popular is "pruning", whereby entire elements of the ANN (links, nodes, channels, ...) and the corresponding weights are deleted. Since the nature of the problem is inherently combinatorial (what elements to prune and what not), we propose a new pruning method based on Operational Research tools. We start from a natural Mixed-Integer-Programming model for the problem, and we use the Perspective Reformulation technique to strengthen its continuous relaxation. Projecting away the indicator variables from this reformulation yields a new regularization term, which we call the Structured Perspective Regularization, that leads to structured pruning of the initial architecture. We test our method on some ResNet architectures applied to CIFAR-10, CIFAR-100 and ImageNet datasets, obtaining competitive performances w.r.t. the state of the art for structured pruning

2 - Learning heuristics for A*
Danilo Numeroso, Petar Veličković, Davide Bacciu

Path finding in graphs is one of the most studied classes of problems in computer science and operations research. In this context, search algorithms are used to find paths from sources to target nodes optimising specific and desired properties, e.g. cost of the path. Optimal algorithms, e.g. Dijkstra / Bellman-Ford, rely on an extensive evaluation of each node in the graph, which might be prohibitive for large instances. As a consequence, in many domains, e.g. Robotics, search algorithms are often equipped with hand-crafted heuristic functions for a more efficient search of target nodes. However, manually constructing heuristics requires domain knowledge, and their design process is often prone to heavy trial-and-error phases. Therefore, in this work we target learning of efficient heuristic functions for arbitrary graphs in order to speed up the execution of search algorithms for path finding problems. Specifically, we combine recent advancements in Neural Algorithmic Reasoning and Deep Learning for Graphs. At training time, we exploit multi-task learning to learn jointly the Dijkstra's algorithm and a consistent heuristic function for the A* search algorithm. At inference time, we plug our learnt heuristics into the A* algorithm. Results show that running A* over the learnt heuristics value can greatly speed up target node searching compared to Dijkstra, while still finding minimal-cost paths.

3 - Learning for Spatial Branching: An Algorithm Selection Approach
Ignacio Gómez-Casares, Bissan Ghaddar, Julio González-Díaz, Brais González Rodríguez, Beatriz Pateiro-López, Sofía Rodríguez-Ballesteros

The use of machine learning techniques to improve the performance of branch-and-bound optimization algorithms is a very active area in the context of mixed integer linear problems, but little has been done for non-linear optimization. To bridge this gap, we develop a learning framework for spatial branching and show its efficacy in the context of the Reformulation-Linearization Technique for polynomial optimization problems. The proposed learning is performed offline, based on instance-specific features and with no computational overhead when solving new instances. Novel graph-based features are introduced, which turn out to play an important role for the learning. Experiments on different benchmark instances from the literature show that the learning-based branching rule significantly outperforms the standard rules.

4 - Predict and Optimize: Through the Lens of Learning to Rank
Jayanta Mandi, Victor Bucarey, Maxime Mulamba, Tias Guns

Combinatorial optimization is one of the key tools to solving decision problems. However, in many applications the decision problems are expressed by partially defined optimization problems as some parameters are not specified. In order to predict these parameters, predict-and-optimize approaches integrate optimization and machine learning (ML) by training ML models from correlated feature variables considering the quality of the decisions obtained by predicted parameters. What stands in the way of applying predict-and-optimize approach in large scale combinatorial problems, is the fact that the optimization problem must be solved and differentiated for each training instances on each training epochs. In our earlier work, we proposed an approach motivated by noise-contrastive estimation, where we introduced a new family of surrogate loss functions considering non-optimal feasible solutions as negative examples. In this work, we argue that predict-and-optimize approach can be more generally viewed through the lens of learning to rank approach. We formulate the predict-and-optimize as a ranking problem and we propose pointwise, pairwise and listwise ranking loss functions to learn the partial ordering of the feasible solutions as induced by the objective function. As a result, we need solve the combinatorial problems repeatedly during training. We empirically validate that the performance of the proposed loss functions are comparable to the state of the art.

■ TD-04

Tuesday, 14:30-16:00 - D

Data driven decision making in OR

Stream: Machine Learning and Mathematical Optimization
Invited session
Chair: Victor Bucarey

1 - Probability estimation and structured output prediction for learning preferences in last mile delivery
Rocsildes Canoy, Victor Bucarey, Maxime Mulamba, Yves Molenbruch, Jayanta Mandi, Tias Guns

We study the problem of learning the preferences of drivers and planners in last mile delivery. Given a data set containing historical decisions and delivery locations, the goal is to capture the implicit preferences of the decision-makers. We consider two ways to use the historical data: one is through a probability estimation method that learns transition probabilities between stops (or zones). This is a fast and accurate method, recently studied in a VRP setting. Furthermore, we explore the use of machine learning to infer how to balance multiple objectives such as distance, probability and penalties. Specifically, we cast the learning problem as a structured output prediction problem, where training is done by repeatedly calling the TSP solver. Another aspect we consider is that for last-mile delivery, every address is a potential client and hence the data is sparse. Hence, we propose a two-stage approach that first learns preferences at the zone level in order to compute a zone routing; after which a penalty-based TSP computes the stop routing. Results show that the zone transition probability estimation performs well, and that the structured output prediction learning can improve the results. We hence showcase a combination of both probability estimation and machine learning, all the while using standard TSP solvers, both during learning and to compute the final solution; this means the methodology is applicable to other real-life TSP variants or proprietary solvers.

2 - A Support Vector approach to create smart rules as constraints for robust pricing optimization
Luis Aburto

The problem of multi-product price optimization has been approached via various methods, mainly via estimation of econometric models based on own-price and cross elasticity. When using these models in an optimization framework, the results obtained are often extreme and unreliable solutions for business. The objective of this project is to use supervised machine learning models such as Support Vector Machines(SVM)to estimate interpretable hyperplanes or rules in the Price attributes space, to be used as restrictions in the price optimization problem. These rules are defined as the hyperplanes which restrict the price space where sales/profit scenarios better than the average are observed. By evaluating the method on different categories, we obtain more robust solutions, reducing price optimization from 1000% (using simple restrictions) to 34%. These results not only facilitate having more robust solutions but also provide important insights regarding expected sales when certain price scenarios exist among products in the category.

3 - Contrastive Losses and Solution Caching for Predict-and-Optimize
Maxime Mulamba, Jayanta Mandi, Michelangelo Diligenti, Michele Lombardi, Victor Bucarey, Tias Guns

Numerous real-life decision-making processes involve solving a discrete optimization problem with uncertain costs in the objective that can be estimated from available data.

Recently, end-to-end approaches successfully addressed this class of problems. However, they require to solve the optimization problem for each training instance in each epoch, which is computationally expensive even in the case of continuous approximations.

We provide two distinct contributions. First we motivate a new solver-agnostic method for decision-focused learning based on Noise Contrastive Estimation. Namely, we define a contrastive loss by considering a set of non-optimal feasible solution as negative examples. Negative samples come from preemptively solving other instances in the data and caching their solution. We design several variants of such loss for discrete problems with linear objectives. Second, We interpret this set as an inner approximation of the full feasible space, which allow to replace optimizations calls by a lookup through the cache. We empirically show that by re-solving only a fraction of the training instances each training iteration, our method performs on par with the state of the art whilst drastically reducing the time spent solving. The method provides an explicit tradeoff between training time and accuracy of the approximate loss.

4 - Labor planning and shift scheduling in retail stores using customer traffic data

Victor Bucarey

Labor costs are one of the largest expenses of retail companies. This work develops a decision tool to manage staffing levels and schedule working shifts, balancing the sales contribution of employees with salary costs. We extend recent empirical studies that estimate the impact of staffing levels on sales, combining detailed sales transactions and hourly customer traffic with employee staffing data. The empirical strategy uses exogenous deviations between the planned and actual schedule to identify the causal effect of staffing on conversion rates and basket value. This empirical model combined with traffic forecasting models is used as an input to a scheduling algorithm that optimizes the workforce schedule by balancing revenues with employee salaries, providing a feasible and detailed specification of working shifts that complies with labor regulations and other practical constraints. We also propose a robust optimization model to face uncertainties coming from parameter estimation. The methodology is tested using real data from a retail chain in Latin America. The results suggest that most stores are understaffed during the weekends and at the same time overstaffed during lunch hours on weekdays, which is in part explained by the reduced flexibility imposed by regulatory restrictions for full-time workers. Finally, by using a robust approach we find staffing plans that produce less variance in the outcomes without losing too much in terms of expected revenue

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■ TD-05

Tuesday, 14:30-16:00 - E

Better Decisions with Data

Stream: Data Science Meets Optimization
Invited session
Chair: Patrick De Causmaecker

1 - Investigating parallel implementations of genetic algorithms in stochastic part-of-speech tagging

Shimanto Rahman

This paper aims to provide a comprehensive benchmark of the performance and speed of parallel architectures of genetic algorithms compared to serial architectures. In particular, four different popular configurations of genetic algorithms are discussed: a panmictic, a distributed, a circularly linked cellular, and a toroidally linked cellular design. The genetic algorithms are evaluated on a variety of popular corpora (i.e., Penn Treebank, Brown, and Susanne) in stochastic part-of-speech tagging. Preliminary results show that on the universal tag set the cellular genetic algorithms achieve superior performance in token, unknown words, and sentence accuracy. Particularly the circularly linked cellular genetic algorithms converge quicker to a (local) optimum. Parallel genetic algorithms are considerably more robust against unknown words compared to more traditional optimization algorithms used in Hidden Markov Models. Compared to previous benchmark studies in the same area, our study examines a wider range of data sets, a more comprehensive set of performance measures, and a more extensive set of parallel architectures.

2 - Product range optimization using geo-spatial data

Ondřej Sokol

The choice of store location is a fundamental, essentially irreversible decision that largely affects the profitability of the store. Luxury locations have expensive rent but in turn guarantee that the store is in plain sight and can attract more customers. Optimization, therefore, is about weighing the benefits of the location against the costs, such as rent. The benefit of the location is dependent on the range of goods offered – and therefore the structure of the products offered should be optimized with respect to the location. It seems natural that a store in a historic city centre will have a significantly higher proportion of small purchases of premium goods than a store on the periphery of the city with an adjacent car park. In this presentation, we focus on the decision-making process of retail chains, specifically interested in how the appropriate product range could be estimated using public and readily available location-specific proxy variables fused with the sales data. The resulting insights allows us to evaluate the benefits of location.

3 - A Reinforcement Learning and Monte Carlo Tree Search Approach for Data-Driven Supply Chain Management

Felipe Maldonado, Florian Antoni

Efficient supply chain management is a key success factor in today's increasingly interconnected world, with huge financial implications for many companies. Developing a good data-driven ordering policy is an essential task, especially when optimal strategies are unknown. In this research, we implement a Monte Carlo Tree Search (MCTS) method for deciding order quantities in supply chains with imperfect information. By using asymmetric decision trees, this strategy is able to circumvent the "Curse of dimensionality", which prevents the application of many simpler methods in realistic environments with a large number of possible states. To capture the decentralised decision-makers the problem is modeled as a Partially Observable Markov Decision Process, and MCTS algorithms tailored to the problem are developed to test their general applicability. In our experiments in which the artificial intelligence controls the wholesaler, significant cost reductions can be achieved in comparison to cases where the agent acts human-like. A comparison with the base-stock policy and other state-of-the- art Reinforcement Learning methods demonstrates that MCTS is similarly effective in most scenarios and in some cases even shows significant advantages. Experiments with the adapted versions of the algorithm further indicate that additional improvements in effectiveness are possible, especially by extending the exploration time, and by dynamically adapting the space of explored actions.

4 - A parallel neural network model to predict molecular parameters from astronomical emission lines with linear speedup

Mauricio Solar

Given that astronomical spectra can be modelled from their underlying physical parameters, it should be possible to predict those parameters using a regression model. In this work, we use several neural networks which take information from the spectrum as an input. Whilst even simple radiative transfer models require several parameters, we consider only two representative parameters: column density and excitation temperature. The column density is an important quantity as it is a measure of how much of a species is present towards an object. The intensity of a line approximately scales with the column density when lines are optically thin. The excitation temperature reflects the relative population of energy levels of a molecule (e.g., following a Boltzmann distribution at local thermal equilibrium) and helps to characterize the conditions of the gas. It primarily determines the relative line intensity among the transitions of a given species. This proposal suggests the use of a feed-forward Neural Network in a first stage, to process the input spectra, and train the learner, to recognize both column density and excitation temperature, for a series of molecules. We can observe that the parallel design of the molecular predictor, allows to have faster predictions for a larger number of molecules than if they were calculated in a serial way. When we calculate the prediction speedup, and it can be observed, that the speedup obtained are close to the theoretical optima.

■ TD-06

Tuesday, 14:30-16:00 - U1

Traveling salesman problem

Stream: Combinatorial Optimization
Invited session
Chair: Paolo Toth

1 - Comparative study of new formulations of asymmetric traveling salesman problem using mixed integer programming

Gabriel Solari Carbajal

The formulation of the Traveling Salesman Problem (TSP) began with the investigations of Dantzig, Fulkerson and Johnson (DFJ) in 1954 and Miller, Tucker and Zemling (MTZ) in 1960. From there, many renowned researchers have developed different formulations for the TSP. The main formulations of the TSP use the Assignment Problem (AP) formulation and add restrictions that eliminate the appearance of sub sequences.

At the 21st Conference of IFORS in 2017, was presented a formulation for the Asymmetric Traveling Salesman Problem (ATSP), which uses a variant of the MTZ where two restrictions were added. Currently, eight variants have been developed for different relationships between the complete variables of the AP and the binary variables of the new restrictions.

In the present investigation, the eight formulations proposed for the ATSP have been compared using Mixed Integer Programming. The commercial software MATLAB with the adjuncts has been used to solve these types of problems. Different problems were solved and the optimal solution was reached in all cases in approximate times with the MTZ formulation.

The results obtained give us a clear idea that the proposed formulations of the ATSP are very promising.

2 - Two-Commodity Opposite Direction Network Flow Formulations for the Travelling Salesman Problem

Konstantin Pavlikov, Niels Christian Petersen

This study considers the well-known Travelling Salesman Problem (TSP) and presents a new approach to formulate the symmetric and asymmetric TSP based on flows of two commodities. Unlike traditional approaches formulating TSP with flows of multiple commodities, the flows of two commodities considered in this study are defined in the opposite directions along a Hamiltonian cycle in the complete graph with n nodes. The proposed two-commodity flow formulations are demonstrated to be strictly stronger than their one-commodity counterparts in terms of the quality of their linear programming relaxations. This is a new result in the sense that the existing two-commodity flow formulations of the TSP provide lower bounds that are no different from the linear programming relaxation of the corresponding one-commodity flow formulations. Moreover, the flows of two commodities organized in the opposite directions allow to formulate the asymmetric TSP with only $n(n - 1)/2$ binary variables, just as in the case of symmetric TSP. This result suggests that various classes of the valid inequalities based upon the polyhedral structure of the symmetric problem are sufficient for designing branch-and-cut algorithms for the asymmetric problem. Finally, the proposed mathematical programming formulations are further evaluated and compared to the existing approaches both analytically and using an extensive computational study.

3 - A discrete artificial humming bird algorithm for asymmetric travelling salesman problem

Karuna Panwar, Kusum Deep

The Artificial Humming Bird (AHA) is a newly introduced bio-inspired algorithm that mimics hummingbirds' unique flying abilities and foraging methods. It was initially proposed to solve continuous optimization problems and report impressive results. In this study, a discrete version of AHA is presented and used to solve well known combinatorial optimization problem, the asymmetric travelling salesman problem (ATSP). As ATSP is a combinatorial optimization problem, the continuous values obtained from the basic AHA are changed to discrete values using the order based decoding method. Further, the exploration and exploitation capabilities of the proposed algorithm are improved by the symmetry operator and the 2-opt algorithm. The proposed discrete AHA (DAHA) has been evaluated over several ATSP instances, and the computational results showed that it is a promising algorithm. Also, the performance of the proposed algorithm is compared with similarly developed algorithms such as particle swarm optimization (PSO), grey wolf optimizer (GWO), whale optimizer (WOA) and sine cosine algorithm (SCA). The proposed DAHA significantly outperformed these algorithms for a majority of ATSP instances.

4 - A two-phase metaheuristic for solving the multi-depot k-traveling repairman problem

Alan Osorio-Mora, John Willmer Escobar, Paolo Toth

This talk presents a two-phase metaheuristic to solve the multi-depot k- traveling repairman problem (MDk-TRP). The MDk-TRP is an extension of the traveling repairman problem TRP (see Fischetti et al., 1993) considering multiple depots and kuncapacitated vehicles. The TRP consists of deciding the sequence in which the customers must be visited, with the aim of minimizing the total sum of the arrival times at the customers. The MDk-TRP was recently introduced in Bruni et al., (2022), where the authors proposed two mathematical formulations and two genetic algorithms for solving the problem. This talk presents a new metaheuristic for solving the MDk-TRP. The first phase of the proposed algorithm consists of a matheuristic procedure, which is able to provide good quality initial solutions. The second phase corresponds to an iterated local search algorithm (ILS) which consists of three steps: perturbation, local search, and a hybrid simulated annealing-variable neighborhood search procedure. Extensive computational experiments on MDk-TRP benchmark instances were performed. The results show that the proposed algorithm is competitive with the state of the art algorithms both in terms of computing time and solution quality. The two-phase metaheuristic is able to find several proved-optimal solutions, and new best known solutions for large size instances.

■ TD-07

Tuesday, 14:30-16:00 - U3

AI in Financial modelling

Stream: Financial Risk Measurement and Management
Invited session
Chair: Rita Pimentel

1 - Pricing Bermudan basket options with stochastic volatility using deep neural networks

Rita Pimentel, Bjørn André Aaslund, Johannes Berge, Ying Ni

In this paper, we propose to use deep neural networks for pricing Bermudan basket options when the underlying follows the Heston model. We consider different specifications for the payoff, namely geometric average and maximum. We show that this approach generalizes to higher dimensions and performs better than traditional methods, particularly for the maximum payoff.

2 - Interpretable and powerful predictions of personal financial volatility in presence of non-linear transactional patterns
Galina Andreeva, Rui Ying Goh, Yi Cao

Volatility forecasting evaluates the uncertainty risk from fluctuating stock prices to capture losses or investment opportunities. In personal finance, financial volatility evaluates the degree of uncertainty from cash flow transactions, which is crucial to detect risky behaviours leading to distress. This study predicts financial volatility from current account transactions. To define a composite index of financial volatility as the target variable, we simultaneously incorporate the fluctuations in income, expenditure, and financial buffer (or balance). The interpretation of how transactional patterns are associated with (high/low) volatility is the key to identify potential financial struggles. We propose spline regression to develop a financial volatility predictive model to capture non-linearity for a white-box explanation of harmful volatile behaviours. First, we compare the predictive performance of spline regression with several state-of-the-art machine learning techniques. Second, we examine the model explainability of spline regression by comparing the interpretation from marginal effects with the output from accumulated local effects plots. Lastly, we identify risky transactional patterns from the non-linear structures to detect potential financial distress. We conclude that spline regression is competitive to machine learning models in capturing complex non-linearities and providing transparent explanations to reveal additional dimensions of financial risks.

3 - Machine Learning Framework to Price Setting Risk-Averse Data-Driven Newsvendor Problem
Eren Atsız, Enis Kayis, Erinc Albey

The price-setting newsvendor problem which is a variant of newsvendor problem having a wide place in the literature is examined. The proposed solution is focused on limited historical data rather than demand distribution. The study provides a data-driven framework for determining the price and the optimal solution in different contexts in which the problem is applied where demand depending on several other exogenous variables (covariate information) such as weather information or location. The main purpose of the study is to propose a new structure that monitors the prediction interval to minimize the overall risk as simultaneously performing demand prediction and optimization problems. The single-period newsvendor problem is discussed together with risk structures. The data-driven newsvendor model is modeled with different risk measures. Foremost among these risk structures, there is the value at risk (VaR) risk measure that defines risk as a probabilistic constraint. Since the VaR extension is added as a probabilistic constraint, it is also treated as a chance constraint. The nonlinear formulation of the mathematical model that meets this constraint is planned to be solved as a nonlinear mixed-integer program. It is planned to create a result that controls the variance by making restrictions on the prediction interval of the prediction model. In this way, it will be ensured that the risk becomes more meaningful for the decision-maker.

■ TD-08
Tuesday, 14:30-16:00 - U4

MAI: The OR/analytics sales pitch

Stream: Making an Impact
Invited session
Chair: Tuomas Lahtinen

1 - Making the OR/analytics sales pitch
Tuomas Lahtinen

No matter how good your OR solution is, it won't get anywhere unless it has customers who have bought in to its potential and are happy to work with you on it. The purpose of this session is to share challenges, experiences of what works and what doesn't, and ideas for new approaches, on topics related to selling OR & Analytics based consulting, projects, solutions etc. Please come if the overall theme interests you! It doesn't hurt if you have some sales related topic in mind, which you would like to discuss with others. We will organize into sufficient number of small groups, which will evolve over the course of the session, using the Open Space method (see for example https://www.mind.org.uk/media-a/4924/open-space-method.pdf) so also come if you would like to learn more about this interactive and participative approach.

■ TD-09
Tuesday, 14:30-16:00 - U5

Stochastic Optimization: Applications to Power Systems

Stream: Mixed Integer Linear Programming
Invited session
Chair: Bismark Singh

1 - Scenario reduction for capacity expansion problems
Daniel Avila

We consider two-stage stochastic problems and propose a general framework to perform scenario reduction over this class of problems. The methodology aims at selecting scenarios that have a representative impact in the optimization rather than selecting scenarios based on statistical properties. We show its benefits against other general purpose scenario reduction schemes. We consider the method in a large-scale capacity expansion problem of the European region and show it achieves a performance comparable to a scenario reduction scheme developed by ENTSO-E for this specific problem.

2 - Exact Mixed-Integer Programming Approach for Chance-Constrained Multi-Area Reserve Sizing
Jehum Cho, Anthony Papavasiliou

An exact algorithm is developed for the chance-constrained multi-area reserve sizing problem in the presence of transmission network constraints. The problem can be cast as a two-stage stochastic mixed integer linear program using sample approximation. Due to the complicated structure of the problem, existing methods attempt to find a feasible solution based on heuristics. Existing mixed-integer algorithms that can be applied directly to a two-stage stochastic program can only address small-scale problems that are not practical. We have found the minimal description of the projection of our problem onto the space of the first-stage variables. This enables us to directly apply more general Integer Programming techniques for mixing sets, that arise in chance-constrained problems. Our method can tackle real world problems, of which a case study is shown on the 11-zone Nordic network with 50,000 scenarios where the optimal solutions can be found in approximately 10 minutes.

3 - Budget-cut: introduction to a budget based cutting-plane algorithm for capacity expansion models
Bismark Singh, Oliver Rehberg, Leander Kotzur, Maximilian Hoffmann, Theresa Gross

We present an algorithm to solve capacity extension problems that frequently occur in energy system optimization models. Such models describe a system where certain components can be installed to reduce future costs and achieve carbon reduction goals; however, the choice of these components requires the solution of a computationally expensive combinatorial problem. In our proposed algorithm, we solve a sequence of linear programs that serve to tighten a budget—the maximum amount we are willing to spend towards reducing overall costs. Our proposal finds application in the general setting where optional investment decisions provide an enhanced portfolio over the original setting that maintains feasibility. We present computational results on two model classes, and demonstrate computational savings up to 96% on certain instances.

■ TD-10

Tuesday, 14:30-16:00 - U6

Banking Risk Management

Stream: Financial Risk Measurement and Management
Invited session
Chair: *Sandra Challita*

1 - Risk management of Commercial Banks caused by CBDC
Tadashi Uratani

From the perspective of efficiency of payment, internet banking, card payment and use of e-money are very popular, but they have no finality of payment. Central Bank Digital currency will have the finality and efficiency of payment. However it may have serious damage to money creation function and default probability of commercial banks. Stochastic behavior of household deposit to banks are assumed and the risk of default of commercial banks will be evaluated.

2 - Cooperative banks business model's efficiency
Sandra Challita, Rym Ayadi, Doriana Cucinelli

In a context of digitalization, consecutive crises, low levels of profitability and increasing regulatory constraints, banks' efficiency is crucial for their sustainability. Cooperative banks in Europe represent about 20% market share. They are very heterogenous, with a spectrum of ranging from large systemic banks to small regional banks. The aim of this paper is to analyze the determinants of cost and profit efficiency of European cooperative banks over the period of 2010-2020, while focusing on their business models (Ayadi et al. 2021). Using the Stochastic Frontier Approach (SFA), we identify cost and profit efficiency measures. The findings on 16 235 observations suggest that in Europe, the majority of cooperative banks are retail-oriented banks with about 10% change of business models (migration) through the years of observations. Also, we observe a decrease in cost and profit efficiency during the sample period. The findings suggest that retail-oriented banks have higher cost and profit efficiency as compared to market-oriented banks. Also, migration from a business model to another improves profit efficiency of cooperative banks. The results suggest that to improve their efficiency, cooperative banks can change their business models rather than seek consolidation or demutualization.

3 - Capital reserve management for a multi-dimensional risk model
Erik Winands

Firms should keep capital to offer sufficient protection against the risks they are facing. In the insurance context methods have been developed to determine the minimum capital level required, but less so in the context of firms with multiple business lines including allocation. This research focuses on the calculation of finite-time ruin probabilities and capital reserves for a multi-dimensional risk model. The individual reserves of these lines of business are modelled by means of a Cramér-Lundberg model with constant incoming premiums and outgoing claims that arrive according to a Poisson process. To allow for dependence between business lines we introduce a common (latent) environmental factor. This environmental factor impacts the claim inter-occurrence times as well as the claim sizes. Considering a fixed environmental process over time, we present a novel Bayesian approach to calibrate the latent environmental state distribution based on observations concerning the claim processes. We then allow for the distribution of individual claims to change over time by using a Markov environmental process. For the latter, we present two approximations for the finite-time multi-variate survival/ruin probabilities: a diffusion approximation and a single-switch approximation. Finally, we point out how to determine the optimal initial capital of the different business lines under specific constraints on the ruin/survival probability of subsets of business lines.

4 - Liquidity Coverage at Risk
Virginia Pugliese, Giacomo Morelli

We propose a new measure to assess the liquidity risk of financial firms. Building on the Liquidity Coverage Ratio provided under Basel III, this paper introduces the notion of Liquidity Coverage at Risk (LCRisk), which is the probability that a bank faces an illiquid event in the next 30-days. LCRisk features the three following properties: it is a forward-looking measure, it captures the tight relation between liquidity and volatility, and it requires inputs that can be simply recovered from the balance sheet data of banks. First, we derive analytically the closed-form solution for the LCRisk obtained as the probability that the ratio between the law of motion of the two components, namely HQLA and TNCO, hits from above the safety liquidity barrier over the next 30 days. Second, we illustrate how LCRisk can be computed directly using banks' balance sheet data. In the empirical analysis, we compute LCRisk for a panel of US and European banks, proving the ability of such a measure to provide an early warning signal of liquidity risk. For instance, we find 48% probability of illiquidity a few days before Banco Popular Español was set under the resolution process in 2017. Third, we introduce the notion of LCRisk capital buffer, retrieved by inverting the LCRisk formula, that assesses the amount of liquid assets necessary to keep the probability of an illiquid event at a given threshold.

■ TD-11

Tuesday, 14:30-16:00 - U7

How to support complex decisions. Negotiating the trade-off between Social, Environmental and Economic values 1

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Alessandra Oppio*
Chair: *Marta DellOvo*

1 - How to tackle marginalization in small towns: an MCDA approach to comparing different strategies in Campania Region
Marco Rossitti, Fabiana Forte, Francesca Torrieri

The struggle against territorial marginalization and depopulation in small towns has been central in the national and international policy agenda in recent years. In Italy, several structural incentives and policies have been set to deal with this issue, but only some villages were able to capture the provided opportunities. In addition, some small towns have stood out for innovative and spontaneous strategies to tackle marginalization. In this context, the research compares different de-marginalizing strategies and tools recently implemented by some small villages in Campania Region. More in detail, it focuses on three municipalities: Mirabella Eclano (Av) where, as part of de-marginalization strategy, is adopted the legal instrument 'administrative barter'; Guardia Sanframondi (BN) where the shrinking dynamics are tackled by attracting new residents; and Preturo Irpino (AV), where the implemented strategy rests on migrants reception and integration. Since marginalization is universally acknowledged as a multi-dimensional phenomenon, the comparison is performed through an MCDA approach based on social, economic, and spatial criteria relevant to interpreting and counteracting it. On the one hand, the results of this comparison can guide the replicability and adaptation of the considered strategies to other realities. On the other hand, it allows reflecting on the selected strategies' capacity to address the different 'marginalization' dimensions included in the analysis.

2 - An integrated multicriteria participatory evaluation approach to support strategic actions for cultural heritage promotion
Marta DellOvo, Vanessa Assumma, Caterina Caprioli

In the European policy agenda, cultural heritage has emerged as a relevant drive for sustainable development, contributing to the socio-economic growth of territories. Different Sustainable Development Goals (SDGs) highlight the importance of conserving, preserving, restoring, and promoting Cultural Heritage, mainly the goal 11, the goal 4, and the goal 8. At the same time, well-known and long-standing programs are developed for this purpose, like the European Capital of Culture (ECoC). This initiative honors cities with the title of Capital for a year of cultural events, contributing to different urban transformations, from historic and heritage-rich settings to long-term effects such as cultural facilities, tourism, and intangible heritage promotion. Within this context, the present work explores the potential of an integrated and participatory approach for supporting the assessment of alternative strategies for long-term and sustainable cultural heritage promotion. The integrated framework makes use of Stakeholder Analysis, SWOT Analysis, and the compensatory multicriteria method called NAIADE (Novel Approach to Imprecise Assessment and Decision Environments) (Munda, 1995). The participatory multi-methodological approach is employed in the case study of Matera (Basilicata, Italy), nominated in 2019 as ECoC and UNESCO World Heritage site in 1993, for testing alternative projects to achieve a long-term and sustainable trajectory for cultural heritage promotion.

3 - A theory-based impact evaluation of cultural policies through policy analytics perspective
Federica Cadamuro Morgante, Alessandra Oppio, Alexis Tsoukias

The present research work studies the mechanism to support impact evaluations of cultural policies. In particular, the aim of this study is to define an impact-driven evaluation approach supported by the Policy Analytics framework in the specific context of cultural policies for protection and valorization of "cultural landscapes", as defined by the 2000 European Landscape Convention. The proposed methodological approach is based on the assumptions that evaluation practice in the public domain has to deal with the multidimensional, as well as tangible-intangible, nature of the cultural landscapes and the legitimation of policies, strategies and actions by participation. According to these premises, the methodological approach aims to combine the Policy Analytics and the Theory of Change frameworks, while focusing on a set of sequential steps, objectives, operational tools and expected outcomes. The methodological steps have been tested on the policy cycle of the Valli Resilienti Project, promoted by Fondazione Cariplo and implemented between 2017 and 2020 on fragile mountainous areas in Brescia Province (Italy). Here, the cultural landscape is one of the main vehicles for territorial development. The proposed integration of the two frameworks contributes to the studies and further good practices for cultural policies impact evaluation.

4 - Expert-based multicriteria assessment of near-future scenarios for the automation of collective transport services in Helsinki
Janne Olin

Self-driving vehicle technology is currently emerging in an institutional void—a state where sociotechnical development is difficult to steer due to uncertainty and the absence of established rules and norms. To cope with these problems, previous research has recommended a range of foresight and impact assessment methods. However, multiple-criteria decision analysis (MCDA)—mostly associated with concrete decisionmaking problems in transport studies—could also be used as a probing tool for examining uncertainties and value conflicts related to future implementations and policies whose effectiveness and implementability has not been adequately evaluated. This study focused on the potential implementation of automated collective transport services in Helsinki. First, 10 key stakeholders from the public and private sectors were interviewed. The interview analysis provided input for three possible service scenarios in two locations and 33 evaluation criteria. The stakeholders then participated in a scenario evaluation exercise, which was followed by an AHP-PROMETHEE analysis. The process revealed several previously unidentified uncertainties, inconsistencies between participants' statements and decisions, as well as value conflicts related to the potential future service scenarios. Thus, the results indicate that MCDA methods could be used and further developed to facilitate meaningful, value-based stakeholder reflection in the domain of emerging mobility technologies.

■ TD-12
Tuesday, 14:30-16:00 - U9

Supporting Energy Communities

Stream: OR in Energy
Invited session
Chair: Paula Carroll

1 - Loads scheduling for energy community Demand Response on Energy Communities
Mariam Sangare

This talk focuses on optimizing collective self-consumption in an energy community composed of households and premises (stadium) by scheduling loads of electrical appliances owned by the members. The corresponding community remains connected to the public grid, and each member can produce and/or store photovoltaic energy. Furthermore, they can exchange this energy with the public grid or other energy community members. The proposed strategy aims at implementing a Demand Side Management program by taking advantage of the controllable loads' characteristics. A MILP formulation of the problem allows, on the one hand, to give the optimal planning of the operation of the electrical devices. On the other hand, it provides the optimal solutions for managing the storage units and the energy exchanges between community members and the public grid to minimize the energy flows from the public grid to the community over the time horizon. However, this MILP does not allow us to efficiently solve the large instances of the problem. Thus, we develop a column generation-based heuristic to find solutions for large problem instances. Our numerical experiments based on real data show that joining an energy community saves money on energy bills and reduces the total energy drawn from the primary grid by at least 15%.

2 - Unit Commitment problem for Local Energy Communities
Cristian Aguayo, Bernard Fortz

With the rise of renewable energy, collective organizations such as Local Energy Communities (LECs) play a key role in the transition to more sustainable energy generation. However, the production of energy at minimum cost is still a topic of interest. For the last five decades, the Unit Commitment (UC) problem is one of the tools that have been used to optimize energy generation. In this work, the UC problem is extended to a LEC schema. For modeling purposes, LECs are considered as sets of units with power demands over a given horizon and the objective is to minimize the total operation costs. Additional features such as power sharing between communities, external power purchasing and power storage are also considered and evaluated using benchmark instances. This work is developed under the framework of the SEC-OREA project.

3 - Methodology for creating representative load profiles - assessment of open-source approaches
Evita Kairiša, Anna Mutule

Good quality load profile forecasting can benefit all involved parties, including consumers, retailers, and operators, as it is essential for grid operations, infrastructure planning, and energy trading. Residential load data acquired from smart meters usually contain valuable information on electricity consumption behaviors. However, researchers often don't have full access to real-world data from the desired location. Additionally, the load profiles should consider the novel electricity consumption trends as more energy users adopt new technologies and participate in energy generation and demand response. Despite many existing models and open-source datasets and tools, forecasting electricity consumption in residential sector remains challenging due to high behavior variability. For better quality load profiling, information about household characteristics, electrical appliance usage patterns (e.g., efficiency classes), and energy requirements are beneficial. If some information is not available, there is the possibility to predict it with different datasets, algorithms, and tools. Within the framework of this study, a methodology for creating realistic electricity profiles for real locations with limited input data. In more detail, combing existing data with ML algorithms, open-source datasets, and modeling tools to obtain realistic load profiles under high uncertainty, considering several possible factors, such as load priority, environmental aspects, user comfort, etc.

4 - A Reverse Stackelerg Game Model for Grid Usage Pricing

Juan Sepulveda, Luce Brotcorne, Hélène Le Cadre

In the context of massive penetration of renewables and shift of the energy system operations towards more consumer-centric approaches, local energy communities are seen as a promising solution for prosumers empowerment. Various designs of the local market have been proposed that often ignore the laws of physics ruling the power flows on the underlying distribution network. Therefore, including the distribution system operator and underlying network in the clearing of the local market arise as a challenge. In this talk, we propose to design short-term incentive policies in the form of grid usage prices to drive the system towards an economically efficient market equilibrium, subject to operational security constraints. Our approach requires expressing the incentive policies as affine functions of the prosumers' active and reactive power outputs. To design the policies, we leverage a reverse Stackelberg game where we look for the optimal policy in a space of affine functions. Conditions for controllability of the policy will be discussed. Market related properties of the policy such as individual rationality, incentive compatibility, and fairness will be rigorously studied. Finally, extensive computational experiments will be carried out on different IEEE test feeders to assess the performance of the proposed approach statistically. Data for experiments will be constructed from actual data sources preserving similar measures of spatio-temporal correlations.

■ TD-13

Tuesday, 14:30-16:00 - U119

Topics in Discrete Optimization I

Stream: Discrete Optimization and Algorithms (contributed)

Contributed session

Chair: *Alfredo G. Hernandez-Diaz*

1 - The Class-Teacher Assignment Problem and its application in Educational Timetabling

Claudio Crobu

High-school timetabling is a typical NP-hard problem. In this research a new type of decomposition is proposed: in the first phase the sets of teachers and classes are partitioned or quasi-partitioned; in the second step a timetable is solved for each partition by a general MIP solver or other heuristic methods. The experimentation on a mix set of realistic and real instances shows that this decomposition is viable especially for large or huge instances and effective in terms of solution quality and time saving are particularly evident. Also, as the second phase is scalable, the timetabling of multiple partition could proceed in parallel mode, further reducing the elapsed time of the entire process.

2 - Localization under two conflicting perspectives: Proximity or fair share?

Alfredo G. Hernandez-Diaz

In this paper we address a location problem that, despite its great interest and applicability in real situations, has been little studied in the literature. Nevertheless, more and more companies are facing it when determining the optimal location of their facilities. Generally, when we want to locate a set of facilities, whether they are bicycle stations, shopping centers or hospitals, among many others, we try to make them as close as possible to their points of demand, i.e., bicycle users, customers or patients. But, at the same time, it is also desired that the workload (demand) is evenly distributed. Thus, the objectives to be optimized would be, on the one hand, to minimize the greatest distance between the facilities and the demand points and, on the other hand, to balance the workload of the facilities to be located, understanding workload as the number of demand points that a facility serves. Therefore, two objectives are considered, which are usually in conflict. Due to the complexity of the bi-objective combinatorial optimization problem at hand, exact methods make it costly or infeasible to solve. This leads us to propose a metaheuristic algorithm capable of solving it quickly and obtaining high quality solutions. Specifically, we propose a hybrid algorithm based on Strategic Oscillation combined with Path Relinking able to offer different efficient solutions of high quality.

3 - A new heuristic approach to the robust team formation problem

Goranka Nogo

A new heuristic approach to the robust team formation problem

Abstract: The team formation problem consists in selecting an effective team of experts, which covers all the required skills for a given task and minimizes the communication cost among team members. We propose a new heuristic algorithm for solving a particular robust variant of the team formation problem: the selected team consists of two disjoint sets of members according to their efficiency. The metaheuristic chosen to solve the problem is based on simulated annealing and greedy approach. We analyse computational complexity and elaborate evaluation results.

Keywords:

team formation problem, heuristics, simulated annealing, greedy approach, complexity, implementation, experiments.

4 - New heuristics for solving the Three-index Assignment Problem

Mohamed Mehbali

The Three-index Assignment Problem (3IAP), also called the multidimensional assignment problem, consists of allocating n jobs to n machines in n factories such that exactly one job is executed by one machine in a factory at minimum total cost. The 3IAP is a combinatorial optimization problem and is an extended version of the classical two-dimensional assignment problem in which n tasks are assigned to n operators at minimum cost. Kadhem, D. (2018) proposed the Diagonals Method (DM), as a heuristic for solving 3IAP. Our paper expands on the DM heuristic by considering tie-cases, thus three variants are suggested. For each problem instance, DM will produce several feasible solutions. Furthermore, by exploring some characteristics of the cost matrices, a class of new heuristics for solving 3IAP is proposed. Numerical experiments show that the proposed heuristics outperform DM, and they always guarantee in polynomial time feasible solutions which are optimal or near optimal in competitive computational times.

■ TD-14

Tuesday, 14:30-16:00 - U261

Quantum Optimization

Stream: Metaheuristics, Matheuristics
Invited session
Chair: Eric Bourreau
Chair: *Philippe Lacomme*

1 - Adiabatic based Algorithm : a comprehensive algorithmic description
Philippe Lacomme, Fleury Gerard

Quantum computing approaches define a promising way in solving a large number of well-known classical problems. Quantum approximate heuristics take advantage of alternation between one Hamiltonian defining the problem to solve and one mixing Hamiltonian. The adiabatic theorem initially defines in quantum physic allow to compute a solution for the Schrödinger equation, but the foundation of this methods requires strong skill in physics and mathematics. Our main objectives in this presentation are at first to provide an algorithm-based presentation (as close as possible of the classical operational research practice) of the adiabatic optimization and secondly to give a comprehensive resolution of two well-known problems including SAT and TSP. Experiments are achieved to validate the theoretical considerations and has been achieved on both simulator and on real quantum computer provided by IBM

2 - Performance evaluation of quantum annealing on bipartite matching instances
Daniel Vert

In recent years, so-called analog quantum machines have appeared, of which the computers currently marketed by the company D-Wave are the first representatives, operating according to a principle of quantum accelerated annealing. These machines implement a noisy version of the quantum adiabatic algorithm which consists in preparing a Hamiltonian initially intended to connect the qubits together. Such a machine can be considered as an oracle specialized in solving an NP-hard optimization problem with an algorithm functionally similar to simulated annealing but with a quantum acceleration. But, does the algorithm implemented in these machines have an acceleration and does it have superior computational performance for problem solving compared to simulated annealing? We experimentally confronted the D-Wave machines with the pathological instances of the maximum cardinality matching problem proposed by Sasaki in order to show that simulated annealing was indeed unable to solve some polynomial problems in polynomial time. In this context, we examine the extent to which the qubit interconnection topology influences these results. To do so, we study how simulated annealing is able to solve our hard cases of maximum cardinality problems when embedded in the Chimera topologies and the Pegasus topology.

3 - Quantum Side Channel Attacks
Eric Bourreau, Florent Bruguier, Imran Meghazi

Quantum Computing is a new paradigm originated from Richard Feymann ideas. During 90's, Quantum Algorithm were discovered (Polynomial-Time Algorithm for Prime Factorization on a Quantum Computer, Shor 94, A fast quantum mechanical algorithm for database search, Grover 95). Recently, in the last 5 years, real Quantum Computing are available and first practical experiments validate expected results derived from the theory (Quantum Supremacy using a programmable Quantum Computer, Google 2019). We have investigated side channel attacks (Differential Power Analysis, Kocher 1999) from a Quantum point of view. By precisely decomposing the AES-128 algorithm (Advanced Encryption Standard), we proposed specific operators to extract hidden key from a sequence of plain text messages compared to encrypted results. To help us in this task, we exploit leaks from side channels (consumption power, EM emissions) by carefully spying the cryptoprocessor and microcontroller chips. Grover Adaptive Search was used with Qiskit python Libray from IBM to illustrate on small examples efficiency of this kind of attacks.

4 - Optimization with Quantum Annealing Machines
Samuel Deleplanque

Quantum annealing is a method based on simulated annealing where temperature variations are replaced by quantum fluctuations that cause qubit state transitions. ISING problems and Quadratic Unconstrained Binary Optimization problems (QUBO) can be tackled by quantum annealing-based machines. We can link the interconnected qubits of the machine and the binaries of our model: qubits are binary variables and each pair of them linked by a coupler has a strong impact on the equality or the non-equality of the two binaries of the associated pair. Quantum annealing is based on the fact that any system tends to seek its minimum energy state. Starting from qubits in a state of superposition where all the solutions to the problem are fairly represented, the machine will apply a magnetic field by targeting the qubits and couplers in such a way as to make their value energetically favorable in the direction of optimization (minimization). For the coupled qubits, it is the quadratic products of the binary variables that are considered here and the physical system will make it energetically favorable for them to take (or not) the same values. To work on these machines based on quantum annealing in order to solve optimization problems with constraints, the latter must be relaxed while penalizing the Objective function. After presenting the case of the Max-Cut problem, we will look at such constrained problems.

■ TD-15

Tuesday, 14:30-16:00 - U262

Artificial Intelligence in Decision Support Systems

Stream: Decision Support Systems
Invited session
Chair: Pavlos Delias

1 - Potentials for decision support in business processes through a multi-layer network embeddings approach
Pavlos Delias, Lefteris Moussiades, Vassilis G. Kaburlasos

In a business process, we expect multiple related entities to interact. For example, in the Order-to-Cash process, one can observe the events that are recorded with respect to the orders, to the packages, or to the items that are included in the order. Each case notion carries only a part of the aspects of the overall situation, thus, reducing the process to a single case notion means to deliberately neglect certain facets of reality, and moreover, it conceals a major risk to present features of one particular case notion as the global truth of the process. The goal of this work is to structure a problem and suggest a solution for discovering patterns when a business process involves multiple entities. We propose an embedding representation that captures simultaneously the similarity of traces within the objects of the same object type, as well as the relationships between the objects of different types. We formulate an optimization problem that involves the similarity matrices, the cross-objects types relationships matrices, and the embeddings. Then, we follow an iterative algorithm to optimize it and deliver the embedding representation, and eventually the cluster memberships for each object type. ACKNOWLEDGMENT This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 777720.

2 - Multiple Beliefs, Dominance and Dynamic Consistency
Tommi Ekholm, Erin Baker

(The presentation is based on a recent paper in Management Science: https://pubsonline.informs.org/doi/abs/10.1287/mnsc.2020.3908)

This presentation considers multi-period decisions under multiple uncertainty characterizations. We explore the dynamic consistency of complete and incomplete preference orderings. We focus on a dominance concept that supports decision-making by ruling out strategies that are dominated across a set of beliefs deemed plausible by the decision-maker. We uncover a distinction between two types of dynamic inconsistency, which we label fallacious and fallible inconsistency. Fallacious inconsistency occurs when an a priori optimal strategy is suboptimal in the second period, thus requiring the decision-maker to depart from the original strategy. Fallible inconsistency occurs when an a priori suboptimal second-period action ceases being suboptimal from the perspective of the second-period preferences. We introduce corresponding definitions of dynamic consistency and show that the two types of consistency are equivalent for complete orderings but differ for incomplete orderings. Subjective expected utility is dynamically consistent and non-expected-utility decision rules, such as minmax, are not. We show that dominance over beliefs falls between these two: it is immune to the more severe fallacious inconsistency, but not to the less problematic fallible inconsistency. We illustrate the method with a numerical example regarding vaccine development.

3 - Explainable Decision Analysis and Support
K.Nadia Papamichail, Theodor Stewart, George Demetriou

The recent advent of AI-powered decision support tools has emphasised the need for explaining services, processes and decisions delivered not only by AI but also any decision algorithm. Yet, developing explainable and interpretable decision models remains a challenge. This work presents a typology of explanations that can be generated by a decision support tool using AI methods such as Natural Language Generation (NLG) techniques. We have developed a framework for generating explanations for Multi-Criteria Decision Analysis (MCDA) tools that rank alternatives based on a set of attributes. Explanations are generated within the context of additive value function models. The system outputs range from data explanations that present data (e.g. attribute weights) and those assumptions under which alternatives were ranked to rationale explanations that convey the logic and reasoning behind a decision model's output. We argue that such explanations increase transparency into the decision-making process.

4 - Artificial intelligence decision-making in supply chain management: A hierarchical agglomerative cluster approach
Xinyue Hao, Emrah Demir, Luigi De Luca

Abstract: A natural language processing (NLP) machine learning technique and a systematic literature review analysis were conducted to examine the existing Artificial Intelligence (AI) decision-making literature. The research identified ten topics in AI decision-making research, namely risk, strategies, human, value, performance, criteria, and evaluation, legal and ethical, process, sustainability and efficiency. Ten topics have been divided into four categories. Risk factors and strategies, respectively, occupy the top and second layers of the hierarchy. Human, value, performance, and criteria and evaluation are all included at the third level. Legal and ethical, process, sustainability, and efficiency are covered at the fourth level of the dendrogram of knowledge. The hierarchical relationship amongst ten topics identifies theoretical gaps in the supply chain domain. Our research contributes to the literature by studying AI decision-making as there is no detailed review is available where topical analysis on AI decision-making in the supply chain domain has been considered. Our work provides an insightful understanding of the components in AI decision-making for the supply chain domain, and it is useful for both supply chain academics and industry practitioners.

■ TD-16

Tuesday, 14:30-16:00 - U264

Risk Management for Insurance

Stream: Set Valued Models in Finance
Invited session
Chair: Mario Sikic

1 - On corporate demand for insurance: a dynamic perspective on property insurance
Mario Sikic

Why do firms purchase property insurance? When the firm has access to external capital and corporate liquidity, what is the effect of protecting productive capital on firm value? We address these questions by analysing the drivers of corporate property insurance when a risk-neutral firm is subject to various frictional costs. The problem is formulated in a dynamic, infinite time horizon model with endogenous investment, financing and demand for coverage against shocks to productive capital. We show that firms' demand for property insurance is driven by the relative size of the costs imposed by financial constraints. These include capital issuance costs, corporate taxes and agency costs of holding cash. Numerical simulations reveal that risk-neutral firms purchase property insurance mainly in response to costly cash retention due to agency costs and, to a lesser extent, to increase debt capacity. We study the impact of adding the insurance channel on firm value, given different choices of available financing decisions. However, due to the complexity of the model, we additionally use Shapley Values as aggregate measures of the impact of property insurance on firm value relative to other corporate policies when frictional costs exist.

2 - A decomposition of general premium principles into risk and deviation
Max Nendel

We provide an axiomatic approach to general premium principles in a probability-free setting that allows for Knightian uncertainty. We show that two simple axioms already imply that every premium principle is given as the sum of a risk measure, as a generalization of the expected value, and a deviation measure, as a generalization of the variance. One can uniquely identify a maximal risk measure and a minimal deviation measure in such decompositions. We show how previous axiomatizations of premium principles can be embedded into our more general framework. We discuss dual representations of convex premium principles, and study the consistency of premium principles with a financial market in which insurance contracts are traded.

3 - Distributionally robust liability-driven pension fund management
Asmerilda Hitaj, Giorgio Consigli, Rui Gao, Anton Kleywegt

We consider a second pillar defined benefit (DB) occupational pension fund (PF) asset-liability management (ALM) problem from the perspective of a PF manager delegated to pay benefits to the employees - the PF members - by a company - the sponsor - who is also funding the pension plans. The pension fund collects the contributions from the sponsor and pays the benefits to the passive members. We do not consider the possibility to cover the fund through an insurance company (which in certain systems is compulsory). The PF manager objective is to determine an investment strategy that allows the fund to cover its liabilities while minimizing the cost of funding, given by the contributions payed by the sponsor and the deficit between liabilities and total asset value at the end of the time horizon. We take into account uncertainty over members' lifetime and assets returns. In particular the LeeCarter model is considered for the survival probabilities and the Nelson/Siegel one for the yield curve. The ALM problem is formulated in constant monetary values to immunize the impact of inflation. To solve the problem we propose a distributionally robust stochastic optimization (DRSO) approach and analyze how the choice of metric affects the worst-case distribution and the out-of-sample performance of the solution.

■ TD-17

Tuesday, 14:30-16:00 - U356

Modelling Tools II

Stream: Software for Optimization
Invited session
Chair: Susanne Heipcke

1 - OMLT: Optimization and Machine Learning Toolkit
Ruth Misener

OMLT (https://github.com/cog-imperial/OMLT) is an open source software package incorporating surrogate models, which have been trained using machine learning, into larger optimisation problems. We discuss the advances in optimisation technology that made OMLT possible and show how OMLT seamlessly integrates with Pyomo. We demonstrate how to use OMLT for solving larger decision-making problems in both computer science and process systems engineering.

This work is joint with the Imperial Computational Optimisation Group (Francesco Ceccon, Alexander Thebelt, Calvin Tsay), Sandia National Laboratories (Jordan Jalving, Joshua Haddad), ad Carnegie Mellon (Carl Laird).

2 - Converting proof-of-concept models into powerful Xpress Insight applications to facilitate academic-industrial cooperation
Jens Schulz

More and more academic projects and theses form part of a joint research project between academia and industry. Unfortunately, we frequently observe that it takes quite some time before first results are ready to be shared with the industrial partners or even with the business users. A lot of time is spent on developing optimization models, tuning their parameters, and finessing textual output into slides for an appealing presentation.

Shortening the development cycle, from problem specification to model development, and closing the feedback loop with users, while removing unnecessary overhead by providing means for easier collaboration between developers and business users is the forefront mission of FICO Xpress. In this session, we will show how to easily deploy analytic and optimization models into visually appealing applications. Xpress includes a web deployment platform, Xpress Insight, enabling solution developers, data scientists, and OR experts to rapidly develop and deploy applications without needing to be a JavaScript or html expert. In particular, we will demo how a Python model can be converted into a user-friendly app via drag & drop within a few minutes

3 - GAMS and cloud native computing
Frederik Proske

Typically, personal computers have been powerful enough to quickly solve the model instances generated by GAMS. If not, users (or their expert IT staff) have implemented custom scheduling systems to run large optimization jobs on central compute resources. Increasingly, users want to run large jobs or large streams of jobs in the cloud. This allows them to access more powerful computers than the usual desktop computers and also to use a highly scalable pool of worker machines. In this talk, we present GAMS Engine - a cloud-native solution for executing long-running (optimization) jobs on a highly flexible pool of heterogeneous nodes. We describe how we use Kubernetes to develop such a system for clusters of any cloud provider or on-premises, and the particular challenges optimization jobs pose to the design of such a cloud native system. We will also talk about how GAMS Engine enables customers to fully automate their OR-related business processes and scale in real time as needed, both vertically (e.g., from a few MB to several TB of memory) and horizontally (from a single job to many parallel scenarios).

4 - SMS++: a Software Framework for Structured Optimization
Antonio Frangioni

The Structured Modelling System++ (SMS++) is a C++ library intended to facilitate the development of solution methods for very large optimization problems with multiple nested heterogeneous structure. The main goals of SMS++ are to allow the development of solution methods that require a tight integration between the model and the algorithm, such as (but not exclusively) those based on reformulations and/or on decomposition, and to facilitate the re-use of the enormous body of work devoted to the exploitation of many different mathematical structures by proposing an unified interface for "any structured problem and its solution algorithms". In the attempt of achieving these goals SMS++ has accrued a number of features that look quite unique in the landscape of modelling systems, so much so as to raise the legitimate suspicion that the reason why these features have never been developed before is because no sane person would have ever thought them a good idea. Yet the system is being SMS++ developed in an highly modular fashion and already counts several separate sub-projects; one of these allows to solve Lagrangian Duals of complex programs with remarkable ease, and it has already been used to solve extremely large stochastic optimization problems with a tri-level approach combining convex optimization, stochastic dual dynamic programming, Lagrangian decomposition and dynamic programming. Hence, there may actually be a few use cases in which SMS++ could be worth considering.

■ TD-18

Tuesday, 14:30-16:00 - U358

Stochastic models in manufacturing and services

Stream: Stochastic and Robust Optimization
Invited session
Chair: Raik Stolletz

1 - A Censored-Data Multiperiod Dual Sourcing Problem
Michalis Deligiannis, George Liberopoulos, Dimitrios Pandelis

Dual sourcing is a strategy that firms use frequently to mitigate supply risk. A common supply risk for a firm is that it may receive a smaller quantity than what was ordered from a supplier, due to the uncertainty in the supplier's capacity; hence the observed capacity realizations are censored. The purpose of this work is to study Bayesian learning of uncertain capacity and investigate how this learning influences sourcing strategies. To this end, we develop a model of a firm that sources from an unreliable and a reliable supplier to satisfy a time-dependent deterministic demand over a finite horizon. The unreliable supplier is cheap but has an unknown random capacity, while the reliable supplier is expensive but always delivers what is ordered. The random capacity of the unreliable supplier is parametrized by an a-priori unknown parameter. The firm's problem is to choose what to order from each supplier in each period. Formulating the problem as Bayesian dynamic programming, we derive properties of the optimal policy. For the case of exponential capacity distribution, we provide conditions under which the optimal ordering policy and the corresponding value function can be explicitly determined.

2 - Scalable policies for the dynamic traveling multi-maintainer problem with alerts
Peter Verleijsdonk

Downtime of industrial assets such as wind turbines and medical imaging devices is costly. To avoid such downtime costs, companies seek to initiate maintenance just before failure, which is challenging because: (i) Asset failures are notoriously difficult to predict, even in the presence of real-time monitoring devices which signal degradation; and (ii) Limited maintenance resources are shared over a network of geographically dispersed assets. In this work, we study the large-scale dynamic traveling multi-maintainer problem with alerts (K-DTMPA) under perfect condition information with the objective to devise scalable solution approaches to maintain such networks with K maintenance engineers. Since large-scale K-DTMPAs are computationally intractable, we extend existing greedy/reactive heuristic approaches that rank assets on urgency, proximity and economic risk. Additionally, we propose a deep reinforcement learning (DRL) approach that optimizes long-term discounted maintenance costs. In our numerical experiments, we investigate the cost-benefit of sharing resources over the network (as opposed to decomposing the K-DTMPA into K smaller 1-DTMPAs) and tackling the assignment problem (i.e., how to assign prioritized assets to available engineers). Moreover, early experiments with networks containing up to 100 identical assets show that the proposed DRL method learns competitive neural network policies, compared to the proposed heuristic approaches.

3 - A Hybrid decomposition approach to solve the network-constrained unit commitment problem
Ricardo Pinto de Lima, Gonzalo Constante-Flores, Antonio Conejo, Omar Knio

We propose a novel hybrid method to solve the network-constrained stochastic unit commitment (SNCUC) problems. We target realistic large-scale instances of the SNCUC problem, including hundreds of generation units, thousands of transmission lines and nodes, thermal generation units, and stochastic renewable production units. The SNCUC is formulated as a two-stage stochastic programming problem with continuous and binary variables in the first-stage and only continuous variables in the second-stage. We develop a hybrid solution method that decomposes the original SNCUC problem into a master problem including unit commitment and dispatch decisions (excluding transmission variables and constraints) and decomposed subproblems representing dispatch and transmission constraints per scenario. The proposed decomposition embeds a column-and-constraint generation step within the traditional Benders decomposition framework. The performance of the proposed decomposition is contrasted with the solution of the extensive formulation via branch-and-cut and Benders decomposition available in commercial solvers, and with traditional Benders decomposition variants. The computational experiments show that the proposed method generates bounds of superior quality and finds solutions for instances where other approaches fail.

■ TD-19

Tuesday, 14:30-16:00 - Y228a

Queueing applications

Stream: Performance Evaluation of Queues
Invited session
Chair: *Yoav Kerner*
Chair: *Binyamin Oz*

1 - Silent Abandonment in Contact Centers: Estimating Customer Patience from Uncertain Data
Antonio Castellanos, Galit Yom-Tov, Yair Goldberg

In recent years, text-based communication with agents in contact centers has become very popular. However, contact centers face operational challenges, since common proxies for customer experience, such as whether customers have abandoned the queue and their patience, are subject to uncertainty. We focus on the impact of a main source of such uncertainty: silent abandonment by customers. These customers leave the system while waiting for a reply to their inquiry but give no indication of doing so, such as by closing the conversation app. As a result, the system is unaware they have left and wastes agents' time until this is realized. A sample of 50 companies shows that, on average, 69.5% of abandoning customers do so silently. A detailed analysis of one company with 14.4% silent abandonment shows that such behavior reduces system efficiency by 11%. We develop methodologies to identify these customers in contact centers that allow customers to write inquiries during waiting and those that do not. We use NLP and an SVM model to obtain the actual abandonment level. We then use a parametric approach and develop an expectation-maximization algorithm to accurately estimate customer patience, which is an important parameter for fitting queueing models to data. We show how accounting for silent abandonment in a queueing model dramatically improves the estimation accuracy of key performance measures. Finally, we suggest strategies to operationally cope with silent abandonment.

2 - The Impact Of Procedural Justice On Patient Flow In Hospitals
Galit Yom-Tov, Anat Rafaeli

We investigate the impact of procedural justice in routing patients between ED and inpatient wards on patient LOS. Using diff-in-diff analysis we show a huge reduction (of more than 20%) in patient's LOS after implementing equalized routing. We investigate the mechanisms that drive this reduction.

3 - Modeling modern call center data through the counting process of a MAP
Pepa Ramirez Cobo, Rosa Elvira Lillo Rodríguez, Marcos Gonzalez Bernal

Markovian arrival processes (MAPs) constitute a class of versatile stochastic models since they allow for dependent and phase-type distributed inter-arrival times. In addition, and in contrast to the Poisson process, the counting process of a MAP is characterized by an overdispersed behavior. Because of these properties, the MAP turns out a suitable model for modern call center data. This work is three-fold: first, new properties concerning the correlation patterns in the counting process of a MAP are derived; second, an inference approach based on descriptors of the counting process is discussed; finally, a thorough analysis of a real call center dataset is carried out where important features concerning the associated queue are estimated.

4 - Left without being seen: The disappearance of impatient patients, combining current-status, right-censored and left-censored data
Yair Goldberg, Avishai Mandelbaum, Jacob Ritov, Jonathan Yefe-nof, Jennifer Wiler

Abstract: I will present a survival-data setting that combines right-censored, left-censored, and current status data. The motivation is the challenge to estimate patience time, namely, the time till leaving without being served, of patients who arrive at an emergency department, and wait for treatment. Three categories of patients are observed. The first category consists of patients who get service, and thus their patience time is right-censored by the waiting time. The second category comprises those who leave the system and announce it, and therefore their patience time is observed while the waiting time is right-censored. The third category consists of patients who leave the system without announcing it; their absence is hence revealed only when they are called to service, which is after they have already left; formally, their patience time is left-censored. The goal is to estimate the (im)patience distribution, based on these three data categories. I will present a novel methodology for distribution estimation using both parametric and nonparametric techniques. I will also present the performance of these estimators via simulated data and data from emergency departments.

■ TD-20

Tuesday, 14:30-16:00 - Y228b

DEA applications in Energy and Eco-efficiency

Stream: Data Envelopment Analysis and Performance Measurement
Invited session
Chair: *Nikos Chatzistamoulou*

1 - Which developing oil-countries are efficient in low-carbon energy transition?
Naeun Yoon, Aliyeva Simuzar, So Young Sohn

The low-carbon energy transition of developing oil-producing countries is important in mitigating climate change. However, the transition is difficult due to economic and technological issues. This study applied data envelopment analysis (DEA) and BERTopic to help establish effective transition strategies to ensure sustainable technological development. First, the efficiency for transition of oil-producing developing countries was compared using DEA. The countries were clustered based on the DEA peer weights, and countries with high- and low-efficiency in transition were identified per group. Then, the technical fields of high efficiency countries and development strategies were suggested to be benchmarked by the low-efficient countries using topic modeling. The findings of this study can assist in establishing national low-carbon energy policies and decision-making for environmental funds.

2 - The joint use of data envelopment analysis and life cycle assessment for eco-efficiency assessment including cost resources

Leonardo Vásquez, Alfredo Iriarte, Marcela C. Gonzalez-Araya, Lidia Angulo Meza, Ricardo Rebolledo-Leiva

The joint use of life cycle assessment and data envelopment analysis (LCA+DEA methodology) has been of increasing interest for eco-efficiency assessment due the complementarity of both techniques. Particularly, this methodology has used technical DEA models seeking to reduce physical resources and environmental impacts. This work goes beyond by employing overall cost DEA model in order to consider resources costs. In this sense, the main aim of this work is to use an overall cost DEA model for eco-efficiency assessment considering resources, costs and ecotoxicity indicator (ET). The five-step method of LCA+DEA methodology is applied to a set of 26 honey production case study. DEA model considers feeds, medicaments, diesel for transport, electricity for extraction and disposable materials, and their associated costs as inputs, while honey production is the only output evaluated. The DEA model assumes an input-oriented approach and a variable returns to scale. Results shows that 22 beekeepers are classified as inefficient, while only four are efficient. For inefficient beekeepers, an average efficiency of 38% is obtained. Inefficient beekeepers should focus their improvement practices on transport, medication and feeding since they present the main variation. This would reduce current ET level on 9% on average. This study is from special interest for beekeepers and honey decision makers, since its helps to focus resources on the key activity for eco-efficiency improvement.

3 - A robust network data envelopment analysis model with undesirable outputs to assess the efficiency in the power industry

Fatemeh Sarvandi, Aliyeh Kazemi, Mostafa Radsar

Data Envelopment Analysis (DEA) is a non-parametric mathematical model for evaluating the efficiency of a set of decision-making units (DMUs) with multiple inputs and outputs. The uncertainty in such mathematical models can be investigated using a robust optimization method. This paper developed a robust three-stage network DEA consisting of inputs and both desirable and undesirable outputs. To analyze the model's performance, the power zones of Iran, including a three-stage network process consisting of generation, transmission, and distribution processes were evaluated. Inputs included fuel cost, domestic consumption, and the capacity of transmission substations, length of power transmission lines, the capacity of transformers, and length of the low- and medium-voltage distribution networks. Intermediate sizes were net power generation, gross power generation, and delivered energy. Desirable outputs included nominal power, practical power, and delivered energy. Undesirable outputs were environmental pollutants, and energy losses. Evaluation of 16 power zones identified four zones as totally efficient because these zones were efficient in all three processes of generation, transmission, and distribution. In contrast, the other remaining zones were identified as inefficient. As indicated, the major source of inefficiency was related to the transmission process. Thus, all zones are recommended to pay special attention to the distribution process to improve their performance.

4 - Performance growth through a multi-hierarhy of technologies and spillovers. is learning facilitated by adopting greener technologies?

Nikos Chatzistamoulou, Kostas Kounetas

Sustainable Development Goals and the recent European Green Deal set sustainable production as one of the priorities facilitating. sustainability transition. However, country economies face uneven opportunities in implementing green technologies. Acknowledging the uneven development levels across the globe, we introduce a conceptual approach including a multi-hierarchy of technologies employing a non-parametric metafrontier DEA. These technologies are characterized by technological complexity, heterogeneity and variety based on alternative shades of green production and learning grids. Multiple scenaria based on the productive assets included in the production process are used to investigate production possibilities that could facilitate the transition. The setting allows to explore whether the nature and effect of spillovers generated influence performance change across development levels. We apply our conceptual approach on 104 country economies over 9 years, that is from 2006 through 2014. Econometric results between production scenaria indicate that performance changes are indeed attributed to knowledge flows, circulating in each learning grid, associated with green technologies, but only up to a certain extend. Therefore, green technologies are a necessary but not sufficient condition for sustainability transition. Regulations and absorptive capacity influence performance change across hierarchies while the use of renewables seems to be pervasive across hierarchies.

■ TD-21

Tuesday, 14:30-16:00 - Y229a

Behavioural issues in preference elicitation (II)

Stream: Behavioural OR

Invited session

Chair: Judit Lienert

1 - How reliable is fast and frugal preference elicitation?

Martijn Kuller, Philipp Beutler, Judit Lienert

Multi-Criteria Decision Analysis (MCDA) can critically support decision-makers facing complex public and environmental problems. Fast and frugal preference elicitation, such as direct ranking and rating of options or objectives, can be an alternative to standard elicitation methods. This study assesses the understandability and compares the direct (objective weights) and indirect (option rankings) outcomes of such fast elicitation with the outcomes of MCDA using Swing weight elicitation. We thus aim to gain insight into the validity and usefulness of direct ranking and direct rating. We gathered data from three real-world case studies: one on the development of a flood forecast system in West Africa and two related to future wastewater management in small Swiss communities. For each case study, we elicited preferences following Swing during one workshop. In parallel, we elicited direct rankings and ratings of the objectives from stakeholders over time, during 3 to 5 workshops over a 3 to 4 year period (depending on the case study). We found that these methods are moderately well understood, but found no evidence of learning over time. Uncertainty in elicited preferences only partly translated to uncertainty in MCDA outcomes. Further analysis will focus on comparisons between outcomes of more rigorous standard elicitation methods and fast and frugal methods.

2 - Do non-linear utility functions matter? A practical analysis of the impact of non-linear utility functions on the final ranking of alternatives

Mendy Tönsfeuerborn, Rüdiger von Nitzsch, Johannes Siebert

Multi-attribute utility theory is broadly used to evaluate alternatives. Decision makers can express their preferences using partial utility functions. The simplest shape of a utility function is linear. However, a variety of other, more complicated shapes exists. Following the assumption that the more precisely the preferences are modeled, the better the results of the decision analysis are, researchers have developed sophisticated methods to elicit preferences as precisely as possible. These time intensive methods lead often to non-linear utility functions. We found only scarce empirical evidence analyzing to what degree the precise elicitation of preferences is worth the effort. We investigate the extent to which linearization of non-linear utility functions leads to rank shifts, especially of the best-ranked alternative. We analyzed more than 1,000 decisions in the decision support tool Entscheidungsnavi. The participants were trained in using the Entscheidungsnavi and spent several hours with their decision. Therefore, we assume that they articulated their preferences accordingly. Most participants used non-linear utility functions. We calculated the rankings for the participants' stated preferences when all utility functions were linearized. Our analysis reveals that in approximately 90% of cases, linearization of utility functions did not affect the best-ranked alternative. We provide recommendation when to use on non-linear utility functions.

3 - Eliciting and quantifying stakeholder preferences with the robust revised Simos method: Robustness analysis and consensus building

Sebastian Schär, Erik Pohl, Jutta Geldermann

Within the multi-attribute decision-making) methods, inter-criterial preferences of the decision-maker (DM) are elicited and expressed in the form of criteria weights. Due to its convenience and simplicity, the revised method of Simos is a widely applied and interactive method to elicit criteria weights. The DM orders a set of cards, where each card represents a criterion, according to the relative importance of each criterion. This information is then used to calculate the vector of criteria weights. However, since the decision-maker is not fully aware of the underlying calculation procedure, this can lead to undesired preference mappings that do not correspond with his or her actual preference model. The revised Simos method determines all possible weighting vectors which form a hyper-polyhedron based the ordered set of cards. Although the concerns about robustness are expressed in the scientific literature, there is currently no methodological approach to process this information for consensus building in decision problems with multiple DMs or stakeholders. We present an optimization model that determines a consensus alternative within the given sets of weight vectors by the robust Simos method, if possible. The model is based on the PROMETHEE method and is applied to a case study for the selection of water desalination alternatives in the Middle East.

4 - Tackling uncertain stakeholder preferences with the ValueDecisions app

Judit Lienert, Alice H. Aubert, Fridolin Haag

In environmental decision processes, we need to deal with various uncertainties. MCDA, specifically multi-attribute value/ utility theory (MAVT/MAUT) helps to support such complex public policy decisions. This talk focuses on uncertain stakeholder preferences, which often receive less attention than the uncertainty of predictions or the future, even though these can strongly influence the MCDA results. The MCDA model requires several preference parameters: shapes of marginal value functions, objectives' weights, aggregation model (e.g., additive, geometric mean), and the risk attitude if MAUT is used. However, stakeholders often are uncertain about their preferences, especially if decisions concern unfamiliar, complex issues. In this case, we can elicit ranges instead of precise preferences. Moreover, we need to reconcile opposing preferences, and eliciting some parameters is less straightforward (e.g., aggregation). To explore effects of such uncertainties on MCDA results, we propose extensive sensitivity analyses. To facilitate comprehensive but fast analysis, we recently developed the open source app ValueDecisions. It allows for such advanced sensitivity analyses in a user-friendly graphical interface. We demonstrate how ValueDecisions supported two cases with uncertain preferences: wastewater management in the Paris region with online participation of 655 citizens, and developing a flood forecast and alert system for West Africa in workshops with 50-60 stakeholders.

■ TD-22

Tuesday, 14:30-16:00 - Y229c

Multi-criteria methods in sustainable supply chains

Stream: Sustainable Supply Chains
Invited session
Chair: *Matteo Cosmi*

1 - Integrating Sustainability and Multi Criteria Decision Maker (AHP Method) in public organisations of Abu Dhabi'

Alia Alkaabi, Matloub Hussain

Abstract: Nowadays, social and environmental responsibilities have become a major focus within supplier selection. It is a new and upcoming criteria that is beginning to show major effects on supplier selection in the UAE. Its importance is known by organizations both private and public, as it strongly relates to the long-term development of a company. This is a study based on sustainable supplier selection using the AHP method. The purpose of this study is to identify the optimal supplier selection processes. The study includes a literature review on sustainable supplier selection in the private and public sectors, but the research concentrates on public organizations. The methodology will focus on reviewing the cited literature and constructing a model that will show supplier selection using the AHP method. A geometric approach will use data which will be collected from a number of organizations in Abu Dhabi, with a preference scale constructed for the analysis. The results showed that using the AHP model of supplier selection processes can minimize purchasing costs, increase long-term profits and reduce required personal. The data highlights the most important and valuable criteria from the perspective of public organizations

2 - A Multicriteria Decision Making Approach for designing Water Banks

María Borrego-Marín, Laura Riesgo

This paper presents a methodological proposal to approach Water Banks design as a multicriteria problem. Water banks are a tool that can be implemented by policy authorities to reallocate water resources among users, specially under scarcity conditions. The policy maker is assumed to optimize his policy objectives considering the response of water users to each policy scenario. In this case we only evaluate water used for agriculture, since agriculture is one of the main water users in Spain. Farmers' behaviour is represented by means of the Multiattribute Utility Theory and the farmers' first order conditions are used as behavioural equations that the policy authority incorporates as constraints in his policy making problem. We define ideal policies, efficient policies and compromise policies following conventional Multicriteria terminology. We illustrate our approach with an application to Andalusia (Spain) and a bi-criteria problem involving a private economic objective and a public environmental objective.

3 - A Two-Phase Decision Framework for the Supplier Selection, Lot Sizing and Facility Location Problem

Haluk Yapicioglu, Mehmet Alegoz

In this study, we consider the integrated supplier selection, lot sizing and facility location problem under uncertainty and propose a two-phase decision framework. In the first phase, a trapezoidal type-2 fuzzy AHP algorithm is used for the initial evaluation of the suppliers based on various economic, environmental and social criteria, whereas in the second phase, a two-stage stochastic programming model is proposed for the integrated supplier selection, lot sizing and facility location decisions. Proposed decision framework is tested with a real-life case study based on a household goods company in Turkey. Computational results bring various managerial insights regarding the effect of considering the economic, environmental and social aspects of sustainability and handling the uncertainties.

4 - Mathematical programming models for managing the profitability-sustainability trade-off in complex chemical value chains
Matteo Cosmi, Joachim Arts, Steffen Klosterhalfen

Limiting the effects of global warming and climate change is one of the main objectives that the international community has set for the next decades. Therefore, several countries approved laws legally binding them to achieve net-zero targets within the next 25-30 years. One of the major greenhouse gases emitted by human activity is carbon dioxide (CO2) which accounts for more than 75% of the global greenhouse gas emissions. Industry and transport sectors account for more than 35% of the global emissions and there is increasing pressure on industry to pledge net-zero emissions. To remain competitive in their markets while reducing their emissions, companies need to re-optimize their entire supply chain focusing not only on financial key performance indicators (KPIs), such as costs, but also on non-financial KPIs, in particular greenhouse gas emissions. In this work we propose two linear programming models to optimize a deterministic multi-objective supply chain problem aimed at minimizing CO2 emissions and their related costs. We perform an extensive campaign of tests motivated by a real-world industry setting to compare the efficiency of the two model formulations and to analyze the differences with the former supply chain structure when emissions were not a primary concern.

■ TD-23

Tuesday, 14:30-16:00 - Y307

Student Video Prize session

Stream: Pricing and Revenue Management
Invited session
Chair: *Christiane Barz*
Chair: *Luce Brotcorne*

■ TD-24

Tuesday, 14:30-16:00 - Y307a

Inventory Management in Retail

Stream: Demand and Supply in Consumer Goods and Retail
Invited session
Chair: *Rob Broekmeulen*

1 - Inventory Optimization for a Grocer in an Omni-Channel Setting with Retailer-driven Transshipment and Customer-driven Substitution
Martin Waitz, Lena Silbermayr

Operating an omni-channel concept as a grocer successfully is a challenging task, due to the characteristics of the market. We investigate the impact of retailer-driven transshipment and customer-driven substitution on optimal inventory decisions in such a setting both analytically and numerically using a newsvendor model. The modelling of customer behavior (i.e., the stochastic demand for different products in both physical and online stores as well as substitution rates) is based on a survey conducted for the Austrian grocery market in 2021 (n=485), which consisted of general questions regarding the grocery shopping behavior and a choice-based conjoint analysis. We present optimal inventory allocation to online and offline stores in presence of product and channel substitution, show the potential benefit of offering transshipment from physical stores to online customers, and derive managerial implications for a grocer in an omni-channel setting.

2 - Allocating to customer orders in online retail with fair policies
Gonçalo Figueira, Willem van Jaarsveld, Pedro Amorim, Jan C. Fransoo

In online retail, customers place orders for a future due date. Therefore, there is a time window that is typically larger than the shipping time, and which results in 'advance demand information' (ADI) that the retailer can use to better manage its inventory. The allocation of specific units to customers affects the performance of the system in various metrics, such as the number of late deliveries (fill rate) and the average delay. Moreover, some allocation policies can be perceived as being unfair, which is critical, especially when customer orders are recurrent. In addition, they can discourage customers to provide information in advance, which reduces the advantage of ADI. We study different allocation policies and propose a new one, which is 'sensible', optimizes fill rate, and provides a better service level to customers with longer lead-times, thus promoting ADI. When compared to the traditional policy of 'committing upon delivery', the new policy results in a higher average delay. However, the fact that the fill rate is improved has an important impact on operational costs, since it avoids additional deliveries. We provide analytical results for the performance of different allocation policies and simulate their behavior with generated and real data from a large food retailer. Our results show that the new policy is especially advantageous when multiple outstanding orders exist.

3 - Inventory decisions for ameliorating products under consideration of stochastic demand
Marjolein Buisman

Product quality is a key factor in the food and drinks industry, allowing companies to distinguish themselves from their competitors and achieve higher profit margins. However, the quality of a product may be subject to change over time and thus complicate planning and decision-making processes. While most of the literature in this area focuses on quality change in the form of deterioration, there are also products that improve in quality over time, resulting in unique challenges with regard to production and inventory management. In this context, this paper introduces an inventory planning problem for ameliorating products under consideration of demand uncertainty and product loss due to evaporation over time. This problem is solved using a MILP model within a rolling horizon approach. The proposed model is illustrated on two case studies from the cheese and whisky industry and investigated different scenario settings. In these settings, we explore the impact of the length of the considered planning horizon, the level of demand uncertainty involved, the available capacity and the effect of holding cost. The general findings show that the differences in profit margins between the quality categories influence the optimal strategy of the manufacturer and that the optimal aging and storage time should be kept to a minimum.

4 - Using Genetic Programming to induce policies for Fulfillment Optimization
Sérgio Castro, Gonçalo Figueira, Bernardo Almada-Lobo

Fulfillment Optimization is the problem of allocating each unit from online orders that arrives dynamically, to a fulfillment node, which may be a warehouse, a store, or another facility. The main underlying hurdle can be summed up as balancing the immediate fulfillment cost with the future fulfillment costs. While current policies are based on deterministic linear problems (DLPs), which are limited by the amount of complexity that can be incorporated, we propose the use of a policy function approximation method using genetic programming (GP) to iterate on policies. These policies, after trained, may have several practical advantages over DLPs, namely low computational effort, simplicity and interpretability. We generated instances based on real-world data from an online Marketplace operating globally. For the optimization through GP, five functions and nine terminals were used, with a population of 200 individuals and 51 generations. GP generated policies were evaluated for each pair of ordered unit and feasible fulfillment node, resulting in a score used to select the fulfillment node. Results show that the best policy was able to improve 2.4% over a myopic policy which minimizes the immediate fulfillment cost. Future work consists of extending the fulfillment objectives towards a more realistic setting incorporating marketplace, vendors and customers-related features.

■ TD-25

Tuesday, 14:30-16:00 - Y308

Optimization in robotic warehousing systems

Stream: Warehouse Design, Planning, and Control
Invited session
Chair: *Allyson Silva*

1 - Order and pod assignment problem in a multi-level robotic mobile fulfillment system
Giorgi Tadumadze, Julia Wenzel, Simon Emde, Felix Weidinger, Ralf Elbert

Robotic mobile fulfillment systems (RMFS) are parts-to-picker type systems, where pickers do not leave the stationary picking station to pick ordered items. Instead, special shelving units (called "pods") with ordered items are carried to them by a fleet of mobile robots. In this work, we study an operational planning problem of assigning orders and pods to stations in a multi-level RMFS, which deals with two issues: deciding on which picking station handles which order and from which pods to pick the ordered items. Due to the relatively poor space utilization of single-level RMFS, such systems are often spread over multiple floors in practice. Therefore, we explicitly consider a multi-level warehouse layout. We optimize the problem with regard to the following three workload-oriented objectives: balancing the total order-processing workload among all pickers, minimizing the total order-consolidation effort for the packers, and the pod-movement effort for the mobile robots. After formalizing the resulting planning problem as a multi-objective optimization problem, we provide two mixed-integer linear programming models. Additionally, we propose a matheuristic approach that can solve large problem instances within reasonable computation time. In a managerial study, we explore insights on the impact of the number of the levels and the length of picking waves on the objective values.

2 - A two-stage approach for order and rack allocation in a mobile rack environment
J. E. Beasley, Cristiano Arbex Valle

In this paper we investigate a problem associated with operating a robotic mobile fulfilment system (RMFS). This is the problem of allocating orders and mobile storage racks to pickers.

We present a two-stage formulation of the problem. In our two-stage approach we, in the first-stage, deal with the orders which must be definitely fulfilled (picked), where the racks chosen to fulfil these first-stage orders are chosen so as to (collectively) contain sufficient product to satisfy all orders. In the second-stage we restrict attention to those racks chosen in the first-stage solution in terms of allocating second-stage orders.

We present three different strategies for first-stage order selection; one of these strategies minimises the requirement to make decisions as to the rack sequence (i.e. the sequence in which racks are presented to each picker).

We present a heuristic procedure to reduce the number of racks that need to be considered.

Computational results are presented for test problems involving thousands of racks and orders.

3 - Mobile Robot Automation in Warehouses: a Multiple Case Study
Hendrik Reefke, Alp Yildirim, Emel Aktas

Mobile robot systems are an automation solution in warehouses that make order fulfilment agile, flexible, and scalable to cope with the increasing volume and complexity of customer orders. Compared with manual operations, they combine higher productivity and throughput with lower operating costs. As the practical use of mobile robot systems is increasing, decision-makers are confronted with a plethora of decisions, but research is lagging in providing the needed academic insights and managerial guidance. Currently, the lack of a structured decision framework tailored for mobile robot system applications in warehouses leaves the phenomenon unexplained. A theory elaborating case study, involving nine warehouses of five companies, provides evidence on how the mobile robot systems are designed and implemented depending on the technology access decision. This study contributes to knowledge by developing an integrated decision framework for the selection and application of mobile robot systems in warehouses supported through literature and practice. This paper illustrates the motivations of mobile robot system application which assist warehouse managers to understand the rationale behind applying such solutions. Furthermore, the managerial decision framework covering decisions at strategic, tactical, and operational levels aids decision-makers to implement a mobile robot solution step-by-step.

■ TD-26

Tuesday, 14:30-16:00 - Y309b

Applications of OR

Stream: Applications of OR
Invited session
Chair: *Rémi Garcia*
Chair: *Deju (James) Zhang*

1 - ICT adoption & impact on informal firm productivity: Evidence from Indian MSMEs
Lokesh Posti

Despite the significant role of Information and Communication Technology (ICT) in the Indian economic growth, due to the evident digital divide in the country, its usage in the capital-constrained informal Micro, Small and Medium Enterprises (MSMEs) is still in the nascent stage. We evaluate firms' ICT adoption propensity (extensive margin) and intensity (intensive margin), and its impact on MSMEs' performance using the latest available nationally representative cross-sectional data by National Sample Survey Office (NSSO) 2015'-16'. We adopt a Resource Based View (RBV) to analyze the individual and joint effects of ICT and Human Resource (HR) capabilities on diffusion of and returns from ICT. We explore the relationship between ICT and productivity with special attention to the firm-specific characteristics and institutional aspects. We use probit and logit regression and quantile regression techniques for our analysis and implement a novel sensitivity analysis to address endogeneity issues. We find that firms which are older, rural, micro sized, female-owned, un-banked and in manufacturing sector are least likely to adopt ICT. Competition level and spillover effects positively impact ICT diffusion. ICT adoption has a significant positive impact on small firms, especially at the lowest quantile of labor productivity with access to internet and web presence having higher impact than computers.

2 - Toward the Multiple Constant Multiplication at Minimal Hardware Cost
Rémi Garcia, Anastasia Volkova

The Multiple Constant Multiplication (MCM) is a core problem for many scientific computing algorithms, e. g., digital filters and neural networks. Instead of using costly generic multipliers on hardware targets such as FPGAs, the common practice is to replace the constant multiplication by a sequence of additions and bit-shifts. Given a set of target constants, the MCM problem consists in finding a multiplierless solution with minimal hardware cost. The real hardware cost depends on the target and is not practically usable. Instead, we propose a hardware model and a low-level cost function based on counting the number of full adders used in the logic circuit. This metric is closely correlated with the real hardware cost independently of the target. Our ILP-based model is enhanced with the support of intermediate truncations that permit to save hardware resources, and symmetry breaking constraints that accelerate the resolution process. The versatility of the ILP permits to incorporate this basic brick problem into the design into more complicated numerical algorithms. We demonstrate how the MCM can be combined with the design of digital filters to yield hardware implementations superior to the state-of-the-art.

3 - Investigating the use of UAVs for product stock count process in warehouses

Nikolaos Christoforos Thomaidis, Vasileios Zeimpekis

In recent years the complexity of supply chain systems has increased significantly, due to several reasons such as the need for quick and error-free order execution, the evolution of e-commerce, and the customers' need for faster response time. For this reason, the increase of productivity and the reduction of operational costs in logistics operations are critical. The concept of Industry 4.0 fosters the evolution of traditional warehouses towards smart distribution centers using some of the latest advances in technological enablers. One of such technologies is the Unmanned Aerial Vehicles (UAVs), which have evolved lately in terms of technology and their cost has significantly been reduced. Drones comprise a promising option concerning logistics processes in warehouses and are considered a key technology for smart warehouses, since they allow carrying out repetitive and dangerous tasks without almost any human intervention or supervision. To this end, the aim of this paper is initially to review the literature that currently exists concerning UAVs technical and operational characteristics as well as parameters that affect UAVs adoption in logistics processes. The review process drills down in the processes that drones may execute in warehouses by focusing on stock count, which is a complex, dangerous and time-consuming process. Subsequently we identify and review the parameters that affect UAVs operational performance in stock count.

■ TD-27

Tuesday, 14:30-16:00 - Y313

Optimization and Deep Learning

Stream: Numerical Optimization Methods with Inexact Evaluations of Objective Functions and/or Derivatives
Invited session
Chair: Simone Rebegoldi

1 - Efficiently combining first- and second-order directions in neural network training

Marco Viola, Daniela di Serafino, Ángeles Martínez Calomardo, Mahsa Yousefi

The problem of training an artificial deep neural network (DNN) can be formulated as a huge scale unconstrained optimization problem characterized by a highly nonconvex objective function. Such kind of problems are usually solved by means of the stochastic gradient descent (SGD) method and its variants, mainly because of their ease of implementation, their low per-iteration cost, and their theoretical convergence properties. However, first-order methods require a fine tuning of hyperparameters (e.g., the steplength sequence) and tend to struggle in case of ill-conditioned problems. In the last few years stochastic variants of Quasi-Newton methods (possibly combined with line-search or trust-region strategies) have been analyzed, with the aim of including partial curvature information in the search direction. Second-order methods may have two potential drawbacks: first, when far from the solution second-order information may be misleading; second, the use of second order information could push towards local minimizers. Inspired by recent developments in the case of deterministic optimization problems, we here investigate efficient strategies to combine trust-region quasi-Newton directions and specialized first-order directions, aiming at exploiting the pros of both the two classes. Numerical experiments, including comparisons with first- and second-order stochastic optimization methods, show the efficiency of the proposed approach.

2 - l1-Regularization in Portfolio Selection with Machine Learning

Valentina De Simone, Stefania Corsaro, Zelda Marino, Salvatore Scognamiglio

In this talk we investigate the use of supervised Machine Learning techniques in a multi-period Markowitz mean-variance framework. The model leads to a constrained optimization problem where a l1 penalty term is introduced into the objective function to reduce the cost of the investment strategy. A crucial issue is the choice of the regularization parameter, that is often based on problem-dependent criteria and related to iterative estimates, requiring a high computational cost. We propose an algorithm based on Deep Neural Networks (DNN) to automatically estimate the regularization parameter via forward propagation [1]. The training involves an unconstrained optimization problem with a Poisson loss function solved by the ADAM method. To fight the vanishing gradient problem that affects the training of deep learning networks, skip connections were introduced. Numerical experiments and comparisons performed on real financial data show the effectiveness of our approach. The DNN-based approximation seems to accurately capture the relation between the selected features and the optimal regularization parameter, producing portfolios with satisfying financial properties.

[1] Corsaro S, De Simone V, Marino Z, Scognamiglio S. l1-Regularization in Portfolio Selection with Machine Learning. Mathematics, 10(4):540, 2022

3 - A new framework combining deep learning and iterative minimization for imaging applications

Elena Morotti, Davide Evangelista, Elena Loli Piccolomini

Inverse problem-based image processing is an active research field that has been recently revolutionized by the advent of convolutional neural networks, as deep learning-based schemes often yield superior results than classical optimization approaches. However, their ability to actually compute the inverse problem solution is still questionable and discussed in the literature, where unstable results have been reported both numerically and theoretically. In this talk, we present a new scheme, called RISING, embedding deep learning tools in an optimization approach. Numerical results and theoretical aspects will be discussed, showing that RISING preserves the convergence properties of iterative solvers and, at the same time, it exploits the accuracy and flexibility of data-driven approaches.

4 - Training of neural networks for monitoring electricity consumption

Stefania Bellavia, Carlo Carcasci, Simone Rebegoldi, Marco Zini

Building energy management strategies lead to important energy saving, especially for energy-intensive buildings. Their development requires carrying out the detailed analysis of the building energy needs for the specific test case of interest. When neural networks are employed for carrying out such analysis, the choice of the model requires a fine and time-demanding tuning process that involves the choice of the network architecture (hidden layers and activation function) and of the parameters (learning rate scheduler and batch-size) of the optimization methods used for the network training. In this talk, we investigate the employment of neural networks for the analysis of the electricity consumption of a healthcare facility located near Florence, Italy. We apply some adaptive first-order optimization methods that automatically choose the learning rate and sample size at each iteration, and compare their performance with that of ADAM and SGD on this real problem. We will show the advantages of adaptive approaches in reducing the tuning efforts in designing and training a neural network. The proposed approach represents a reference methodology for machine learning-aided building energy monitoring, applicable to several different contexts and applications.

■ TD-28

Tuesday, 14:30-16:00 - Y405

Learning Methods for Stochastic Models

Stream: Stochastic Dynamic Programming and Learning Policies
Invited session
Chair: Odysseas Kanavetas

1 - A stochastic game framework for patrolling a border

Matthew Darlington, Kevin Glazebrook, David Leslie, Rob Shone, Roberto Szechtman

We consider a stochastic game for modelling the interactions between smugglers and a patroller along a border. The problem we examine is a group of cooperating smugglers making regular attempts at bringing small amounts of illicit goods across a border. A single patroller has the goal of preventing the smugglers from doing so, but must pay a cost to travel from location to location.

We model the problem as a two-player stochastic game and look to find Nash equilibria so that we can gain insight to real world problems. Our framework extends the literature by assuming that the smugglers choose a continuous quantity of contraband, complicating the analysis of the game. There are a number of properties of the Nash equilibria in the game, which we can prove analytically, that lead towards new methods of calculating them.

The methods we have developed are then significantly more computationally efficient than existing general ways to find Nash equilibria in our model. Due to this efficiency, we have been able to investigate various scenarios and examine the behaviour of the players. This has led us to explore how parameters such as the penalties applied to the smugglers by the patroller and topology of the border can affect the patroller's strategy.

2 - Adjusted Distributionally Robust Bounds on Expected Loss Functions

Yasemin Merzifonluoglu, Joseph Geunes

Optimization problems in operations and finance often include a cost that is proportional to the expected amount by which a random variable exceeds a given quantity, known as the expected loss function. In practical settings, a decision maker may possess limited information about the underlying distribution of the associated random variable, such as the mean and variance, but not the exact form of the associated probability density or distribution function. In such cases, a distributionally robust optimization approach seeks to minimize the maximum expected cost among all possible distributions that fit the available information. Past research has recognized the overly conservative nature of this approach because it accounts for worst- case probability distributions that almost surely do not arise in practice. Motivated by this, we propose a distributionally robust approach that accounts for the worst-case performance with respect to a broad class of common continuous probability distributions, while producing solutions that are less conservative than those produced by existing distributionally robust approaches in the literature. To do this, we generalize the concept of standardized loss functions for normal distributions to other well-known classes of distributions, while also using a generalized and standardized version of the Student's t-distribution to determine worst-case bounds for the associated standardized loss functions.

3 - Optimal Discrete Search with a Map

Edward Mellor, Kevin Glazebrook, Rob Shone, Kyle Lin

Effective search strategies are required in many areas. Salvage missions, such as that for missing Malaysian Airline flight 370, can be very expensive and so it is important to ensure that the odds of success are as high as possible. After a natural disaster, finding survivors quickly can greatly improve their chances of recovery. Locating hidden explosives before they have a chance to detonate can save lives. Search theory is an area of operations research that aims to find the best possible strategy for such problems. The classical discrete search problem (CDSP) involves a single stationary object that had been hidden in one of finitely many distinct locations with known hiding probabilities. Searching each location takes a known amount of time and is successful with a known probability if the target is there. In this problem, a strategy that minimises the expected search time can be obtained by following an index rule. Here, we generalise the CDSP to incorporate the geography of the problem by including travel times between each pair of locations. An index-based approach is developed using restless bandit theory. The resulting strategies are then augmented using a variety of approximate dynamic programming techniques. The effectiveness of these approaches are then compared in an extensive numerical study.

■ TD-29

Tuesday, 14:30-16:00 - M1

Complex Scheduling I

Stream: Industrial Production, Planning and Inventory Management
Invited session
Chair: Robert Moss

1 - A GRASP for a real-world scheduling problem with unrelated parallel print machines and sequence-dependent setup times

Alberto Locatelli, Manuel Iori, Marco Locatelli

We consider a real-world scheduling problem arising in the color printing industry. The problem consists in assigning print jobs to a heterogeneous set of flexographic printer machines and finding a processing sequence for the jobs assigned to each machine. The machines are characterized by a limited sequence of color groups and can equip additional components (e.g., embossing rollers and perforating rolls) to process jobs that require specific treatments. The process to equip a machine with an additional component or to clean a color group takes a long time, with the effect of significantly raising the setup times. The aim is to minimize a weighted sum of total weighted tardiness and total setup time. The problem derives from the activities of an Italian food packaging company. To solve it, we developed a greedy randomized adaptive search procedure equipped with several local search procedures. The excellent performance of the algorithm is proved by extensive computational experiments on real-world instances, for which it produced good-quality solutions within a limited computing time. The algorithm is currently in use at the company to support their weekly scheduling decisions.

2 - The medical-radioisotope cyclic-scheduling production cost optimization

Ron Weitzman, Inessa Ainbinder, Daniel Lifshitz, Gavriel David Pinto, Amiram Azarzar, Gad Rabinowitz, Eyal Mishani

The F-18 radioactive isotope is used to diagnose and monitor many types of cancer. The isotope production process consists of several stations, including cyclotron irradiation, module cell synthesis, and vial filling division. At each station there are several alternative machines and the produced vials with the isotope are transported to different hospitals. The F-18 isotope is an unstable substance, with a half-life equal to about 110 minutes (the time required for half of the atoms of the isotope to decay). The demand is provided daily by each hospital together with their treatment schedule and the level of radioactivity planned for each treatment at the time of delivery. In our work, inspired by cyclic-scheduling production in supply chains, we developed a model for the production stage of the cyclotron, to determine the optimal number of daily batches and their quantity to meet all hospitals' demand at a minimum cost (production, holding, loss of radioactivity level). Inventory levels depend on production rate, demand rate and isotope exponential decay rate. Therefore batch-cycles were split into three distinct periods: production, delivery, and patient treatment to create an additive optimization cost function. The proposed model is a novel relaxed optimization model with a convex cost function that can be solved analytically.

3 - Dispatching Heterogeneous AGVs with Battery Constraints using Deep Reinforcement Learning
Nitish Singh, Alp Akcay, Tugce Martagan, Ivo Adan

Automated Guided Vehicle (AGV) manufacturers provide simple dispatching rules for controlling AGV movements since they are scalable and easy to implement. The dispatching rules are not cost-effective as they do not use spatial and temporal data that could position the AGVs better. Further, the applications of AGVs have grown enormously because of their benefits, such as flexibility in processes, space utilization, product safety, and computer integration and control. Heterogeneous tasks, prevalent in the high-tech manufacturing sector, require specialized equipment for material handling. The advancement in AGV technology facilitates different capabilities of AGVs, such as lifting light or heavy loads and towing loads. A fleet of AGVs with varying capabilities can fulfil heterogeneous tasks. Artificial Intelligence techniques have been shown to extract temporal and spatial patterns for decision making. Their ease of use and their robustness to changes, such as fleet size, order arrival patterns and order characteristics, make them an attractive alternative to simple dispatching rules. Thus, we develop an AI-based AGV fleet management algorithm to serve requests where the requests are serviced by a fleet of AGV, which is heterogeneous with a diverse set of capabilities and travel costs. Our algorithm is compared against a simple dispatching rule to prove its superiority.

4 - Improving wafer fabrication plant KPIs through deployment of a multiobjective hybrid MILP scheduling model
Robert Moss, Sharon Feely, Laura McElhinney, Semya Elaoud, Martin Breslin

Real world wafer fabs have multiple manufacturing KPIs such as throughput, cycle time, load balancing between tools, reticle moves and batch size. Some of these KPIs might be conflicting, for example maximising the throughput of a photolithography toolset while reducing the number of reticle movements between tools. We present Flexciton's novel solution strategy that combines MILP optimisation with heuristic techniques to schedule thousands of wafers and a large variety of tool types. This has been deployed in Seagate fabs and has shown significant KPI improvements in low/high WIP and slow/fast moving toolsets. Using Seagate's production data we showcase how we accommodate complex problem features to provide high quality schedules.

■ TD-30

Tuesday, 14:30-16:00 - M237

Vector and Set Optimization I

Stream: Vector and Set Optimization
Invited session
Chair: Miguel Sama

1 - Vector optimization with respect to variable domination structures
Christiane Tammer, Truong Q. Bao, Boris Mordukhovich, Antoine Soubeyran

In this talk, we are dealing with vector optimization problems in infinite-dimensional spaces where the solution concept is given by variable domination structures. Vector optimization with variable domination structures is a growing up and expanding field of applied mathematics that deals with optimization problems where the domination structure is given by a set-valued map. Interesting and important applications of vector optimization with variable domination structure arise in economics, behavioral sciences, in portfolio management, location theory and radiotherapy treatment in medicine. We introduce several concepts for (approximate) solutions to vector optimization problems with variable domination structures and show corresponding characterizations by means of nonlinear functionals. Furthermore, we derive necessary conditions for approximate solutions using techniques from variational analysis. These results are useful for further research on the field of vector optimization with variable domination structure, especially, for deriving numerical procedures.

2 - Extension of continuous quasiconvex functions
Carlo Alberto De Bernardi

In the talk, we will present some recent results, obtained in collaboration with L. Vesely, concerning the problem of extending quasiconvex functions from subspaces and subsets of a nontrivial real normed linear space X, in such a way that the extension preserves the continuity properties of the starting function. For example, we proved that if Y is a closed subspace of X such that the quotient X/Y is separable then each continuous quasiconvex function defined on Y admits a continuous quasiconvex extension defined on the whole X. Concerning the extension from subsets, we proved that each uniformly continuous quasiconvex function, defined on a uniformly convex subset A of X, admits a uniformly continuous quasiconvex extension to the whole X. Finally, we will present some examples showing that the assumptions of our results cannot be avoided.

3 - New efficient search strategies for direct search algorithms in multiobjective derivative-free optimization
Ludovic Salomon, Sébastien Le Digabel, Jean BIgeon

In the last decade, researchers have developed new convergent-based multiobjective derivative-free optimization algorithms, most of them extensions of reliable single-objective methods. Among them, direct search methods have shown promising performance compared to common evolutionary algorithms. Direct search methods are organized around a search-poll paradigm. The poll, a local step around an incumbent solution, guarantees the convergence of the method. The search, an optional step, enhances the performance of the algorithm. Search strategies have been extensively investigated in single-objective optimization, but are almost inexistant in multiobjective optimization. This work presents several extensions of single-objective search strategies to multiobjective optimization. One is based on the use of polynomial models, the other on the Nelder-Mead algorithm. Computational results illustrate the performance of these new approaches.

4 - Stability analysis of conically perturbed linearly constrained least-squares problems. A vector optimization approach.
Miguel Sama, Akhtar Khan

This talk addresses the linearly constrained least-square optimization problems in Hilbert spaces for which the KKT system is not necessarily available to analyze and compute the solution. A possible remedy is the conical regularization method that replaces the constraint cone with a family of dilating cones. This talk will present new stability estimates for the regularization error in the conical regularization approach. For that, we associate the notion of stability with the solvability of some scalar and vector optimization problems defined in terms of the regularized trajectory on the domain space and the regularized state trajectory on the constraint space.

■ TD-31

Tuesday, 14:30-16:00 - M240

Splitting methods in convex optimization II

Stream: Variational analysis and optimization
Invited session
Chair: *Francisco Javier Aragón Artacho*

1 - Resolvent splitting with minimal lifting
Matthew Tam, Yura Malitsky

In this talk, we examine some fundamental limitations of fixed point algorithms for finding a zero in the sum of n≥2 maximally monotone operators using their resolvents. A common approach to this problem involves reformulating as an equivalent two operator inclusion within an n-fold Cartesian product space and applying the Douglas-Rachford algorithm. In the setting where each resolvent may only be evaluated once per iteration, we show that any fixed point algorithm is necessarily defined on a d-fold Cartesian product space with d≥n−1. Further, we show this is unimprovable by providing a new family of methods which attain the lower bound.

2 - A reformulation on a product space with reduced dimension for splitting algorithms
Rubén Campoy

The product space reformulation is a powerful trick when tackling monotone inclusions defined by finitely many operators with splitting algorithms. This technique constructs an equivalent two-operator problem, embedded in a product Hilbert space, that preserves computational tractability. In this talk, we discuss a new reformulation that reduces the dimension of the outcoming product Hilbert space. As an application, we obtain a new parallel variant of the Douglas-Rachford algorithm with a reduction in the number of variables. The computational advantage is illustrated through some numerical experiments.

3 - Constraint reduction reformulations for projection algorithms
Neil Kristofer Dizon, Minh Dao ngoc, Jeffrey Hogan, Matthew Tam

We present a reformulation technique that converts a many-set feasibility problem into an equivalent two-set problem. The technique involves reformulating the original feasibility problem by replacing a pair of its constraint sets with their intersection, before applying Pierra's classical product space reformulation. We apply the reformulation to obtain constraint-reduced variants of well-known projection algorithms such as the Douglas-Rachford algorithm and the method of alternating projections, among others. As part of the convergence analysis, we generalize a classical result which guarantees that the composition of two projectors onto subspaces is a projector onto their intersection.

■ TD-32

Tuesday, 14:30-16:00 - F101

Bilevel Optimisation

Stream: YoungWomen4OR
Invited session
Chair: *Annunziata Esposito Amideo*

1 - Convergent algorithms for a class of bilevel programs
Martina Cerulli, Antoine Oustry, Leo Liberti, Claudia D'Ambrosio

A bilevel problem is an optimization problem where a subset of variables is constrained to be optimal for another given optimization problem parameterized by the remaining variables. The outer problem is commonly referred to as the upper-level problem, the inner one as the lower-level problem. Throughout my PhD at Ecole Polytechnique (France), I worked on different applications which can be modeled using bilevel programming, such as aircraft conflict resolution problem, to mention one. On a more theoretical level, I focused on a particular class of bilevel problems having a lower level with a quadratic objective function, the value of which is contained into an upper-level inequality constraint. They can be obtained by reformulating semi-infinite programming problems with an infinite number of quadratically (potentially nonconvex) parametrized constraints. Based on the Lagrangian dual of the lower-level problem, we derived a convex and tractable restriction of the considered bilevel problem. We stated sufficient conditions for the optimality of this restriction. To deal with formulations for which these conditions are not met, we introduced a new Inner-Outer Approximation algorithm, that progressively enlarges the restriction set so as to generate a sequence of feasible points, the values of which converge to the value of the original bilevel problem. This new algorithmic approach is compared with the classical Cutting Plane algorithm. We also propose a new rate of convergence of the Cutting Plane algorithm, directly related to the iteration index, derived when the objective function is strongly convex, and under a strict feasibility assumption. The talk will give an overview on these promising results and on the direction of my research.

2 - Robust and Bilevel Optimization playing together for Decision Making
Marina Leal Palazón

Combinatorial Optimization problems have been largely studied in the specialized literature; however, in the last decades, there has been a paradigm shift towards the treatment of more realistic problems, in which uncertainty sources in the data and multiple criteria or levels of optimization are included. This trend continues growing due to the economic importance of the existing applications in areas such as Location, Transportation, Planning, Design, etcetera. When uncertainty is present in the parameters defining a problem, a compromised solution can be achieved by using the minmax regret paradigm from Robust Optimization. In the minmax regret models, each feasible decision is evaluated with respect to the most unfavorable possible reaction in the system. When hierarchies are present in the decision process, solutions can be managed via Bilevel Optimization. The goal of this talk is to show that the minmax regret criterion can be seen and rewritten as a bilevel model, and to present novel combinatorial optimization models, in the context of decision-making, in which uncertainty is incorporated in the parameters defining the problem; and also models in which there exist several decision-makers and a hierarchical decision structure. All the models we present are nonlinear, with applications in areas such as Design, Transportation, Location, Planning or Portfolio Selection.

3 - Feature Selection in (Functional) SVM via Bilevel Optimization.
M. Asuncion Jimenez-Cordero

Feature selection plays a key role in Data Science. Apart from reducing the computational burden of the problems involved, it provides interpretability to the results obtained. In addition, it can improve the performance values by removing superfluous information. On the other hand, one of the most popular techniques in Data Science is binary classification and Support Vector Machines (SVM) is often used to solve these types of problems. In this talk, we focus on the formulation of new Bilevel Optimization models designed to select the most important features in binary classification problems solved with SVM. Note that, apart from the standard multivariate data belonging to the Euclidean space of real numbers, our approaches can be applied to Functional Data. In other words, our proposals can be used in datasets whose individuals are functions instead of points. The efficiency and usefulness of our proposals are numerically tested on synthetic datasets and real-life applications.

4 - Urban Logistics and Mobility - How can we do better?
Layla Martin

Optimizing planning and operations of urban logistics and mobility is complex: Margins and budgets are often slim and customers demand a high service level given by a variety of metrics, and have alternative options. This environment is shifting due to new market entrants and technological advancement. Moreover, cities consider restricting private services due to their contribution to emissions and congestion. Further, market outsiders must make decisions with limited information. To account for these complexities, we must (i) bring together traditional operations research and transportation science methodologies with methods used in nearby fields such as artificial intelligence and game theory. In urban retail, customers have the choice among multiple supermarkets, but their choice behavior is hidden from market outsiders. To obtain some insight into the customers' choice, they must inversely optimize parameters. (ii) We must integrate additional features into classic models. For example, to obtain a high service level, budget-constrained vehicle sharing services must decide where to offer the service first, to finance later expansion. Operators must balance their investment in expensive, but easy to control, driverless and cheap, but difficult to operate, human-driven vehicles. (iii) We must rethink our measures of service quality, and the objectives we optimize for. For example, giving a customer a tight delivery time window may be more important than the shortest route.

■ TD-33

Tuesday, 14:30-16:00 - F102

Game Theory, Solutions and Structures II

Stream: Game Theory, Solutions and Structures
Invited session
Chair: *Joaquin Sánchez-Soriano*

1 - Sharing the Cost of a Gas Distribution Network.
David Lowing

A gas distribution network draws gas from a gas arrival point to deliver it to the consumers. This network is managed by an operator, whose job incurs a variety of costs, some of which may not be attributable to a particular consumer. Assuming that the operator recovers these costs by charging the consumers, the problem is then to determine how to share them among the consumers. We address this problem and propose cost sharing rules that depend on the network and the demands of the consumers. To that end, we adopt a normative approach and resort to three principles: (i) the independence of higher demands principle, (ii) the connection principle and (iii) the uniformity principle. Applying (i) and (ii), we derive the Connection rule and applying (i) and (iii), we derive the Uniform rule. It appears that (ii) and (iii) are incompatible. To make a trade-off between these two principles, we propose the Mixed rules, which compromise between the Connection rule and the Uniform rule. For each cost sharing rule, an axiomatic characterization is provided. Then, we show that the Connection rule coincides with the multi-choice Shapley value of a specific multi-choice game derived from the problem. Moreover, the Connection rule is in the Core of this specific multi-choice game. Similarly, we show that the Uniform rule coincides with the multi-choice Equal division value and the Mixed rules coincide with the multi-choice Egalitarian Shapley values.

2 - A new approach for rankings in graphs using game theory
Alejandro Saavedra-Nieves, Encarnación Algaba, Herbert Hamers, Andrea Prieto

In this talk, we introduce novel centrality measures for ranking terrorists in a network that integrate its complete topology (nodes and edges). The innovation lies in the fact of considering a coalitional structure on its nodes that describes their characteristics, their possible relationships, as well as coalitional information independent of the network. For this purpose, different centrality measures, based on game theoretical solutions, can be considered as well as the associated computational problems for their obtaining that sampling techniques clearly reduce. As illustration, we rank the members of the Zerkani network, responsible for the attacks in Paris (2015) and Brussels (2016).

3 - "The tragedy of the commons" when a scarce renewable resource becomes strategic in short run
Agnieszka Wiszniewska-Matyszkiel, Rajani Singh

We model the problem of "the tragedy of the commons" that appears when, because of an unpredicted emergency need, a scarce resource becomes a strategic input in a production of the countermeasure to the current threat to the society's safety. The model uses the terminology connected to the squalene market in the context of COVID-19 vaccines with adjuvants based on squalene obtained from endangered deep-sea shark species and it has a compound dynamic game form taking into account various aspects of this market and the privileged position of relatively small number of vaccine producers.

The game describes a market consisting of pharmaceutical, cosmetic and fishing sector, in presence of a regulatory institution. We calculate Nash and Stackelberg equilibria in which COVID-19 vaccine producers do not take into account their influence on the population of sharks. We prove the existence and uniqueness of equilibria together with deriving the formula to find it.

The tragedy of the commons in both cases results in endangering of the vaccination programme: either because of depletion of the shark population or its reduction to a level at which the cost of squalene production exceeds the maximal price that can be paid for it. Various remedies are suggested.

Despite specific terminology, this is a starting point to a general theory emphasizing the need to indicate other potential scarce renewable resources for which similar phenomena can appear in the future.

4 - Allocation rules based on priority when claimants can't get all they could
Joaquin Sánchez-Soriano

This paper deals with conflicting claims problems when allocation rules based on priority are implemented but withdrawal limits are fixed by a central planner. Two approaches to limit withdrawals are assumed. One is based on the principle that agents can only obtain at most a fixed part of the endowment each time and the second is that agents can only receive at most a portion of their claims each time. We illusttrate both cases by only considering the cases in which the amount that each agent can obtain is fixed for each of the possible rounds. We show that those iterative procedures to obtain the allocation rules converge in a finite number of rounds until the endowment is completely distributed. We also present their relationship with the classic bankruptcy rules and the properties satisfied by these rules.

■ TD-34

Tuesday, 14:30-16:00 - T003

Incentives and Performance in Healthcare Delivery

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: *Heikki Peura*
Chair: *Jonas Oddur Jonasson*

1 - Pricing Algorithmic Insurance for Medical Malpractice
Agni Orfanoudaki

As machine learning algorithms start to get integrated into the decision-making process of healthcare organizations, insurance products will be developed to protect their owners from risk. We introduce a quantitative framework for insurance companies, machine learning modelers, and healthcare practitioners in order to price the risk of these products. Using properties of the model, such as discrimination performance, interpretability, generalizability, and robustness, we provide mathematical formulations for its financial evaluation. We present a case study of medical malpractice in the context of breast cancer detection where we estimate the risk exposure of a binary classifier.

2 - Operations Planning in Covid-19 Surveillance Testing Programs
Mathieu Dahan, Hannah Wilborn Lagerman, Pinar Keskinocak, True Merrill

Surveillance testing is a key portion of Covid-19 pandemic management efforts. However, competitive supply chain conditions early on resulted in lack of supplies and limited testing capacity for testing laboratories. In this work, we study the benefits of double pooling strategies, in which samples from multiple individuals are combined and tested as one. The pooling structure enables the identification of positive samples when the number of positive samples is low. However, as more samples are positive, more pools become ambiguous, for which individual samples must be re-tested. We develop a detailed discrete event simulation model to represent testing operations and determine effective testing capacities as a function of selected pool sizes and disease prevalence. We then develop an optimization model to determine the optimal tradeoff between pool sizes and re-tests that maximizes a laboratory's testing capacity, as a function of the disease prevalence. We conduct a computational study utilizing the data from Georgia Tech Covid-19 testing laboratory and demonstrate the value of adjusting the pooling strategy as the pandemic evolves.

3 - Resource Reallocation: Empirical Evidence from Drug Shortages in the United States
Iva Rashkova

Drug shortages in the United States have been persistent in recent years with more than 100 drugs on shortage nationwide at a given point in time, on average. The adverse impact of drug shortages on health outcomes is well-documented. Yet, rigorous research on the reasons behind such shortages is scarce.

We leverage a combination of publicly available data sources to study the link between new drug approvals and drug shortages. Specifically, we classify drug approvals by therapeutic class of the drug as well as by type - brand name, generic with or without market exclusivity. We observe that the event of a new drug shortage reported by the FDA is correlated with a subsequent drug approval for the same firm. Interestingly, the time lag between these events is increasing in the attractiveness of the drug approval's type. With the time lag identified based on the drug approval type, we also find a positive correlation between the time-to-recovery of an individual drug-shortage event and the associated drug approval. Furthermore, a drug shortage by one firm is correlated with shortages of the same drug by the other firms approved for its production.

Our results potentially offer healthcare providers and policymakers insights into industry-wide capacity and resource reallocation trends.

4 - Coordinating Health and Social Services: Impact of Allowing Non-Medical Services in Medicare Advantage Programs.
Jonas Oddur Jonasson, Heikki Peura

Following the Creating High-Quality Results and Outcomes Necessary to Improve Chronic (CHRONIC) Care Act of 2018, CMS allowed Medicare Advantage (MA) plans to offer non-medical supplementary benefits to patients with chronic conditions from 2020. The impact the CHRONIC Care Act will have on the cost, quantity, and quality of health services offered to the Medicare population is unclear. It might also affect beneficiaries' enrollment choice between MA and MO. We ask two main questions. First, when is it in the best interest of MA providers to offer non-medical services? Second, will the increased flexibility of service offerings give MA providers additional opportunities to cream-skim? To answer these questions, we develop a model of the interaction between CMS, MAs, and Patients. We find that cream-skimming can increase as MA providers are allowed to offer a wider scope of services.

■ TD-35

Tuesday, 14:30-16:00 - T004

Transportation modelling I

Stream: Transportation
Invited session
Chair: Carla Binucci

1 - The impact of bus punctuality on users' decisions and welfare
Fernando Feres, Franco Basso, Raul Pezoa, Mauricio Varas, Eusebio Vargas-Estrada

This paper proposes a public transport users scheduling model that considers crowding inside vehicles, waiting time, and punctuality as a reliability measure. Commuters simultaneously make two choices: the preferred bus and the timing to arrive at the bus stop (on time or late). Public transport punctuality is the probability of being on time or late, generating a parameter of public transport reliability. We compute users' equilibrium, social optimum, first best pricing and analytically devise a methodology to obtain second-best pricing. Using numerical analysis, we show that: i) punctuality plays an essential role in the commuters strategy modifying according to its level, ii) commuters' strategy changes according to how reliable the system is, and iii) second-best pricing is efficient only for limited cases.

2 - Choice-based Routing in Attended Home Delivery
Dorsa Abdolhamidi, Virginie Lurkin

While e-commerce has been long on the rise, the closure of shops and restaurants during Covid lockdowns has further bumped up the requests for home deliveries in limited urban spaces, worsening the issues related to urban logistics. Customers expect to be delivered at home at a convenient time and fast and reliable way. To meet customers' expectations, many e-shops allow consumers to select their favorite delivery time windows from a menu of time-slots. Enabling consumers to select their preferred delivery time increases customers' satisfaction but might cause higher delivery costs for the online retailer. In this study, we explore a static vehicle routing in which the customers' preferences regarding time windows are explicitly taken into account. More specifically, customers' choice is captured with a multinomial logit model. Using simulation, we present a mixed-integer linear programming formulation. The goal is to minimize the retailer routing costs while maximizing customers' utility functions. We demonstrate the effectiveness of the formulation on several instances solved exactly.

3 - A System to support personalized travel experiences and local policies of tourism promotion.
Carla Binucci

Automatic planning of personalized tourist itineraries is a hard task both on the methodological side, relating to how to effectively exploit the large amount of data sources available, and on the algorithmic side, relating to the high computational effort characterizing the nature of the problem. A Content-based travel recommender system helps a tourist planning itinerary by suggesting attractions, named points of interest (POIs), that better match with user's preferences. A critical aspect of such systems is to have a knowledge base that indicates how relevant each POI is for a given set of topics of interest (TOIs). We study the problem of designing the content analyzer of a content-based travel recommender system, which, given a set of POIs and a set of TOIs, computes the relevance of each POI with respect to each TOI. We propose a graph-based algorithmic approach that is unsupervised, fully automatic, and relies on publicly available sources of information. In a complementary view, data deriving from recommendation services or other sources may help local administrators to implement effective local policies of tourism promotion. In this direction, we also study the problem of designing tools for the visual analysis of touristic flows, which support in understanding relevant patterns and behaviors. Acknowledgements: Supported by the Italian Ministry of Instruction, University and Research within Project "SMARTOUR: Intelligent Platform for Tourism"-Grant n.SCN_00166

4 - Challenges in Home to School Transport: Large-Scale School Bus Routing Inclusive of Special Needs Students
Ozioma Paul, Manuel López-Ibáñez, Julia Handl

In England, there is a growing population of Special Educational Needs and Disabilities (SEND) pupils and increasing awareness about the importance of inclusion in education. A significant part of this inclusion is to provide safe transportation to and from school. The need for this study was highlighted by the fact that while School Bus Routing Problem (SBRP) for general-education pupils has received considerable research attention, not much has been done for SEND pupils. Furthermore, because of the mobility constraints unique to SEND pupils, the resources needed are more than is needed for general-education pupils. Hence, it is important and useful to research ways to solve SBRP for SEND pupils in a cost-effective and inclusive manner. This study is focused on the initial phase of developing and evaluating optimization models to solve SBRP for SEND pupils using real-world datasets within England. We investigate mobility constraints unique to SEND pupils through an extensive systematic literature review and engagement from relevant stakeholders within the education ecosystem. Some of these constraints include students' maximum riding time and extra space for mobility aids such as wheelchairs and caretakers. For future work, we would explore multi-objective optimization techniques and SBRP techniques such as mixed riding and heterogeneous fleets to allow for more optimal transportation of both special-needs and general-education pupils.

■ TD-36

Tuesday, 14:30-16:00 - U006

COVID-19 - Vaccines

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: *Roberto Aringhieri*

1 - Linear Mathematical Models for Real Time Scheduling of Vaccination with Inventory Constraint
Gercek Budak

Covid-19 virus pandemic has shown that humanity is unprepared for the decision making problems under the pandemic situations in various fields. One of those fields is the management of vaccination distribution and sorting the importance levels of who should be vaccinated. This study proposes three different linear mathematical models for giving the optimal decision of ordering and scheduling the groups of people to be affected from the concerned disease. In a pandemic situation, it has been seen that the amount of vaccination is a scarce resource in terms of inventory. The proposed models give the decision maker who should be vaccinated depending on the importance level, the risk of getting the disease and the risk of losing one's life when diseased. These mathematical models can be run in any time of the pandemic for these decisions for different situations depending on the inventory levels and the remaining people who have not been vaccinated. The models are generalized models that can be used for different pandemics which is certainly going to effect the parameters of the proposed models.

2 - Waterfall approach to minimizing wastage in vaccine supply chains
Katarzyna Gdowska, Radosław Kapłan, Roger Książek, Piotr Łebkowski

The problem of vaccine distribution during a mass vaccination campaign consists of a variety of decision-making issues, including the decision of how many vaccines to prepare for a given day with assumed demand, so that the aggregate loss of unused doses is minimized. The magnitude of these issues during COVID-19 reactive vaccination has become even more important. It is important to remember that proper vaccine allocation during an outbreak of an infectious disease leads to reducing both the total cost of a vaccine campaign and the total number of infections. Note, that anti-COVID vaccines like influenza vaccines are one-time newsvendor products, while other vaccines are rather perishable economic order quantity (EOQ)-type products. In OR the newsvendor problem is considered as a fundamental decision-making model for determining order policy when supply and/or demand is uncertain. The problem addressed in this paper can be formulated as minimizing the total number of unused doses, using the newsvendor problem as a starting point. The newsvendor model has previously been successfully used to plan the distribution of various goods supplied under subsidy programs such as food, household equipment, and drugs or vaccines. This approach fits into the discourse on mass vaccination policy and the humanitarian goods supply chain, where minimizing the number of unused goods (e.g. vaccine doses) is crucial, as it is minimizing the waste of public funds.

3 - Two Stage Stochastic Optimization Model for Vaccine Supply Chain Network in Pandemic Situation
Paulina Kus Ariningsih, Chandra Irawan, Antony Paulraj

The uncertainty during the pandemic situation had been a challenge to set up a supply and distribution network, resource allocation, and inventory in the healthcare supply chain. This condition also exists in the vaccines supply chain, which is crucial for developing public herd immunity to overcome the pandemic. In this study, we propose a two-stage stochastic multi-period mixed integer linear programming optimization model for vaccine supply chain network design to accommodate the capacity expansion decision during the horizon of the strategic planning period. The model implies supply and demand uncertainties to develop the network structure (network topology) and commodity flow access throughout the network. We predict the uncertainty of demand through the epidemic spread SEIR model (Susceptible-Exposed-Infected-Recovery) and apply the SAA method (Sample Average Approximation) to solve the proposed model. We use a case study of six major islands in Indonesia to evaluate the model's performances.

4 - A linear programming model to evaluate the anti-covid vaccination campaign in Italy
Roberto Aringhieri, Alberto Guastalla

Coronavirus pandemic is probably the most challenging crisis ever that the entire world has to face globally. At March 24, 2022, the number of confirmed cases are more than 477 millions in the entire World, 174 millions in Europe, and 14 in Italy [1]. A global anti-covid vaccination campaign started from the beginning of January 2021. At March 24, 2022, 64.2% of the world population has received at least one dose of a COVID-19 vaccine [1].

In our talk we present a linear programming model to evaluate the vaccination campaign in Italy exploiting the available institutional and open data [2]. Our model is capable to consider the different policies adopted in Italy in accordance to the different authorizations (in time horizon and age group) for the available vaccines. Our model represents the hub (national level) and spoke (Regions) distribution model adopted in Italy. It allows also to consider an unlimited number of boosters, and recovered people that uses less doses. The objective is to maximise the number of vaccinated people by age group, giving priority to older and less vaccinated ones.

We discuss the actual scenario and other scenarios obtained varying the distribution rules and the different vaccination rates per Region.

[1] Coronavirus Pandemic (COVID-19), published online at OurWorldInData.org [2] Covid19 Italia, published online at github.com/ondata/covid19italia

■ TD-37

Tuesday, 14:30-16:00 - V001

Rich Split Delivery Routing Problems

Stream: Vehicle Routing and Logistics
Invited session
Chair: Rosario Paradiso

1 - **Multi-depot routing with split deliveries: Models and a branch-and-cut algorithm**
Markus Leitner, Luís Gouveia, Mario Ruthmair

We study the split-delivery multi-depot vehicle routing problem (MDSDVRP) which combines the advantages and potential cost-savings of multiple depots and split-deliveries and develop the first exact algorithm for this problem. We propose an integer programming formulation using a comparably small number of decision variables and several sets of valid inequalities. These inequalities focus on ensuring the vehicles' capacity limits and that vehicles return to their initial depot. As we show that the new constraints do not guarantee these aspects our branch-and-cut framework also includes an efficient feasibility check for candidate solutions and explicit feasibility cuts. The algorithm is tested on the MDSDVRP and two well-known special cases, the split-delivery vehicle routing problem (SDVRP) and the multi-depot traveling salesman problem (MDTSP). The results show that the new inequalities tighten the linear programming relaxation, increase the performance of the branch-and-cut algorithm, and reduce the number of required feasibility cuts. We report the first proven optimal results for the MDSDVRP and show that our algorithm significantly outperforms the state-of-the-art for the MDTSP while being competitive on the SDVRP. For the latter, 20 instances are solved for the first time and new best primal and dual bounds are found for others.

2 - **Inventory Routing Problems: Split and Unsplit Deliveries**
Nho Minh Dinh, Luca Bertazzi, Claudia Archetti

We study different policies for the Inventory Routing Problems in which customer demands must be served by a fleet of vehicles from a depot over a planning horizon. The delivery policy can be that each customer is served by either one (unsplit) or multiple (split) vehicles at a time. The replenishment policy can be either maximum inventory (ML) or order-up-to (OU). We use different formulations of these policies and perform a worst-case analysis to study the largest possible difference. Finally, we run experiments on benchmark instances to estimate the average cost improvement each policy has compared to the others.

3 - **A Split-based Dynamic Programming approach for the Inventory Routing Problem**
Diego Perdigão Martino, Philippe Lacomme, Katyanne Farias, Manuel Iori

Designing vehicles itineraries and defining amounts of products to be delivered based on pre-defined demands is a major task when considering costs involved in transportation and warehousing. This scenario can be modelled as an Inventory Routing Problem (IRP) and consists in finding the best arrangement of routing and delivering to satisfy the customers' demands over certain discrete periods of time. We propose a dynamic programming algorithm for IRP that consists in splitting the demands over a time horizon considering the availability of resources including supplier's production capacity and the number of vehicles for each period of time aiming to satisfy the customers' demands. Based on the number of delivering points and its respective demands, the algorithm can provide optimal solutions considering a pre-defined customers order.

4 - **The Commodity constrained Split Delivery Vehicle Routing Problem with Temperature requirements**
Rosario Paradiso, Said Dabia, Wout Dullaert, Joaquim Gromicho

In this work we study a decision-making problem faced by logistic providers specialized in refrigerated transport of fresh products. Different commodities must be transported under different temperature regimes. Trucks are equipped with cooling/heating units to ensure the desired temperature for the cargo (target temperature). This temperature must be set in accordance to the temperature requirements of the consolidated products. The resulting problem, the Commodity Constrained Split Delivery Vehicle Routing Problem with Temperature requirements (C-SDVRP-T), extends and generalizes the Commodity Constrained Split Delivery Vehicle Routing Problem (C-SDVRP). The C-SDVRP consists of defining a distribution plan to serve a set of customers, each requesting a quantity of different commodities. Each customer can be visited multiple times if each visit delivers different sets of commodities. In the C-SDVRP-T each commodity must be transported under certain temperature conditions. A set of commodities is feasible if a target temperature that satisfies the temperature requirements of all the commodities in the set exists. Given a homogeneous capacitated fleet of vehicle, the aim is to define the route and the target temperature of each vehicle such that each customer is served while respecting temperature requirements and capacity, minimizing costs due to routing and target temperature decisions. To solve the problem, we propose an exact approach based on decomposition techniques.

■ TD-38

Tuesday, 14:30-16:00 - V002

Shared Mobility II

Stream: Shared Mobility
Invited session
Chair: Beatriz Brito Oliveira

1 - **Capturing Travel Mode Adoption in Designing On-demand Multimodal Transit Systems**
Beste Basciftci, Pascal Van Hentenryck

This paper studies how to integrate rider mode preferences into the design of On-Demand Multimodal Transit Systems (ODMTS). The paper proposes a bilevel optimization model to address this challenge, in which the leader problem determines the ODMTS design, and the follower problems identify the most cost efficient and convenient route for riders under the chosen design. The leader model contains a choice model for every potential rider that determines whether the rider adopts the ODMTS given her proposed route. To solve this model, the paper proposes an exact decomposition method that includes Benders optimal cuts and nogood cuts to ensure the consistency of the rider choices in the leader and follower problems. Moreover, to improve computational efficiency, the paper proposes upper bounds on trip durations for the follower problems and valid inequalities that strenghten the nogood cuts. The proposed method is validated using an extensive computational study on a real data set on Ann Arbor and Ypsilanti region in Michigan. The designed ODMTS feature high adoption rates and significantly shorter trip durations compared to the existing transit system and highlight the benefits in accessibility for low-income riders. Finally, the computational study demonstrates the efficiency of the decomposition method for the case study and the benefits of computational enhancements that improve the baseline method by several orders of magnitude.

2 - **Mobility as a Service (MaaS): A Conceptual framework for Travel Behaviour Change Analysis**
Seda Sucu, Nima Dadashzadeh, Hassana Abdullahi, Djamila Ouelhadj, Lee Woods

Enabling a change in travel behaviour towards more sustainable transport mode choices could facilitate overcoming the adverse effects of private car dependency. The concept of Mobility as a Service (MaaS), which combines journey planning, booking and payment into a single mobile app interface, has been developed in the last decade by scholars and practitioners to support sustainable travel behaviour change. Recently, the Solent Future Transport Zone MaaS project, funded by the UK Department for Transport, has developed a multi-city MaaS app across the Solent region. The Solent MaaS app aims to provide convenient and customised transportation alternatives to a private car, thus reducing private car dependency. MaaS has been implemented and trialled in various cities. However, to the best of our knowledge, very few research studies have addressed the environmental, social, and economic impacts of travel behaviour change caused by MaaS. This research study proposes a conceptual framework for the quantitative and qualitative analysis approaches to monitor and evaluate the travel behaviour change caused by the MaaS and the economic, environmental and social impacts. The implementation of the proposed framework will be presented, including the preliminary data collected through the Solent MaaS app, alongside the travel behaviour change and sustainability impact analysis.

3 - Carsharing pricing and relocation: exploring and exploiting what we do (not) know about demand
Beatriz Brito Oliveira

In carsharing, multiple products (rentals) share the same resources (vehicles). The rentals start and end at different times and locations. There are locations with varying demand pressures, and the operator can relocate the fleet to meet demand. Even if the prices are set beforehand, it is common for operators to offer promotions in specific areas and times to influence demand and reduce relocations. The price-demand curve in this context is usually unknown to the operator. On-the-fly dynamic decisions on prices and relocations are usual, based on demand forecasts. Still, learning methods can be applied so that the operator gets a better knowledge of the demand curves. We propose an active learning method that experiments with price, pushing other regions of the curve, sacrificing profits today for better profits in the long run. We propose a mathematical model for carsharing's operational management (integrating pricing and relocation decisions) and demand learning. In this model, we use a logit choice model and consider that the demand function depends on price and other factors that influence users' preferences, such as walking distances or time value. Our goal is to select prices dynamically, resulting in i) higher profits, according to the best estimate of demand we have (exploitation objective), and ii) improved knowledge of the demand curve (exploration objective). A multi-objective solution method is applied to tackle the trade-off between these two objectives.

4 - Service Performance of Stochastic Clearing Policies with Applications in Shared-Mobility
Sila Cetinkaya, Bo Wei, Daren Cline

Historical application domains of stochastic clearing include bulk service queues, inventory control, and transportation planning (e.g., vehicle dispatching). Motivated by temporal shipment consolidation practices common in the context of emerging shared mobility applications, we investigate the notion of service performance for stochastic clearing decisions. Our goal is to compute, evaluate, and compare service performance of alternative clearing policies, as quantified by average order delay, a fundamental measure of timely service and delivery. The results are of practical value in the context of the design and operation of shared-mobility as well as supply-chain systems.

■ TD-39

Tuesday, 14:30-16:00 - U8

Problems on graphs

Stream: Combinatorial Optimization
Invited session
Chair: James Orlin

1 - Price&Cut for the graph coloring problem
Alexandre Dupont-Bouillard

Adding strenghtening inequalities, like Chvátal-Gomory Inequalities (CGI), is the key ingredient to improve the value of the linear relaxation of integer programs. However, such a reinforcement is often hard to perform on formulations with an exponential number of variables as the pricing phase depends on the dual values of the added strenghtening inequalities. This is the case for the stable set based formulation of the graph coloring problem. We propose a Price&Cut algorithm using CGI for this formulation. We investigate and compare several strategies for alternating the pricing and cutting phases and exhibit a strategy in which both the number of generated columns and the value of the relaxation are improved. We also consider dual optimal inequalities (DOI) which stabilize the column generation by cutting the dual space without removing any optimal dual solution. In the primal, DOI correspond to artificial columns added to reduce the number of iterations of the column generation and the total solving time. As adding CGI changes the set of optimal solutions of the dual problem, the dual optimal inequalities must be modified accordingly. We propose three methods to simultaneously use DOI and CGI, focusing on the coefficients of DOI columns in CGI. We finally propose an experimental analysis where DOI and CGI are used together within our alternating strategies. This is a joint work with Pierre Fouilhoux, Mathieu Lacroix and Roland Grappe

2 - Reconstructing the tree topology in telecommunication networks
Siv Sørensen, David Pisinger

We consider Hybrid fiber-coaxial (HFC) networks in which data is transmitted from a root node to a set of customers using a series of splitters and coaxial cable lines. The physical locations of the components in a HFC network are always known but frequently the cabling is not. This makes cable faults difficult to locate and resolve. In this study we consider time series data received by costumer cable modems, to reconstruct the topology of HFC networks. We assume that the data can be translated into a series of events relating the 'closeness' of costumers in the network depending on how many events are shared. This approach allows us to use maximum parsimony to minimize the total number of character-state changes in a tree based on observations in the leaf nodes. Although exact algorithms exist for calculating the parsimony score of a given tree, all possible trees must be constructed to guarantee that the most parsimonious tree is found. Maximum parsimony is well-studied in biology for unconstrained, binary trees. In our case the topology is non-binary, and we know the location of the internal nodes. We consider a two-stage approach in which we first construct a binary-tree using local search methods, and then map it to the known nodes. Furthermore, we consider a holistic approach, where the known nodes are taken into consideration while constructing the parsimony tree. Computational results are reported for simulated costumer data with various degrees of noise.

3 - An upper bound on clique coloring of B1-EPGt graphs
Vitor de Luca, María Pía, Fabiano Oliveira, Jayme Szwarcfiter

We consider the problem of clique coloring, that is, coloring the vertices of a given graph such that no (maximal) clique of size at least two is monocolored. The approaches for solving clique coloring can be very different from those for ordinary vertex coloring. The main reason is that clique coloring is not a hereditary property: it is possible that a graph is k-clique-colorable, but it has an induced subgraph that is not. Another difference is that even a 2-clique colorable graph can contain an arbitrarily large clique. However, clique coloring shares similarities with vertex coloring. For example, every k-coloring is also a k-clique coloring. Moreover, the clique number and the clique chromatic number of G coincide if G is triangle-free. The decision problem of clique-coloring on general graphs is coNP-complete, and NP-complete on graphs with maximum degree 3.

We study the clique coloring problem in the context of the edge intersection graphs of paths on a triangular grid (EPGt graphs). These graphs generalize the well-known intersection graphs of paths on a rectangular grid (EPG graphs). A motivation for studying EPGt graphs comes from circuit layout problems. The triangular grid has been studied in the context of the channel assignment problem with separation (CAPS).

Similarly to EPG graphs, a turn of a path at a grid point is called a bend. A graph is Bk-EPGt if each path of its EPGt model has at most k bends. We prove that B1-EPGt graphs are 7-clique colorable.

4 - All pairs shortest paths in O(nm) time.
James Orlin, Laszlo Vegh

We present an O(nm) algorithm for all-pairs shortest paths computations in a directed graph with n nodes, m arcs, and nonnegative integer arc costs. This matches the complexity bound attained by Thorup for the all-pairs problems in undirected graphs. Our main insight is that shortest paths problems with approximately balanced directed cost functions can be solved similarly to the undirected case. Our algorithm starts with a preprocessing step that transforms the cost vector into a reduced cost vector that is approximately balanced. Using these reduced costs, every shortest path query can be solved in O(m) time using an adaptation of Thorup's component hierarchy method. The balancing result is of independent interest, and gives the best currently known approximate balancing algorithm for the problem.

Tuesday, 16:30-17:30

■ TE-01

Tuesday, 16:30-17:30 - A

Andrea Lodi [IFORS Distinguished Lecture]

Stream: Plenaries
Plenary session
Chair: Dolores Romero Morales

1 - Fairness over time and dynamic resource allocation
Andrea Lodi

Decision making problems are typically concerned with maximizing efficiency. In contrast, we address resource allocation problems where there are multiple stakeholders and a centralized decision maker who is obliged to decide in a fair manner. Different decisions give different utility to each stakeholder. In cases where these decisions are made repeatedly, we provide efficient mathematical programming formulations to identify both the maximum fairness possible and the decisions that improve fairness over time, for reasonable metrics of fairness. We discuss the application of this framework to a number of contexts, for example in ambulance allocation, urban policing operations, and goods delivery. Where decisions in consecutive rounds are constrained, we prove structural results on identifying fair feasible allocation policies and provide a flexible exact algorithm based on column generation.

Wednesday, 8:30-10:00

■ WA-01

Wednesday, 8:30-10:00 - A

James Cochran

Stream: Keynotes
Keynote session
Chair: Christine Currie

1 - OR Education for Developing Nations - Everybody Wins!
James Cochran

In this talk, we will discuss the reasons why it is imperative that operations research education is available to students at all levels worldwide. We will review the progress that has been made in ensuring operations research education is available worldwide and what still needs to be done to achieve this lofty and ambitious goal. We will provide an overview of several successful initiatives designed to address this goal. These initiatives include the International Teaching Effectiveness Colloquia (TEC) series, INFORMS Transactions on Education, Wiley's Encyclopedia of Operations Research and Management Science (EORMS), INFORMS Analytics Body of Analytics Knowledge (ABOK), the O.R. and Mathematical Analytics for High School Math Teachers: When will you ever use this? series, IFORS Developing Countries OR Resources Website, Statistics Without Borders, and INFORMS Pro Bono Analytics Initiative. We will also consider what still needs to be done and where opportunities exist for individuals and organizations to contribute to the effort to make operations research education available worldwide. We hope attendees will formulate new ideas on how to contribute to the goal of making operations research education available to students at all levels worldwide!

■ WA-03

Wednesday, 8:30-10:00 - C

Numerical methods in/for Machine Learning (I)

Stream: Machine Learning and Mathematical Optimization
Invited session
Chair: Emilio Carrizosa

1 - On the convergence of controlled mini-batch gradient algorithms
Laura Palagi, Giampaolo Liuzzi, Ruggiero Seccia

In this talk, we consider the widely studied problem of minimizing a finite sum of functions. The problem naturally arises in many applications such as machine learning as the minimization of the regularized empirical risk. Many gradient-based minibatch methods (e.g. incremental and stochastic gradient methods) have been proposed and their convergence has been deeply studied in the literature which usually require strong assumptions both on the terms composing the objective function and on the overall structure of the function as well. We introduce minimal modifications to standard minibatch algorithms from the literature that allow proving convergence toward stationary points under basic assumptions generally satisfied in unconstrained non-convex optimization. In particular, a control of the stepsize at the end of an epoch, or after a finite number of epochs, based on a gradient-free nonmonotone line search coupled with a watchdog rule are exploited to define efficient globally convergent algorithms. We prove convergence and show on a set of benchmark problems that the proposed control strategy does not deteriorate the computational performance of the algorithm in comparison with standard incremental/stochastic gradient methods while guaranteeing stronger convergence properties.

2 - Multi-objective simulation-based optimization: a neural network approach
Marco Boresta, Tommaso Giovannelli, Stefano Lucidi, Massimo Roma

We present a novel approach for the resolution of a multi-objective simulation-based optimization problem that involves the usage of Artificial Neural Networks (ANN) as an approximating model of the objective function obtained by the simulation software.

This approach consists in the replacement of the objective function that requires the usage of a simulation software with a metamodel that has the structure of a Multilayer Perceptron, thus enabling the usage of gradient-based methods for the resolution of the optimization problem. The Pareto Frontier is then generated by solving multiple single-objective problems where the objective function is obtained as the weighted combination of the different objective functions.

We test this approach on the resolution of the Emergency Department (ED) problem of a large Italian hospital which is significantly affected by the problem of overcrowding: the ED of Policlinico Umberto I in Rome, Italy, one of the largest EDs in Europe.

We compare its performance with the results obtained on the same data, with the same budget of function evaluations, using a globally convergent Derivative Free (DF) algorithm. The results are encouraging, showing that the ANN approach provides several advantages over the DF one, such as a drastic reduction of the computation time, the production of a Pareto Frontier with more distinct, better distributed points and it is also more robust to changes in the statement of the problem.

3 - Data-driven search and population management in a heuristic
Fulya Atalay, Necati Aras, Mustafa Baydoğan

Valuable information is generated during the execution of the iterations of a heuristic algorithm. The collection of visited solutions can be mined using data analytics techniques to generate information on the characteristics of inferior and superior solutions which can be used subsequently to guide the search procedure employed. This type of learning, called online learning, is applied in solving the well-known p-median problem. We focus on the online learning category, where data collected during the execution of the search procedure is used for mining. In this respect, we select the p-median problem, which is an NP-Hard problem. First, we assume there are a set of solutions. Then, we propose a data representation and learning procedure for a simple neighborhood search algorithm requiring solution selection for modification, and in a solution, selection of decisions to be modified, and also in population management. The learning procedure is applied by using a tree-based methodology. Our training set is a set of solutions that are represented as 1s and 0s, i.e. binary representation. We built a tree-based classification methodology with binary features, which are our decisions. The target variable is the objective value. We make trials on all PMed1-40 instances, which are in OR-Library. We implement the tree-based method in the local search and population management phases of a naïve population-based heuristic.

4 - OptiCL: A Package for Mixed-Integer Optimization with Constraint Learning
Ade Fajemisin

OptiCL is a Python package that provides a comprehensive, open-source tool for data-driven decision making with learned constraints. Given data on decisions, contextual features, and outcomes of interest, OptiCL fits machine learning models to the outcomes, selecting from a broad class of algorithms, and embeds the trained models as either constraints or objective terms in a mixed-integer optimization formulation. It further imposes trust region constraints through a convex hull and optionally leverages clustering to better approximate the trustable decision space. In combination with domain-driven constraints and objective terms, these components combine to form a mixed-integer optimization problem that can be solved directly with standard solvers.

OptiCL equips practitioners to jointly harness machine learning and optimization in decision-making settings.

■ WA-04

Wednesday, 8:30-10:00 - D

Mathematical Optimization for Interpretable Supervised Learning

Stream: Machine Learning and Mathematical Optimization

Invited session

Chair: Vanesa Guerrero

1 - Developing a relation between neural networks and polynomials with Taylor series and combinatorics: NN2Poly.

Pablo Morala, Jenny Alexandra Cifuentes Quintero, Rosa Elvira Lillo Rodríguez, Iñaki Ucar

The method NN2Poly is presented as a tool that can help explain deep artificial feed forward neural networks by means of an alternative representation with polynomials. To achieve this goal, a previous version that was limited to a single hidden layer is extended to work with arbitrarily deep neural networks. This representation is obtained by using Taylor expansion on the activation functions and combinatorial properties, which allow to obtain the coefficients of a polynomial that performs similarly to a given neural network using its weights. Therefore, the number of parameters in the model is reduced, improving its interpretability, while also allowing to find interesting connections between neural networks and polynomials. However, the practical implementation of the method presents some computational limitations, specially related with the amount of different combinations and multiset partitions needed to compute the polynomial coefficients. Therefore, this needs to be studied in order to optimize the computational implementation to be efficient and scalable when solving deep neural networks.

2 - A quantile based algorithm for partial least squares

Álvaro Méndez, Rosa Elvira Lillo Rodríguez

Partial least squares (PLS) is a well known dimensionality reduction technique used as an alternative to ordinary least squares (OLS) in collinear or high dimensional scenarios. Being based on OLS estimators, PLS is sensitive to the presence of outliers or heavy tailed distributions. Opposed to this, quantile regression (QR) is a technique that provides estimates of the conditional quantiles of a response variable as a function of the covariates. The usage of the quantiles makes the estimates more robust against the presence of heteroscedasticity or outliers than OLS estimators. In this work, we introduce the fast partial quantile regression algorithm (fPQR), a quantile based technique that shares the main advantages of PLS: it is a dimension reduction technique that obtains uncorrelated scores maximizing the quantile covariance between predictors and responses. But additionally, it is also a robust, quantile linked methodology suitable for dealing with outliers, heteroscedastic or heavy tailed datasets. The median estimator of the PQR algorithm is a robust alternative to PLS, while other quantile levels can provide additional information on the tails of the responses.

3 - Feature selection on high dimensional additive models

Manuel Navarro García, Vanesa Guerrero, Maria Durban

Feature selection plays an important role in modern regression analysis, which aims to produce interpretable models without compromising their performance. However, most of the existing techniques either assume linearity on the predictors or use convex penalties to gain sparsity in the prediction model, which may be suboptimal regarding the accuracy of the model. In this work, we address the problem of finding the best subset of variables from a given set in a non-parametric regression setting. Our approach allows the variables to enter in the model as linear and/or non-linear via reduced-rank basis (B-splines). This basis representation generates a group structure on the parameters to be estimated, so the initial best subset problem becomes a best group subset problem. The full model is fitted using the P-splines approach and the cardinality constraint considers grouped features, yielding a mixed integer quadratic optimization problem. We compare our approach with other state-of-the-art algorithms on both synthetic and real-world data sets.

4 - On spline surrogate models and reformulation techniques for MINLPs with separable non-convexities

Vanesa Guerrero, Claudia D'Ambrosio, Renan Spencer Trindade

The vast amount of data available nowadays makes possible to model complex phenomena in accurate ways. However, being able to use these models within a mathematical optimization framework to solve instances of real problems is often a challenge. Many of these data-driven models are 'black-box', in the sense that they do not have an explicit mathematical formula which describes it. In other cases, even if an explicit expression exists, including it into a mathematical optimization model may make solving the problem computationally intractable.

In this work we propose the use of a special kind of surrogate models, regression splines, together with some reformulation techniques to deal with 'black-box' or too complex functions involved in Mixed Integer Nonlinear Programming (MINLP) problems. The choice of spline functions is not arbitrary. On one hand, they offer a good compromise between accuracy in capturing the main trends in the data and complexity, since they are piecewise polynomials. On the other hand, their functional form allows us to approximate general non-convex MINLPs by a more tractable subclass of problems which can be efficiently solved by customized algorithms.

Our approach is tested in real instances of problems arising in industry and in an application of the use of machine learning tools for the configurations of optimization solvers.

■ WA-05

Wednesday, 8:30-10:00 - E

Automated algorithm tuning, configuration and construction

Stream: Data Science Meets Optimization

Invited session

Chair: Manuel López-Ibáñez

1 - Selector: An ensemble for automated algorithm configuration

Elias Schede, Dimitri Weiß, Kevin Tierney

Solvers contain parameters that influence their performance and these must be set by the user to ensure high-quality solutions are generated, or optimal solutions are found quickly. Manually setting these parameters is tedious and error-prone, since search spaces may be large or even infinite. Existing approaches to automate the task of algorithm configuration (AC) make use of a single machine learning model that is trained on previous runtime data and used to create promising new configurations. We combine a variety of successful models from different configurators to an ensemble that proposes new configurations. To this end, each model in the ensemble suggests configurations and a hyper-configurable selection algorithm down-selects them to match the number of configurations to try to the amount of computational resources available. Using multiple models leads to a more diverse search, since each model has a unique belief about good regions of the search space, from which it can propose configurations. The new configurator will be made available as open source software package.

2 - Realtime Gray-Box Algorithm Configuration
Dimitri Weiß

A solver's runtime and the quality of the solutions it generates are strongly influenced by its parameter settings. Finding good parameter configurations is a formidable challenge, even for fixed problem instance distributions. However, when the instance distribution can change over time, a once effective configuration may no longer provide adequate performance. Realtime algorithm configuration (RAC) offers assistance in finding high-quality configurations for such distributions by automatically adjusting the configurations it recommends based on instances seen so far. Existing RAC methods treat the solver to be configured as a black box, meaning the solver is given a configuration as input, and it outputs either a solution or runtime as an objective function for the configurator. However, analyzing intermediate output from the solver can enable configurators to avoid wasting time on poorly performing configurations. To this end, we propose a gray-box approach that utilizes intermediate output during evaluation and implement it within the RAC method CPPL. We apply cost sensitive machine learning with pairwise comparisons to determine whether ongoing evaluations can be terminated to free resources. We compare our realtime gray-box configurator to a black-box equivalent on several experimental settings and show that our approach reduces the total solving time in several scenarios.

3 - A Real-world Case Study of Automatic Selection of GRASP Configurations with Single-selectors vs Multi-Selectors
Manuel López-Ibáñez, Nicolás Álvarez, Silvino Fernández Alzueta, Pablo Valledor Pellicer

We report a case study in algorithm selection and configuration of a GRASP used in the steel industry. The goal of the project was to automatically set the 18 parameters that control the GRASP given the value of 102 features of a new instance to be solved. The effort required to evaluate the GRASP with different parameter configurations precludes the application of traditional automatic configuration methods, such as irace. Instead, we generated a small number of configurations using optimized latin-hypercube sampling. Then, we trained regression models, namely, ridge regression and extremely randomized trees, to predict the performance of these configurations given instance features. We compared two ways of setting up such models: A multi-selector creates one separate model per configuration whereas a single-selector creates a single model for all configurations using the parameter settings as additional features of the model. Our preliminary results suggest that single-selectors outperform multi-selectors. Ridge regression performed better in cross-validation, whereas the tree models performed best in completely new instances. Moreover, the models were not able to identify the best features by themselves, thus feature selection was crucial. Due to the commercial sensitivity of the project, data and feature names are fully anonymised and algorithmic details have been simplified. Nevertheless, we believe our experience can be useful for future similar projects.

4 - The Hurst parameter: a way of finding statistical significant differences between healthy subjects and congestive heart failure patients
Mar Fenoy

This heart rate variation (HRV) is reflected in the data we obtain from an electrocardiogram, data such as the RR intervals which are commonly used in this context. The point of this research area is to find a model capable of describing the HRV. In this study, we give an approach to this problem based on the Hurst parameter, a measure of the fractality of the data. This allows us to obtain a way of finding statistical significant differences by means of confidence intervals between healthy subjects and congestive heart failure patients.

■ WA-06

Wednesday, 8:30-10:00 - U1

Heuristic algorithms for graph problems

Stream: Combinatorial Optimization
Invited session
Chair: *Raffaele Cerulli*

1 - A Genetic Algorithm for the 2-edge-connected Minimum Branch Vertices problem
Carmine Sorgente, Francesco Carrabs, Raffaele Cerulli, Federica Laureana, Domenico Serra

In optical networks supporting multicasting communications, switch devices allow to split the entering light signals and send them to several adjacent vertices. These devices are located in branch vertices, namely vertices of the network having a degree greater than two. Designing a tree to connect all the vertices of the network, while keeping the number of the branch vertices minimum due to budget motivations, is known as the Minimum Branch Vertices (MBV) problem. To restore the network services in case of edge failures, additional constraints are considered by the 2-Edge-Connected Minimum Branch Vertices (2ECMBV) problem, a recently introduced variant of the MBV in which the spanning subgraph has to be 2-edge-connected. In this talk, we show how MBV can be polynomially reduced to 2ECMBV, as a proof of NP-completeness for the latter. Then, we focus on finding good solutions for the 2ECMBV problem in a short computing time and describe a genetic algorithm, enhanced by ad-hoc operators contributing to perform a wide exploration of the solution space. Literature-provided procedures are also exploited to efficiently carry out feasibility-related tasks. Computational tests on benchmark instances show the speed and the effectiveness of the proposed algorithm, which often finds the optimal solution in a short computing time.

2 - A matheuristic approach for the graph vertex coloring problem
Reshma Chandrasekharan, Tony Wauters

The graph vertex coloring problem (VCP) is one of the most popular problems in Combinatorial Optimization. Due to its numerous applications, it is often desirable to find the smallest number of colors required to color a graph, which, constitutes an NP-hard problem. Random graphs only up to 100 vertices can be colored using the best mathematical methods available for the VCP. This work presents a matheuristic approach for the VCP that combines local search and mixed integer programming techniques and is efficient in coloring large graphs in short runtime. A decomposition-based technique has been employed where subgraphs of the original graph are colored to optimality iteratively using mixed integer programming and constraint programming. Based on the decomposition strategy used, solutions that are substantially different on structure and final solution quality are obtained. Various decomposition approaches have been tested for their influence on the final solution quality and based on this study, a decomposition framework has been arrived at that automatically selects the most efficient decomposition approach based on the graph structure. The matheuristic employs multiple look-ahead functions based on integer programming relaxations and experiments concerning their effects on the final solution quality will also be discussed.

3 - Integer optimization model and algorithms for multi-agent pathfinding problem with time-spacing constraints
Seyoung Oh, Kyungsik Lee

In this study, we consider the multi-agent pathfinding problem with time-spacing constraints (MAPF-TS). The multi-agent pathfinding problem (MAPF) is defined as the search for a collision-free route plan for agents with their own origins and destinations on a given directed graph. Due to its highly abstract structure, MAPF has been widely studied in the field of artificial intelligence and robotics. However, MAPF is difficult to be directly utilized in emerging applications such as autonomous warehouse robots because of the physical characteristics of robots and inexact execution of planned routes. To overcome these limitations, MAPF-TS was suggested, which considers a constraint to prevent multiple agents from occupying the same point in too close a time. We propose a new integer optimization model for MAPF-TS which does not require big-M constraints and effectively reduces solution space without loss of optimality. We devise various solution approaches including conflict-based search, branch-and-price, and devised algorithms based on the Lagrangian decomposition and the conflict-based search. Through computational experiments, those solution approaches are tested and compared.

4 - A Heuristic Approach for the maximum flow problem with additional conflict constraints
Domenico Serra, Raffaele Cerulli, Carmine Sorgente

Given a directed graph, we investigate a variant of the maximum flow problem in which some arc pairs are incompatible or conflicting. These arcs are not allowed to bring positive flow at the same time. To the best of our knowledge, the maximum flow problem with conflicts was first introduced by Pferschy et al., proving that the problem is strongly NP-Hard. Subsequently several exact approaches were proposed by Suvak et al. In this talk we address this problem through a heuristic technique, which are often used to identify solutions to complex problems in a short time. Our algorithm is inspired by the classical approaches used to solve the maximum flow problem (MFP), with the addition of ad hoc mechanisms to deal with arcs conflicts. The algorithm was tested on the instances generated by Suvak et al. so as to compare the results obtained with exact approaches. The computational tests show that our algorithm often finds good solution in a short computing time.

■ WA-07

Wednesday, 8:30-10:00 - U3

Urban and Territorial Planning in MCDA 1

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Francesca Abastante*
Chair: *Isabella Lami*
Chair: *Marta Bottero*

1 - An integrated vision of the Triple Bottom Line perspective through a methodological advancement of the ITACA Protocol
Francesca Abastante, Isabella Lami

Despite the increasing importance, the sustainability protocols in Italy convey a vision of sustainability still strictly rooted in the environmental sphere and do not seem to be interested to embrace a broader and more integrated vision in the Triple Bottom Line perspective. The objective of this research is to provide considerations to broadening the criteria considered to include economic and social aspects, thus reinforcing the operational and evaluative role that sustainability protocols can play in sustainable development. To do so, we analyse the ITACA protocol, one of the most used in Italy. It is configured as a tool for environmental and energy assessment of buildings based on the multicriteria system SBTool, which is a compensatory hierarchical model providing a structure divided into Areas, Categories and Criteria. From an in-depth analysis of this protocol, it emerges how the various elements of the hierarchy are evaluated in a disconnected way despite having, in fact, numerous elements of correlation in terms of dependencies and interactions. The research is methodologically proactive, focusing on three important issues: i) which economic and social criteria could be included in the ITACA protocol in the perspective of the Triple Bottom Line? ii) how to measure them?; iii) how the current multicriteria system SBTool can be implemented in order to consider the possible positive/negative interactions and dependences that can occur among the criteria.

2 - Low carbon morphology city planning based on indicator-based approach
Sara Torabi Moghadam, Patrizia Lombardi, Francesca Abastante, Chiara Genta, Maurizia Pignatelli

The present study is part of a wider research context belonging to the MOLOC (Low Carbon Urban Morphologies) project, co-funded from Interreg Europe 2014-2020 Programme, which aimed at developing a new city-building approach with specific attention on the climate change and energy transition issues. In this regard, the use of appropriate assessment tools and decision-making models is crucial to tackling these issues. This research aims at defining an innovative methodological framework to spatialize and assess the key performance indicator (KPIs) to support the revision of the new City Masterplan of the city of Turin in Italy. The method implements a new indicators-based system to aid decision-makers and urban actors to evaluate the sustainability level of the city. Eight indicators have been selected through a number of participatory approaches, and accordingly, assessed by the collection of data to define the "baseline" scenario. In this context, Geographic Information System (GIS) technology is used to map the phenomena represented by Key Performance Indicators, and to provide their spatial impact assessment.Finally, a forward-looking sustainable scenario has been provided towards a "Low carbon morphology city.

3 - Supporting the assessment of strategic regeneration scenarios using the A'WOT method
Marta Bottero, Caterina Caprioli, Federico Dell'Anna

The urban regeneration of abandoned sites represents an opportunity for meeting new challenges in terms of major environmental, social, and economic aspects. The COVID-19 pandemic has acerbated these needs, particularly highlighting the importance of public and green spaces, that represent the only chance that people have to meet each other in a safety way and to experience nature. Within this context, the present work explores the hybrid A'WOT method for supporting the assessment of strategic urban regeneration scenarios. A critical area in the city of Turin (Italy) is used as case study to test its potentialities and abilities in the design and assessment of a green infrastructure. A'WOT combines two well-known techniques in decision-making processes, specifically the SWOT (Strengths, Weaknesses, Opportunities and Threats) Analysis and a multicriteria decision approach, called the Analytic Hierarchy Process (AHP). The combination of SWOT and AHP allows the analyst to determine the priorities of the SWOT elements and use them in the evaluation of alternative project scenarios. This hybrid method can support decision-makers in the definition of structured and coherent scenarios able to achieve the main opportunities and strengths of an area, reducing its weaknesses and possible threats.

4 - Value functions for marginal territories: a spatial methodological approach
Alessandra Oppio, Marta DellOvo, Catherine Dezio

The marginal territories, in continuous depopulation, require policies and strategies capable of activating sustainable regeneration processes by involving local communities. This work, inspired by the current actions for Italian fragile areas, proposes the application of a hybrid methodological approach aimed at investigating both the territorial Attractiveness and Vulnerability by a spatial Multicriteria Analysis. The research explores the definition of Value functions for Vulnerability maps generation. Since Value functions are a mathematical representation of human judgments, they capture the value systems of stakeholders involved in the decision processes. Criteria are not analyzed for their face value but for their meaning. This makes explicit what counts for the decision (the value) compared with what is measured to support the decision (the decision variable).The contribution proposes the results of focus groups where experts have been involved to elicit their values about Economic, Social and Environmental vulnerability criteria with the support of the Evalue technique developed by Demetriou et al. (2012) through a process divided in four steps: i) selection of curves; ii) values assignment; iii) revision of curves; iv) consistency control. The purpose persuade by the work goes in the direction of the 'policy analytics' line of research which is based on the concept of constructive approach to support decision processes in the public domain.

■ WA-08

Wednesday, 8:30-10:00 - U4

Combinatorial Optimization for Social Good II

Stream: Combinatorial Optimization
Invited session
Chair: *Helena Ramalhinho Lourenco*

1 - The Mixed Fleet Green Vehicle Routing Problem with Green Zones
Jesper Bang Mikkelsen, Sune Lauth Gadegaard, Jens Lysgaard

Public administrations all over Europe have started introducing environmental zones in city centers to limit noise and air pollution generated by industries in densely populated areas. As part of this, several types of green zones have been proposed across Europe. For road freight transport, the introduction of green zones poses a new operational challenge where certain vehicles are either not allowed to enter a zone or must pay compensation for GHG emissions inside the zone. Especially for companies operating a heterogeneous fleet of internal combustion engine vehicles and alternative fuel vehicles in areas with green zones, optimal utilization of the fleet becomes vital.

In this work, we introduce a new VRP variant called the Mixed Fleet Green Vehicle Routing Problem with Green Zones (MFGVRP-GZ) that aims to serve all customers at a minimum travelled distance, such that no green zone restrictions are violated. Through computational studies, we (i) investigate different green zones restrictions and their impact on distribution operations and (ii) test the performance of different formulations to solve the problem.

2 - Capacitated Regret p-median model for the location of public facilities
Carolina Castañeda P., Daniel Serra

Location decisions are a key factor in improving the population's access to public services. Accessibility greatly impacts people's quality of life, reduces inequalities, and facilitates the development and growth of regions. Consequently, it is important to make robust location decisions regarding that these are strategic, involve infrastructure that should last in time, and need to respond to the uncertainty that appears in the spatial region, for instance, population dynamics or travel times in different ranges of hours during the day. We propose a capacitated regret p-median model that locates p facilities while minimizing the maximum regret over several scenarios, regarding the capacity associated with the potential facilities. The regret represents the difference between the optimal solution of the p-median problem applied to each scenario and the average distance from facilities to demand nodes computed for all scenarios. Depending on the duration of the period where planners need to make the location decisions, the model considers uncertainty in the demand and/or travel times across scenarios. In addition, we design a solution method based on the Variable Neighborhood Search (VNS) metaheuristic. We use several data sets, testing the method for large instances, including the case study of the location of public pre-schools in Barcelona considering the city's current population projections and socio-economic analysis.

3 - Modeling COVID-19 Optimal Testing Strategies in Retirement Homes: An Optimization-based Probabilistic Approach
Mansoor DavoodiMonfared, Ana Batista, Abhishek Senapati, Weronika Schlechte-Welnicz, Justin Calabrese

Retirement Home facilities have been widely affected by the COVID-19 pandemic. The residents in these homes are usually elderly people with a high risk of mortality from being infected. Since they are in contact with each other, once an infection arrives at the facility, it propagates quickly. To prevent the outbreaks, it has been demonstrated that regular testing of the residents is the most practical approach. However, testing may result in extra time for the staff that performs the test as well as residents' discontent, which presents a trade-off between the time invested in testing, daily caring activities, and viral spread containment. We introduce a novel optimization approach for testing schedule strategies in retirement homes. We develop a mixed-integer linear programming model for balancing the staff's workload while minimizing the expected detection time of a probable infection inside the facility. We present a probabilistic approach in conjunction with the optimization models to compute the risk of infection, including contact rates, incidence status, and the probability of infection of the residents. To tackle the combinatorial nature of the problem, we proved an efficient property, called symmetry property of optimal testing strategy and utilized it in proposing an enhanced local search algorithm. We perform several experiments with real-size instances and show that the proposed approach can derive optimal testing strategies.

4 - Workers-stations assignment in second-hand clothes-processing line with high absenteeism from workers
Marc Juanpera, Ariadna Costas-Mañero, Laia Ferrer-Martí

Different entities in Spain are devoted to the reuse of second-hand clothes, collecting them, separating them according to quality and typology and reintroducing them to local markets and abroad. They employ workers at risk of social exclusion, which can present high unannounced absenteeism that condition the everyday worker-station assignment within the clothes-processing line. This feature motivates an ad-hoc study to optimize the work-station assignment, based on the real case of a Foundation operating in Barcelona with a complex line of 39 workers and 22 stations with different supply forms (conveyor belt or discharge hopper). The aim of the study is to define, for each daily number of available workers, a distribution of them along the work stations to maximize the processing of clothes and reduce the on-going stock below a threshold. Also, management criteria are included to deal with particular expertise of the workers, tackle constraints related to space and characteristics of the work (e.g., supply form of the stations), and avoid unbalanced workloads. Indeed, the exact portion of a day to assign each worker in each station is robustly obtained with a deterministic heuristic complemented with a stochastic analysis using the simulation tool Witness Studio. Results significantly improve the current capacity of clothes-processing of the Foundation while reducing on-going stock and addressing management difficulties.

■ WA-09

Wednesday, 8:30-10:00 - U5

MILP in logistics and last-mile delivery

Stream: Mixed Integer Linear Programming
Invited session
Chair: *Alberto Santini*
Chair: *Diego Delle Donne*

1 - Reinforcement Learning Approaches for the Orienteering Problem with Stochastic and Dynamic Release Dates
Yuanyuan Li, Claudia Archetti, Ivana Ljubic

Orienteering problem with stochastic and dynamic release dates (RD) is a problem in which a company receives goods from its suppliers and distributes them to customers. Each customer is associated with an RD indicating the time when her parcel becomes available at the distribution center. The RDs are considered to be stochastic and dynamically updated during the distribution. We model the problem as a Markov decision process. We generate scenarios representing realizations of RDs and for each of them, we approximate the future value using a batch approach. Two approximation approaches are proposed: policy function approximation through a consensus function in which a deterministic model determines the requests to serve immediately and those included in future routes, and a consensus function over all scenarios determines the final solution; one-step look-ahead policy with value function approximation where we build a two-stage stochastic model in which the first stage is to determine the route leaving immediately, while the second stage concerns future routes.

2 - Extended formulations and column generation for the Freight on Transport problem
Diego Delle Donne, Alberto Santini, Claudia Archetti

The boom of e-commerce in the last decade raises new challenges as retailers and couriers innovate their supply chains to keep up with demand. Last-mile delivery (LMD), the segment of the supply chain which starts at the last distribution centre and ends at the customer's doorstep, is particularly affected. The growth of volume in LMD has also caused concern, especially in dense urban environments where the externalities (traffic, emissions, etc.) have become noticeable. Several authors in Operational Research (OR), Environmental Engineering and Urban Planning have proposed alternative LMD implementations which aim at reducing the externalities while guaranteeing a service level. We focus on one promising operational practice: integrating public transport within LMD, to leverage unused capacity and reduce the number of delivery vehicles in the city. This concept has emerged during the last years and is gaining attraction, both academically and in practice. In our study, we consider a 3-echelon system. In the first echelon, trucks move parcels from distribution centres to public transport depots or large stations. In the second echelon, public transport vehicles transport the parcels towards the city centre and drop them off at some of their scheduled stops. In the third echelon, zero-emission vehicles (such as cargo bikes) deliver the parcels to the customers' preferred locations. In this work, we propose an extended IP formulation to tackle this problem in practice.

3 - Tactical Green Fleet Sizing Decisions for Last-Mile Delivery Systems
Minakshi Punam Mandal, Claudia Archetti, Alberto Santini

We study a Last Mile Delivery (LMD) problem that deals with fleet sizing decisions of a company. While existing studies primarily focus on the day-to-day operational aspect of the LMD systems, our aim is to explore the problem at a tactical level where the number of freighters to be hired by the company is fixed for a long period of time (e.g. 4 months). We mimic large real cities that are usually divided into regions, and further divided into areas, and packages first reach Local Distribution Centres (LDCs) located within each area, from where they need to be delivered to the end customers using green means like bikes or simply walking. This study is particularly aimed to complement innovative LMD strategies, when the use of delivery trucks is limited. We intend to estimate the number of freighters to be hired by the company not only for the entire city but also for each region and area, to serve the demand during different time periods of the day. The unserved demand is assumed to be outsourced and our objective is to balance the hiring and outsourcing costs over the planning horizon. We propose mixed integer programming techniques to study a stochastic version of the problem. We use an approximation algorithm to capture the operational requirements of the system and embed it into our model. We provide computational studies to support the viability of our system.

4 - A Mixed Integer Programming Approach for Blacklisting Products in E-Commerce
Ahmet Çınar

We study a real-life problem in which a decision maker is required to determine the set of products that will be put into blacklist. Due to the several different performance metrics such as unsupplied ratio, dispatch on time ratio, defective ratio and so on, she needs to find an optimal weight set corresponding to these metrics. Once the optimal weights are decided, using these weights a unique score for each product is calculated. Finally, if the score of a product falls below a predetermined threshold value, the product is put into blacklist and its sales are closed on the e-commerce platform. We propose a mixed integer programming approach to determine the optimal set of weights. The objective is to minimize the gross marginal value (gmv) loss, while keeping the current global performance metrics same or getting them improved. The model is applied for different categories varying from customer electronics to branded textile. Tests on real-life data show that the model produce high-quality solutions and provide substantial revenue gain when compared to the current solution.

■ WA-10
Wednesday, 8:30-10:00 - U6

Robust optimization in Finance

Stream: Financial Risk Measurement and Management
Invited session
Chair: *Cyril Izuchukwu Udeani*

1 - Solution of HJB equation arising from Portfolio Management problem using monotone operator technique
Cyril Izuchukwu Udeani

In this study, we investigate a fully nonlinear evolutionary Hamilton-Jacobi-Bellman (HJB) parabolic equation utilizing the monotone operator technique. We consider the HJB equation arising from portfolio optimization selection, where the goal is to maximize the conditional expected value of the terminal utility of the portfolio. The fully nonlinear HJB equation is transformed into a quasilinear parabolic equation using the so-called Riccati transformation method. The transformed parabolic equation can be viewed as the porous media type of equation with the source term. Under some assumptions, we obtain that the diffusion function to the quasilinear parabolic equation is globally Lipschitz continuous, which is a crucial requirement for solving the Cauchy problem. We employ Banach's fixed point theorem to obtain the existence and uniqueness of a solution to the general form of the transformed parabolic equation in a suitable Sobolev space in an abstract setting. Some financial applications of the proposed result are presented in one-dimensional space.

2 - Estimating the potential of fuel cell buses with real option analysis
Tero Haahtela

This paper investigates the uncertainty and flexibility of gradually investing in fuel cell (FC) driven buses and their re-fueling infrastructure. The prices of fuel cells have steadily declined as well as the production costs of hydrogen. At the same time, fossil fuel prices have increased, and there is a global need to significantly reduce Co2 emissions and oil dependency. The method used for analyzing and comparing the alternatives is based on applying a cash-flow simulation real option valuation approach. Compared alternatives are full electric battery-driven buses, hybrid combustion engine buses (with fossil fuel and biofuel), and fuel cell buses.

The results show that fuel cell buses are viable for longer distances while purely battery-driven buses dominate city transportation. The related infrastructure costs of re-fueling and hydrogen production have a better economies of scale in comparison with the charging infrastructure of the battery-driven buses. Also, optimally expanding and scaling both the FC infrastructure and the bus fleet size are valuable. Furthermore, the operational option to produce and store hydrogen when the electricity prices are lower increases the value of flexibility. Considering the total cost of ownership (TCO), fuel cell buses are soon the optimal choice for long-distance buses.

3 - New Approaches for Identifying Robust Dominating Portfolios Based on Second-Order Stochastic Dominance
Peng Xu

Second-order Stochastic Dominance (SSD) criterion can be used to support portfolio decision making under risk and uncertainty. In this paper, we develop novel robust SSD criteria to capture the strength of dominance and portfolio optimization models utilizing these criteria to identify portfolios whose in-sample SSD dominance over a given benchmark is likely to hold also out-of-sample. The developed models can incorporate incomplete probability information by allowing a set of feasible state probabilities. We also show that these portfolio optimization models can be formulated as linear programming problems. We report results from applying these SSD-based portfolio optimization models with different sets of state probabilities in an empirical application, with a focus on evaluating the out-of-sample portfolio performance of the optimized portfolios.

4 - Exploring the unit commitment problem to assess the potential of hydroelectric flexible technologies

Flávia Barbosa, Luis Guimarães, Armando Leitão

Hydropower plants have a very long lifetime. To evaluate the total costs and benefits of both the initial installation and the upgrades resulting from new flexible technologies, we developed a unit commitment problem (UCP) focusing on the OPEX costs. The UCP in electrical power production is a mathematical optimization problem where the output of electrical generators is coordinated to achieve some common targets. Our model minimizes simultaneously three components of costs: start-ups and planned and unplanned interventions costs. The unplanned intervention costs are computed considering the risk of a breakdown and restoring an asset to a better condition. Moreover, we evaluate the usage of the hydroelectric technologies proposed in the European project XFLEX HYDRO to provide enhanced flexibility services to the European power system. Each technology comes with distinct possibilities and limits in terms of operating modes, thus introducing different risk profiles in the operation of the units.

■ WA-11

Wednesday, 8:30-10:00 - U7

How to support complex decisions. Negotiating the trade-off between Social, Environmental and Economic values 2

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Alessandra Oppio*
Chair: *Marta DellOvo*

1 - Towards a heterodox DCFA/OR perspective in the promotion of the spread archaeological heritage

Maria Rosa Trovato, Salvatore Giuffrida, Carmelo Marisca, Cheren Cappello, Ludovica Nasca

The archaeological landscape is the superstructure of the deep identity stratifications of settled communities; consequently, archaeological sites take on a more or less explicit iconic value depending on the age and consistency of their finds, which influence the awareness of the link between community and territory. The territorial value of minor sites implies a considerable effort in archaeological research; the latter is a resource whose present value is compared with the discounted value of the long-term benefits. The economic-financial evaluation of the musealisation of an archaeological area of the Province of Enna (Italy), stimulates reflections on the convergence of three evaluation modes, Appraisal, DCFA and Operational Research in a "heterodox approach" as for the inverse use of the economic-financial indices typically expressing the intertemporal link between the resources at stake. In the perspective of a social agreement generated as an output of the decision-making process aimed at the valorisation of the minor archaeological heritage, the implementation of the IMO-DRSA model constitutes a robust communicative interface to support the system of shared rules of intra-systemic communication; this specification of social communication assumes as a communicative code the deepest essence of this territorial asset pointing out, in this specific subsector of the cultural industry, the need to evaluate carefully claims of economic-financial self-sustainability ".

2 - New SDG11-related indicators to underpin complex urban decisions

Marika Gaballo, Beatrice Mecca, Isabella Lami, Elena Todella, Francesca Abastante

Within a global strategy for the pursuit of sustainable development (SD), the governments are responsible for following, developing and reviewing the 2030Agenda at global, national and regional levels. EU Member States pursue the SD framework, promoting an efforts' coordination to implement the SDGs. According to the Council of the European Union, the scenario for best achieving the SDGs within the EU envisages taking them as a guiding criterion for EU policies. In this shared global framework, regional and local authorities are free to choose whether and how to adapt their activities to achieve SD. Moreover, the economic and social consequences of the Covid-19 pandemic have progressively outlined the need for a realignment of the SDGs and their respective Targets and indicators to support complex urban decisions. In this framework, the aim of the research is to provide some initial considerations by focusing on SDG11 exploring the Targets 11.1 (Affordable Housing) and 11.3 (Inclusive and Sustainable Urbanization) to consider economic, social and environmental dimension of the phenomenon and to reflect about the trade-offs for the prioritization of actions and resources. The research provides: i) a recognition of existing indicators, highlighting the missing dimensions on each Target and their transposition from European to national and regional level; ii) the definition of the modalities of implementation; iii) new indicators to support the development of urban policies.

3 - Selection of complex energy-related technological R&D pathways with Multi-Criteria Decision Analysis

Francisco Silva Pinto

Electricity consumption has increased significantly worldwide. By relying severely on fossil fuel-based technologies, this industry is restricting the achievement of a safer and more sustainable future. The CATCHER project aims to exploit atmospheric humidity as an alternative renewable energy source. To promote scalability allowing to integrate with existing grid, we had to assess possible technological R&D pathways, as well as other existing energy sources, across the multiple economic, social, and environmental criteria by means of a requisite multi-criteria decision analysis (MCDA) value model. This context contains, due to its nature, criteria measurements/predictions and preference information are highly uncertain, inaccurate or partially missing. To target those shortcomings, we use a stepwise interactive MCDA framework with scenario planning. To target the existing contextual ignorance, we allow for criteria measurements/predictions, elicited value functions and weighting coefficients, to be represented by probability distributions. The Monte Carlo simulation outputs were then assessed and discussed using traditional statistical measurements (i.e., Kendall Tau and Spearman rho) and a computation of each alternative value-at-risk. We also use a comparable computation within the Stochastic Multi-criteria Acceptability Analysis method to assess the advantages and disadvantages between the two types of methods in terms of complexity, time, and required resources.

4 - Development of a Spatial Decision Support System (DSS) using Multi-criteria Analysis for Flood Management Planning

Mohammad Fikry Abdullah, Sajid Siraj, Richard Hodgett

The consequences of flood catastrophes include loss of life, economic disruption, and environmental degradation. To address the impacts of these disasters, decision-makers must evaluate various criteria to facilitate flood management planning. In this context, Disaster Management Plan (DMP) has been a crucial instrument for managing disaster and their impacts since the 1970s. This study investigates and implements the use of multi-layer spatial criteria based in the DMP for supporting decision-makers in taking the most appropriate actions. The macro-domain criteria were identified and selected using a systematic literature review and then refined using expert interviews. Based on data feasibility and availability, this study shortlisted six criteria to implement a spatial decision support system (DSS) to support the decision process. These six criteria are historical rainfall, land use, population, health and safety facility, terrain data and projected rainfall data. The aim of this spatial DSS is to help the management of flood victims in their evacuation and provide a safe place until the (effect of) disaster is over. The prototype is a work in progress. The proposed DSS has the potential to enable resource allocation and planning to be established during the early preparedness and mitigation phases, preventing more expensive future interventions. The proposed framework can also be adapted for managing other disasters such as drought, storms, and earthquakes.

■ WA-12

Wednesday, 8:30-10:00 - U9

Optimization and Equilibrium Modeling in Energy-2

Stream: OR in Energy
Invited session
Chair: Steven Gabriel

1 - Prosumers with PV-Battery Systems in the electricity markets - a mixed complementarity approach
Marco Sebastian Breder, Felix Meurer, Christoph Weber

Previous studies have shown that decentralised sector coupling and flexibility options play an important role in the integration of renewable energies into energy systems in the future. Recent developments include increased investments in PV battery systems underlining the increased importance of decentralised flexibility. At the same time, the present design of retail tariffs means that private households operate coupled PV battery systems primarily with the aim of increasing self-consumption. Our contribution examines in a stylised setting which adjustments to the regulatory framework can work towards a system-oriented operation of decentralised flexibilities with a focus on PV battery systems. We use the format of Mixed Complementarity Problems (MCP) to combine the optimisation calculus of decentralised actors at the retail level with cost minimisation at the wholesale market level. A special feature of our approach is the explicit and detailed modelling of a retailer. As a link between the two markets he covers the household's demand with quantities from the wholesale market facing time-variant prices. However, he charges households a time independent retail-price. The generation-portfolio at the wholesale level is characterised by a significant share of renewables resulting in volatile prices. When considering decentralised actors, we focus on prosumers, which in our simplified setting are depicted as representative households with a PV system and battery storage.

2 - Equilibrium modeling for coupled energy markets
Nena Batenburg

We demonstrate the existence and uniqueness of Cournot-Nash equilibria in coupled oligopolistic markets in which the players are subject to asymmetric production costs and capacity constraints. The inclusion of capacity constraints provides appropriate bounds on each player's profit maximization problem and will eventually allow for the consideration of investment decisions in addition to production decisions. Analytical results for stylized convex profit maximization problems provide general insights into the dynamics of coupled markets. These are complemented by more detailed numerical results from the application to energy sector coupling, in which technical and economic modeling are consolidated.

3 - A new pricing mechanism based on uniform and locational pricing for electricity balancing markets
Mariusz Kaleta

We consider a new class of pricing mechanisms, which generalize locational marginal pricing (LMP) and uniform pricing (copper-plate, CP) mechanisms. In the literature and practice of market design, there is an ongoing debate on the superiority of LMP and CP mechanisms. We propose a new mechanism that takes the best elements from both approaches. It acts as a trade-off between LMP and CP and presents sustainable properties. First, the security-constrained unit commitment problem with DC power flows is solved. Then our proposed mechanism divides nodes into two disjoint subsets of competitive and forced nodes. A CP-like mechanism can be applied for competitive nodes, while forced nodes need an LMP-like mechanism. We define quality measures for pricing mechanism assessment, including so-called system costs, social welfare, fairness, market signals. Based first on simple test grids and then on the case of the Polish balancing market data, we show the properties of the mechanism in relation to the LMP and CP mechanisms. The results were obtained from the analysis of the static market game (under the assumed strategies) and multiagent simulations.

■ WA-13

Wednesday, 8:30-10:00 - U119

Topics in Discrete Optimization II

Stream: Discrete Optimization and Algorithms (contributed)
Contributed session
Chair: Marcel Turkensteen

1 - Column-and-constraint generation for risk-averse two-stage stochastic programs
Jongheon Lee, Kyungsik Lee

In this talk, we introduce risk-averse representations of two-stage stochastic programs with finite support, where the risk is represented as conditional value-at-risk for the set of scenarios, to deal with potential risks of inaccurate estimation of the underlying distribution. Especially, we also propose a partition-based risk-averse two-stage stochastic program, where the set of scenarios is partitioned into several groups and the risk level of the model is obtained as an expectation of risk level for each group. To solve the models exactly, a tailored column-and-constraint generation method is proposed, which is a generalization of the methods in the previous literature. With a properly devised partitioning method, which makes the risk of the model similar to a target, we illustrate that a decision-maker can have an opportunity to choose a model with a certain level of risk and less computational effort. We demonstrate our computational experiments to show the effectiveness of the model and the efficiency of the proposed solution approach.

2 - Incremental Maximum Satisfiability
Andreas Niskanen, Jeremias Berg, Matti Järvisalo

Various applications require solving a sequence of related optimization problems. This calls for the development of incremental solvers, which can be invoked iteratively while reusing information obtained from previous calls. Due to recent advances, the optimization paradigm of maximum satisfiability (MaxSAT) offers a viable alternative to more classical approaches, such as integer programming (IP), for modeling and solving real-world discrete optimization problems. Internally, state-of-the-art MaxSAT solvers are based on employing Boolean satisfiability (SAT) solvers, which readily offer incremental interfaces. In contrast, current state-of-the-art MaxSAT solvers are designed to solve a single MaxSAT instance, offering no or limited forms of incrementality.

To facilitate the implementation of incremental MaxSAT solvers and applications making use of incremental MaxSAT, we design IPAMIR, a generic interface for incremental MaxSAT. Then, we detail how incrementality is enabled in a SAT-IP hybrid approach to MaxSAT solving, focusing in particular on handling changes to objective function coefficients and assumptions (i.e., partial assignments which can be reverted). As an end result, we develop an adaptation of a state-of-the-art MaxSAT solver to a fully-fledged incremental MaxSAT solver, implementing IPAMIR in full. Finally, we provide empirical evidence on the advantages of incremental MaxSAT solving, showing that significant runtime improvements are obtained.

3 - Efficient computation of tolerances of combinatorial bottleneck problems
Marcel Turkensteen, Gerold Jäger

In combinatorial optimization problems, one aims to find the best combination of a set of elements such that problem-specific constraints are satisfied. Each element has a cost value and the objective value of a solution is a measure depending on the costs of the elements in the solution, usually the sum of the costs is to be minimized. In our context, the objective value of the solution to be minimized is the maximum of the costs of all elements in the solution. This is the objective of type bottleneck, and we call the corresponding problem a combinatorial bottleneck problem (CBP).

We consider upper and lower tolerances of CBPs, which provide the range of cost changes of individual elements such that a current optimal solution remains optimal. Even though the stability and sensitivity of a solution is relevant, cost changes of CBPs have not received a great deal of attention in the literature. Thus, current computation methods are not very efficient, i.e., it generally takes much more time to compute all tolerances than to solve an instance of the problem. In our study, we introduce efficient computation approaches for the upper and lower tolerances of all elements of CBPs. Our results significantly improve computation times for relevant CBPs such as the Linear Bottleneck Assignment Problem (LBAP), which is the problem of assigning jobs to workers and vice versa such that the duration of the longest job is minimized.

■ WA-14

Wednesday, 8:30-10:00 - U261

Metaheuristics (contributed)

Stream: Metaheuristics, Matheuristics
Invited session
Chair: Adam Górski

1 - Combined optimization for offshore wind farms
Davide Cazzaro, David Franz Koza, David Pisinger

The two main challenges of optimizing a wind farm are the design of the turbine layout and the design of the cable routing. The first task consists in placing each turbine such that overall power production is maximized, the wake effect (wind shadow) between turbines is minimized, and foundation costs are minimized as well. The second task is to select the minimum cost cable routing to connect the turbines with submarine cables, which transfer the produced electricity to a substation and then onshore.

Although the typical procedure is to solve the two problems sequentially, we investigate the benefit of solving them together. Few studies in the literature attempt to join these two optimization problems, which are often simplified to keep the computational complexity low. In our work, we model the combined problem with all constraints relevant to practical applications of wind farm design. We also present a novel local search that integrates the two problems, thus allowing the cable routing to give direct feedback to the turbine positions in the layout. We benchmark the combined optimization on a set of realistic industry-scale wind farm instances. Our results show that the combined optimization outperforms the sequential approach, especially for lower energy density wind farms, due to the significant savings in the cable routing which widely compensate for a slight reduction in power production.

2 - Solving the Hamiltonian completion problem by customized evolutionary computing
Krunoslav Puljic, Robert Manger

The Hamiltonian completion problem (HCP) consists of finding the minimal number of extra arcs, which have to be added into a given graph in order to make it Hamiltonian. It is easy to see that the HCP is NP-hard. Also, the HCP can easily be reduced to the better-known traveling salesman problem (TSP). It is expected that both problems can be solved by similar algorithms where the same components are reused. This work is concerned with evolutionary algorithms for the HCP. The aim is to verify suitability of various crossover and mutation operators within the HCP setting. Some of those operators are standard, i.e. they have previously been used for the general TSP, some of them are adjustments of standard TSP operators, and some are custom-designed especially for the HCP. The considered crossovers and mutations are tested on a set of randomly generated problem instances. The obtained results of testing clearly show that the behavior and relative ranking of the considered operators within the HCP environment is different than within the TSP environment. Moreover, the results indicate that our modified or custom-designed operator variants assure much better performance for the HCP than the standard variants.

3 - Genetic algorithm approach with penalty function for concurrent real-time optimization of detecting unexpected tasks in Internet of Things design process
Adam Górski, Maciej Ogorzałek

Internet of Things (IoT) is internet based network consisted of billions of devices called things. Such devidces can be: embedded systems, sensors, satellites, and many more. Nowadays more and more solutions are based on IoT. IoT is mostly used in smart solutions like: smart houses, smart cities or smart cars. During the work the network can meet some unexpected situations. The situations were not predicted by the designers and even for smart solutions design process or at least a part of it must be repeated. This could generate too much costs and sometimes could be even impossible. Unexpected situaltions can be solved in many ways. It is very important to check which way is better. In this paper we propose genetic algorithm based method to concurrent real-time optimisation of detecting unexpected tasks in IoT design process. Unlike other approaches our algorithm in evolution process investigate not only valid solutions by using penalty function. Therefore the algoritm is able to escape from local minima of optimizing parameters. The algorithm chooses number of unexpected tasks and assign them to available resources. The process is divided on two phases. Each phase impacts another in real time. Therefore any change in one phrase can make change in the second one in the same moment.

■ WA-15

Wednesday, 8:30-10:00 - U262

Policy Analytics and Decision Support Systems

Stream: Decision Support Systems
Invited session
Chair: Pavlos Delias

1 - Time and Space Predictive Analytics of Crime and Policing For Vehicle Routing and Optimal Resource Allocation.
Thyago Nepomuceno, Rayane Araújo Lima, Jean Gomes Turet, Lucio Camara e Silva, Ana Paula Costa

Like many other regions in the world, Brazil carries out a responsive policing, which means that an increase in crime for a given community provokes an increase in the policing time for that specific community as a response. Nevertheless, long-term sustainable public security requires a preventive policing seeking to anticipate criminal occurrences instead of only responding to them for providing a safe atmosphere for tourists and residents with a better allocation of vehicles and officers. This work aims at combining the advances in the Autoregressive Integrated Moving Average (ARIMA) modeling with the inclusion of spatial regressors and Bootstrapping simulations for predicting property, violent crimes and policing over time and space. The dataset has more than 100 million geographic coordinates of police vehicles in Pernambuco, Brazil, updated by seconds, and data on several types of violent and property crimes over the years, aggregated at a microlevel (census sectors) provided by the state public administration. Using a dedicated geographic information system, seasonal and locational predictions of different types of crimes can support weekly police strategies based on sport, music, or cultural events, or based on contextual, demographic and socioeconomic characteristics of the space, and estimates for the police productivity.

2 - Comparison of metaheuristics for the location of firebreaks in wildfires combat
David Palacios, Jaime Carrasco, Sebastián Dávila, Cristobal Pais, Andrés Weintraub

In the research, different metaheuristics are studied, implemented and compared in order to offer a tool that allows, through operations management, the adoption of firebreak location strategies to reduce the area burned due to forest fires as much as possible. It incorporates the randomness of the nature of wildfires through variations in ignition points and wind direction. In addition, the metaheuristics are tested on different sizes and types of forests (with homogeneous and heterogeneous fuels). In a first implementation, different metaheuristics were tested under basal conditions. In the final implementation, 3 metaheuristics were compared: Genetic Algorithm, GRASP and Taboo Search, which correspond to those that gave better results in previous implementations, highlighting GRASP (Greedy Randomized Adaptive Search Procedure). This result is consistent with one of the conclusions obtained by Mark Finney et al. in the 2008 paper: Simulation of long-term landscape-level fuel treatment effects on large wildfires, where he finds topologies that better favor firewall performance compared to other topologies. Some improvements are proposed, such as not seeking to minimize the burned area in the average of simulated scenarios, but seeking to minimize the burned area of the fire that burns the most area within the simulated scenarios. Finally, it is concluded that GRASP could be a good tool to assist in preventing the impact of forest fires in Chile.

3 - Paris Agreement targets under uncertain negative emission technologies and climate sensitivity
Theresa Schaber

The research maps cost-effective emission pathways with uncertain negative emission technologies (NETs) satisfying the Paris temperature targets of 1.5'C under uncertainty in climate sensitivity that decreases over time through exogenous learning. More specifically we investigate the implications from having a fixed assumption of future NETs characteristics today, i.e. betting on negative emissions. We implemented three assumptions (pessimistic, average and optimistic) for the cost, potential and deployment times of six different NETs. Scenarios are calculated with SCORE, a lightweight Integrated Assessment Model with stochastic capabilities. Our results indicate that NETs can have a notable role already in mid-century mitigation for hedging the climate sensitivity risk. An underestimation of NETs costs and overestimation of potentials (optimistic scenario) leads to tremendous marginal costs [$/tCO2] to meet Paris targets. Considering the uncertainty in climate sensitivity exacerbates this effect for all modeled scenarios.

4 - Complex systemic problems in regulation - case study in demand response in Finland
Anni Niemi

The whole energy sector is undergoing a historic transformation as generation is distributed, sectors are integrated and the need for flexibility is increased. Research alone can't give direct answers to complex and multidimensional energy questions, so the need for interpretation and cooperation is emphasised. Often the research supposed to support decision-making is passive preparing of models and reports, expecting the decision-makers to find it useful. Evidence from previous studies shows that this is not an effective way to exchange information. Researchers must gain a better understanding of the context in which decision-makers act to build more inclusive interaction with the decision-makers. The objective of this work is to explore the current ways of interaction between policymakers and researchers regarding the energy transition, and to present a new improved process of communicating research findings to be the most useful support for decision-makers. The study delves into the subject through a case study of incentivising electricity end-users participating in demand response - to find what policymakers need from researchers to make decisions regarding complex regulation questions. The objectives are answered based on multi-criteria decision-making theory and one-on-one interviews with Finnish policymakers. Based on the findings, the information needs in different stages of the regulation process are identified, and suitable collaboration options are evaluated.

■ WA-16

Wednesday, 8:30-10:00 - U264

Portfolio Risk Management

Stream: Risk Management in Finance
Invited session
Chair: Tomas Tichy

1 - Application of Technical Trading Rules to Approximated Returns by Semiparametric Regression with Copula PCA Approach
David Neděla, Noureddine Kouaissah

The aim of this research is to investigate the application of simple technical analysis (TA) rules in the portfolio optimization strategy. To remove a strong limitation of TA whilst improving risk and performance of a portfolio, we consider a new attitude based on ex-ante predicted asset returns and the consequent approximation of cumulative returns. To simulate the future evaluation of daily gross returns of assets, we apply semiparametric regression models, which provide a more accurate expression of the asset return behaviour, especially modelling of heavy tails. The principle of this approach is based on the derivation of returns time series to main factors using copula principal component analysis, leading to reduction main factors of the asset dependency structure expressed by the Student's t-copula. We used the simple and exponential moving average and the momentum as TA indicators adapted for the predicted data. The main advantages of these indicators are their simplicity for application and variability in the definition of the trading signals. Additionally, we use two asset preselection strategies and various portfolio performance ratios included in the maximizing reward-risk portfolio model to determine the particular weight vector of assets. Based on the empirical results, we observed that strategies with considering TA rules outperform the mean returns, final wealth, and monitored performance ratios of the simple portfolio model and defined benchmark.

2 - The effects of ETF ownership on the risk of the underlying stocks: Evidence from international markets
Livia Carneiro, Sergio Ortobelli

The popularity of exchange-traded funds (ETFs) has grown tremendously over the past few years, mainly due to their low transaction costs, high liquidity, and trading flexibility. However, ETF attributes also allow more arbitrage opportunities that may disseminate demand shocks for the assets in their baskets and consequently distort prices. The alternative conjecture is that ETFs might generate a liquidity buffer for shocks that could any other way affect their assets' prices. We investigate the consequences of ETFs growth on the risk measures and on the returns distribution symmetry of the underlying stocks by exploring a large sample of funds from 32 different countries. Our results suggest that ETF ownership is associated with an increase in volatility and sustained losses for the underlying assets in the United States. We find opposite results for developed markets. Nevertheless, the growth of ETF-owned securities has asymmetric effects on the left tail and the right tail of the return distributions in both markets. The impacts of ETFs in increasing maximum and expected tail losses of the underlying assets in the United States outweigh their positive effects on gains.

On the other hand, ETFs reduce maximum and expected tail losses for developed markets stocks, but also more intensely the gains. ETFs do not seem to affect stocks risk metrics in emerging markets.

3 - Conditional and dynamic portfolio strategies
Noureddine Kouaissah

In this paper, we revisit and develop dynamic portfolio strategies based on Ruttiens type performance measures. Our main contributions can be outlined as follows. First, we incorporate investor preferences into these typical dynamic portfolio strategies using new definitions of returns that are consistent with a well-defined ordering classification. Second, we propose a modified Ruttiens-type risk measure to account for downside losses. Third, we approximate the conditional expected value using a nonparametric local linear smoother together with asymmetric kernel estimation. Finally, ex-ante wealth analyses of the S&P 500 components confirm the proposed methodologies and provide valuable managerial insights.

4 - Tracking the benchmark of Lithuanian pension funds
Audrius Kabasinskas

In this study we analyze daily tracking error of Lithuanian lifecycle pension funds. The tracking error is understood as difference between current net value and benchmark of the fund. Preliminary results show that probability distribution of tracking error of some funds has few peaks, mean is significantly different from zero and variance is period dependent.

■ WA-17

Wednesday, 8:30-10:00 - U356

Optimization Software: Other Topics

Stream: Software for Optimization
Invited session
Chair: Robert Fourer

1 - Progress in Mathematical Programming Solvers from 2001 to 2020
Thorsten Koch

We report on a study that investigates the progress made in LP and MILP solver performance during the last two decades by comparing the solver software from the beginning of the millennium with the codes available today. On average, we found out that for solving LP/MILP, the total speed-up was about 180 and 1,000 times, respectively. However, these numbers have a very high variance and they considerably underestimate the progress made on the algorithmic side: many problem instances can nowadays be solved within seconds, which the old codes are not able to solve within any reasonable time. We will report on how we measure performance and why it is very difficult to come up with one reasonable number.

2 - Efficiently Explaining Constraint Satisfaction Problems with Unsatisfiable Subset Optimization
Emilio Gamba, Bart Bogaerts, Tias Guns

We build on a recently proposed method for explaining solutions to constraint satisfaction problems. An explanation here is a sequence of simple inference steps, where the simplicity of an inference step is measured by the number and types of constraints and facts used, and where the sequence explains all logical consequences of the problem. We build on these formal foundations and tackle two emerging questions, namely how to generate explanations that are provably optimal (with respect to the given cost metric) and how to generate them efficiently. To answer these questions, we develop 1) an implicit hitting set algorithm for finding optimal unsatisfiable subsets; 2) a method to reduce multiple calls for (optimal) unsatisfiable subsets to a single call that takes constraints on the subset into account; 3) a method for re-using relevant information over multiple calls to these algorithms and; 4) a method for imposing stronger constraints on the computed subsets balancing efficiency and quality. The implicit hitting set-based algorithm is also applicable to other problems that require finding cost-optimal (weighted) unsatisfiable subsets. We specifically show that this approach can be used to effectively find sequences of optimal explanation steps for a large set of constraint satisfaction problems.

3 - Understanding Solver Logs and Parameter Tuning
Mario Ruthmair

In this short tutorial we discuss the log output of Gurobi's solver based on some exemplary models. We identify important information related to model characteristics and the solution progress. Based on this we suggest actions to improve the solution performance in terms of decreasing runtime or the residual MIP gap when a time limit is set. These actions might refer to model reformulations, e.g., to compensate for observed numerical issues or weak dual bounds. We also consider solver parameter settings that are deduced from the logs and focus on phases in the solution process that are not handled efficiently with default settings for the investigated models. The log and parameter discussions are illustrated with Gurobi 9.5.1 but the findings might also be applicable to other solvers that often have similar outputs and parameters.

■ WA-18

Wednesday, 8:30-10:00 - U358

Cutting and packing session 1

Stream: Cutting and Packing
Invited session
Chair: José Fernando Oliveira

1 - New Approach to Solution of Packing and Covering Problem with Complex-Shape Objects
Sergiy Yakovlev

The report discusses the problems of packing and covering of areas and objects of complex geometric shape. There are no effective methods for such problems, which is primarily associated with the difficulties of an analytical description of the conditions of admissible location of the objects. For packing problem, the pfi-function method is known, however, it is effective as a rule for simple shapes of objects. For covering problem, the use of this method is significantly difficult. The report proposes a new approach to formalizing the conditions of placing and coating, based on calculating the measure (area) of spatial configurations (complex geometric object) with different metrical and placement parameters. Currently, there is a powerful list of libraries that allow you to work with geometric objects of arbitrary form, in particular, Sympy, Shapely, CGAL, SpaceFuncs and many others. Based on the analysis of existing libraries, taking into account the necessary requirements for calculating the area of spatial configurations, the Shapely library is choosed. Shapely is Python Package for theoretical analysis of point sets. This package manipulate with geometric objects using Ctypes Python Module and GeoS library. Packing and Covering Problems are formulated as maximizing of the area of the corresponding spatial configuration. To solve it, methaheuristic methods of global optimization are used.

2 - A fast deepest-left-bottom-fill algorithm to solve 3D nesting problems using a semi-discrete representation
Sahar Chehrazad, Dirk Roose, Tony Wauters

We present an efficient algorithm to solve the strip packing problem for 3D irregularly shaped polyhedral pieces, using a semi-discrete representation. The pieces are placed in a cuboid container, while minimizing the x-dimension of the container. Both the pieces and the container are discretized in the x- and y-directions. A discretized piece is represented by line segments in the z-direction for each (x,y) grid point. Non-overlapping placement of the line segments guarantees non-overlapping placement of the pieces. Placement of the line segments by a deepest-left-bottom-fill method can be performed very efficiently because of using appropriate data structures, simple arithmetic operations to detect and avoid overlap and an optimised ordering of the segment overlap tests. In case rotation of the polyhedra is allowed, the placement of each polyhedron is done with the optimal rotation angle. To execute the algorithm on multiple cores of a multicore processor, testing the placement of the segments in each y-z-plane is done in parallel. The performance and the computational cost of the deepest-left-bottom-fill heuristic depend on the resolution, i.e., the distance between the grid points, and on the number of rotation angles. Placement of 36 polyhedra without rotation, with a fine resolution, requires 34 ms on 8 cores of an Intel i9 CPU. Hence our algorithm can be used as a high-performance building block in heuristics for optimal 3D placement.

3 - An Intelligent Packing System (IPS) with Industry-Grade Features

David Álvarez-Martínez, Daniel Cuellar-Usaquen, Juan Carlos Pachon, Germán Fernando Pantoja Beanvides, Juan Camilo Martínez, Luis Miguel Escobar Falcón, Cesar Marin, Laura Escobar, Camilo Quiroga, Julio Daza Escorcia

Correct (un)loading and storage of goods provide efficiency, lower costs and tangible benefits for any supply chain. However, obtaining these benefits remains an unsolved problem for many companies. IPS has been developed with the user in mind, with extensive possibilities for creating, defining, saving, editing, and exporting packing patterns by performing clear, precise, and concise interactions. IPS is a consumer-grade application developed using the Unity game engine that illustrates packing patterns from user-defined instances of the (ir)regular three-dimensional packing problems. IPS can create packing patterns for boxes and convex polyhedra employing metaheuristic algorithms. IPS also intends to contribute to the development of new algorithms since its modular structure allows the optimization engine to be easily changed, thus allowing the academic community interested in Cutting and Packing to save time in creating software, focusing on conceiving better solution algorithms. The default optimization modules included in IPS for boxes and connected polyhedra have been tested against the best methods in the literature, showing similar results in run time and space usability. For the future of IPS, we intend to create a web application so that users can run it from any computer, allowing them to access their goods and load spaces. Additionally, it pretends to include more complex packing constraints.

■ WA-19

Wednesday, 8:30-10:00 - Y228a

Queueing systems for services 1

Stream: Performance Evaluation of Queues

Invited session

Chair: *Binyamin Oz*

Chair: *Yoav Kerner*

1 - Foresee the Next Line: On Information Disclosure in Tandem Queues

Ricky Roet-Green, Jingwei Ji, Ran Snitkovsky

We consider a system where customers have to go through two service stages. For example, customers who visit the Apple Store first have to join a queue to check in, and then wait in another queue to be served by the Genius Bar technician. %For example, patients who arrive to an ER first wait for being admitted and then wait to be seen by a physician. Assuming customers are served according to the order of their arrival, we first study the fully-observable model, in which queue-length information of both queues is available at arrival: customers observe the state of the entire system and decide whether to join or not. We calculate the equilibrium strategy and show that customer strategy is not necessarily a function of the total number of customers in the system. We also show that when customers join the system they might balk in front of the second queue, but never renege from either queues. To learn the value of information we compare the fully observable system with the partially observable system in which, instead of observing the full system state, customers observe queue length only at arrival to each queue. We prove the existence of an equilibrium strategy in the partially-observable model and show that the customers will also not renege from either queues. Our comparison yields managerial insights regarding the optimal disclosure policy for revenue-maximizing and social-planner providers.

2 - Information uncertainty in service systems

Igor Rochlin, Yoav Kerner, Gail Gilboa Freedman

The role of information in queuing systems has long been recognized and investigated from many different angles, such as considering the possibility that the information is partial, delayed, unavailable or random. Surprisingly, none of these researches questioned the effect of the reliability of the information on the decision making process and system's performance. Since we have so much available information, part of our daily routine is to decide which information is reliable enough and which is not. Our motivating example considering a manager that decides whether to pass assignments to his worker according to the observed amount of assignment the worker already has. The worker passes unreliable information regarding the assignments she has. She may report finished assignment as unfinished ones and she may report unfinished assignments as finished. We refer to the first behavior as the complainer- as the worker complains about his amount of work and thus misinforms the manager. We refer to the second behavior as the hoarder- as an over motivated employee hoards assignments by misinforming the manager. In this work, we analyze the effect of these types of misinformation separately, the hoarding type worker and the complainer type worker. We examine the effect of information uncertainty on system's throughput, and provide an interesting perspective of how mis information can act as a regularization technique for suboptimal decisions of the manager.

3 - The impact of information on the performance of M/g/1 queue with strategic customers.

Yoav Kerner, Ricky Roet-Green, Lin Zang

We consider and M/G/1 queue to which customers decide strategically to whether to join or balk. We assume that the customer observe the queue length. We examine the impact of providing the customers the information of the elapsed service time. The latter makes the information Markovian, and hence only pure strategies. We compare the social welfare and the throughput resulted in these two models and provide conditions for "more information-> worse performance"

4 - Waiting Time Distribution Asymptotics in the Accumulating Priority Queue

Joris Walraevens, Thomas Van Giel, Stijn De Vuyst, Sabine Wittevrongel

We analyze the asymptotics of waiting time distributions in the accumulating priority queue. The accumulating priority queue was suggested by Kleinrock in the 60s (coined as time-dependent priority) to diversify waiting time objectives of different classes, while also taking into account the time customers have already waited. All customers build up priority while waiting in the queue at class-dependent rates. At a service opportunity epoch, the customer with highest priority present is served. The LSTs of the waiting time distributions of the different classes are readily known in the literature, but expressions can be complicated. We show that exact asymptotics of the corresponding distributions from these LSTs can be obtained by studying the location and nature of the dominant singularities of these LSTs. We show that different singularities of the LSTs can play a role in the asymptotics, depending on the magnitude of service differentiation between both classes.

■ WA-20

Wednesday, 8:30-10:00 - Y228b

Performance Measurement

Stream: Data Envelopment Analysis and Performance Measurement
Invited session
Chair: Paulo Nocera Alves Junior

1 - Green total factor productivity: Quantile shadow-price Fisher index approach
Sheng Dai, Timo Kuosmanen

Measuring green total factor productivity (GTFP) is widely recognized as a longstanding challenge to economists and of extreme interest to policy-makers. This paper proposes a quantile shadow-price Fisher index to gauge GTFP change. The developed penalized convex quantile regression approach yields the unique shadow prices estimates, takes inefficiency explicitly into account, and is more robust to outliers and the choice of the direction vector. The proposed quantile shadow-price Fisher index does not require the real price data, can avoid an ad-hoc choice of quantiles, and allows the quantiles to move in the inter-period sample. An empirical application to OECD countries during 1995–2019 confirms that the quantile shadow-price Fisher index generally yields a good approximation of the conventional Malmquist index and is a better choice for measuring GTFP change.

2 - Efficiency and Productivity Assessment of OECD Countries: An Application of Data Envelopment Analysis
Fatemeh Abbasi, Sahand Daneshvar

Research and Development is the process of creating new or improved technologies and is generally a part of innovation studies. It is also known as one of the main drivers of economic growth and includes innovative and systematic activities that lead to an increase in human knowledge, society and culture. Each country uses R&D for a variety of mentioned functions and invests a significant portion of its resources. R&D at the national level plays a crucial role in long-term economic development. R&D investments are critical to reflecting a competitive advantage at the national industrial or economical level. One of the main concerns for the growth and development of countries is the importance of paying attention to the productivity of R&D. "A prerequisite for making R&D more productive is to be able to measure its productivity." Since research and development are considered as a process of generating knowledge and technology with multiple inputs and outputs, data envelopment analysis (DEA) can be used to assess the productivity of these countries and make relative comparisons between nations. Considering the OECD countries that creatively carry out R&D activities with high productivity growth, in this empirical study, we compare the R&D efficiency of 17 OECD countries plus Russia and China in the years 2013-2018. The analysis is conducted using three inputs and three outputs. Interesting results are obtained based on the industrial and economic progress of nations.

3 - Cost Efficiency Analysis of Control Systems when there is a relationship among variables: A Data Envelopment Analysis approach with an Intermediate Measure
Paulo Nocera Alves Junior, Isotilia Costa Melo, Daisy Rebelatto

Data Envelopment Analysis (DEA) is a non-parametric method of mathematical programming used to measure the relative efficiency of Decision-Making Units (DMUs) in a system with multiple inputs and outputs. Other characteristics were incorporated into DEA models, such as carry-overs (links) and intermediate measures. And specifically, in the dynamic efficiency literature, inventory is one of the five most common factors that are attributed to the temporal interdependence between different periods. Usually, these characteristics are associated with dynamic, network, or two-stage DEA literature, but there is a lack of studies considering these characteristics on the static framework. Given the context, the objective of this presentation is to study the category of intermediate measures outside of the dynamic efficiency literature and its impact on static performance measurement. An application will be made to verify the impact in the efficiency of inventory control systems from DMUs when considering inventories from the beginning and the final of the analysed period and their relationship to demand and production measures. A type of constraint called variational (or difference of state) will be considered for this purpose, which comes from the Optimal Control Theory (OCT). The expected result is a more realistic efficiency analysis of control systems. It will avoid goals that ignore the relationship and that are physically unfeasible in practice.

■ WA-21

Wednesday, 8:30-10:00 - Y229a

Behavioural decision making

Stream: Behavioural OR
Invited session
Chair: Ilkka Leppanen

1 - Post-decision surprises and poor choices: The impact of evaluation uncertainties in multiattribute decision-making
Taeyoung Kee, Eeva Vilkkumaa, Juuso Liesiö, Pekka Malo

Decisions that involve multiple attributes are often supported by decision analysis methods deploying a multi-attribute value/utility function, which captures decision makers' preferences on the multiple decision attributes and risk attitude. Often, there are uncertainties related to the evaluation of the performances with respect to these attributes. In the context of single attribute problems, these uncertainties cause ex post realized performances of the selected alternatives be systematically lower than ex ante estimates, causing the decision maker to experience post-decision disappointment. In this paper, we study the impact of attribute-specific estimation uncertainties and non-linear utility functions on post-decision surprises and the quality of decision making in a multi-attribute setting. In particular, we study the performance of several choice heuristics and examine whether they lead to the optimal choice that maximizes the expected multi-attribute utility and whether these choices correspond to truly optimal choices that maximize ex ante true multi-attribute utility. Furthermore, we develop Bayesian-based methods that adjust the uncertainties and show that decisions based on adjusted estimates can produce significantly better result under certain circumstances.

2 - Multi-criteria decision-making processes during the Covid-19 pandemic
Gil Greenstein

In the global environment decision-makers should take into account several aspects. Some of them contradict each other, and some aspects are not comparable to others. It limits the ability of decision-makers to take the several aspects into account. Moreover, when the real-world changes occur in small intervals of time, the considerations of decision-makers are changing frequently and drastically. This leads us to the need for better understanding the human decision-making process. For example, this approach could lead to better understanding of decision making (by leaders) in these days of a pandemic crisis. This research presents an extension of the utility function, in order to understand the mechanisms of multi-criteria decision-making (MCDM) processes. A consequent analysis explains decision-making behavior under assumptions of bounded rationality. The analysis deals with decision situations, in which it is assumed that a decision-maker cannot formulate a joint utility function constituted from different criteria, which are completely or partially inestimable (intangible). The model is based on an assumption of bounded-rationality, that a decision-maker takes several criteria into account, but cannot formulate a joint utility function constituted from different criteria. The results of the analysis suggest that an optimal solution cannot be obtained. In contrast, a different approach, called optimization is subject to rational satisfaction is proposed.

3 - Combining stakeholder preferences with social network analysis in Swiss pesticide governance
Milena Wiget, Karin Ingold, Judit Lienert

Growing concerns about human health risks and environmental impacts have placed pesticide use and risk reduction on the top of the Swiss water and agricultural policy agenda. This is a complex socio-environmental decision problem. It involves various stakeholders with different preferences towards numerous objectives and includes many uncertainties. In the public discourse, the focus so far has been primarily on potential policy instruments and agricultural practices to reduce pesticide use and risks. Little is known about the full range of objectives that national pesticide governance must address and stakeholders' preferences in view of these objectives. We aim to elicit stakeholders' preferences toward the full range of relevant objectives in Swiss pesticide governance for finding best strategic options and political consensus. To this end, we will carry out an online survey to receive indications about stakeholders' preferences regarding the importance of objectives and their risk attitude. We combine this with Social Network Analysis to investigate how collaboration and information exchange among the stakeholders might affect their preferences, and vice versa. The research builds upon the Advocacy Coalition Framework and Multi-attribute Value / Utility Theory. Ideally, this innovative combination leads to a better understanding of the decision problem and stakeholders' behavior, in this example concerning Swiss pesticide governance.

4 - Cognitive ability in risky decision making: The role of decision inconsistency
Ilkka Leppanen, Tianqi Hu, L. Alberto Franco, Maxwell Shinn

All life domains involve risky decisions that can have significant implications. Because it is well known that decision makers are often inconsistent, a large literature has developed to study reasons for this inconsistency. Recently it has been suggested that there is an inverse relationship between decision inconsistency and cognitive ability. Low cognitive uncertainty is an indicator of superior judgement because it implies that a decision maker can more accurately process relevant information and/or be more capable of acting based on the true preference, but cognitive uncertainty is not the sole cause of decision inconsistency. The inverse relationship may also reflect differences in the response caution of decision makers. The lack of response caution from low-ability individuals causes them to be more willing to trade decision accuracy for a shorter response time, hence their decisions appear to be more inconsistent. We investigate whether cognitive ability can predict a decision maker's cognitive uncertainty and response caution levels. We measure cognitive ability with psychometric tests and correlate this with choices in risky decision making tasks. Cognitive uncertainty and response caution are measured with Drift Diffusion Modelling. Our results contribute to the knowledge about how different levels of cognitive abilities affect quality of decision making.

■ WA-22

Wednesday, 8:30-10:00 - Y229c

Risk and Resilience

Stream: Supply Chain Management
Invited session
Chair: Pedro Amorim

1 - A Hybrid Simulation Model to Facilitate Resilience in Short Food Supply Chains
Suad Saliju, Christian Fikar

Short food supply chains (SFSC) are seen as a solution towards more sustainable and resilient food supply chains. At the same time, however, an increasing number of disruptions, caused by severe natural hazard events and man-made disasters, have seen food supply chains severely affected. While the impact of disruptions on various supply chains have been extensively investigated, there is still a lack of research regarding their impact on food supply chains and particularly SFSC considering the perishability nature of food produces. The purpose of this work is to study the impact of demand and supply disruptions on SFSC and by introducing appropriate mitigation strategies. For this, a decision support tool is developed using a hybrid simulation modeling, which enables a cost-effective approach to address resilience in the context of SFSC. Unlike most work, the model developed incorporates both resilience, through the evaluation of various mitigation strategies, and sustainability, in terms of total post-harvest costs and food losses by integrating food quality function. The developed simulation model is demonstrated on a regional asparagus supply chain in Franconia, Germany. Results highlight the importance of enabling alternative distribution channels to both, facilitate resilience and reduce food losses.

2 - The effects of risk consideration on a supply chain of free mobile apps with in-app advertising
David Fine, Tatyana Chernonog

We investigate a two-echelon supply chain of a free mobile app comprising an app developer and a platform distributing this app to users. The monetization strategy adopted by the app developer is in-app advertising, i.e., charging a fee for displaying various adds within the app. Revenue generated by the app is shared between the app developer and distribution platform (i.e., agency business model). The main contribution of this research is to analyze this business model combined with the developer's in-app advertising strategy in an uncertain environment (the app's quality level is a random variable). Unlike previous studies that addressed either paid app distributing or comparison between paid and free app monetization strategies, our work focuses on decision making of supply chain members that may be risk neutral or target-oriented. We proved that if the app developer is risk neutral, then the distribution platform's utility function has no effect on the equilibrium strategies due to a stochastic dominance property. In addition, we found that the distribution platform earns twice as much as the risk-neutral app developer. On the other hand, if both parties are target-oriented, the developer can earn more than the platform. Interestingly, if the developer is target-oriented, the app's quality level is not affected by the distribution platform's utility function.

3 - The impact of uncalled disruptions on manufacturers- An empirical analysis
Shradha Kapoor, Manish Shukla

There has been limited research on the level of financial and non-financial impact a manufacturer has during disruptions within a supply chain. In case of atypical disruptions, the buyers generally have higher decision-making power which results in manufacturers bearing higher losses. For example, buyers tend to cancel orders leaving manufacturers with finished and semi-finished inventory which they must sell at huge discounts. Assuming that maximum pressure is faced by manufacturers, this study studies a three-tier supply chain consisting of a buyer, manufacturer, and supplier.

It is evident from the literature that there have been studies related to the financial losses that a buyer goes through during an uncalled disruption and the recent Covid-19 pandemic has shed more light on this topic of operations management. With minimal research on the losses borne by manufacturers, the current study shifts the focus from buyers to manufacturers. For this study, we empirically investigate disruptions caused by the bullwhip effect due to fluctuating demand of the final customers in an uncalled situation. Our findings extend the knowledge on the consequences of disruptions caused in a supply chain and help in understanding the operational and financial impact on the manufacturers.

4 - Relationship between short-term disruptive events in logistics infrastructure and the resilience of the dairy supply chain: a network modeling approach
Nicolas Clavijo-Buritica, Pedro Amorim, Andres Gonzalez

Short-duration, high-frequency disruptions in road infrastructure networks can dramatically affect Agri-food supply networks. This study analyzes the impact of road disruptions on supply network operations through a case study of the dairy supply network in Colombia. The first phase was modeling the disruptions from a Machine Learning perspective, where prediction models for binary outputs were compared. In the second phase, a capacitated network was modeled using Mixed Integer Programming (MIP). Finally, under a process of computational experimentation, we evaluated resilience improvement strategies that provide the feasibility of implementation in the context of emerging economies. With this study, it was found that several of the supply chain resilience improvement strategies reported in the literature can be modeled under a hybrid modeling approach between ML and MIP. However, only some strategies are feasible to implement in Agri-food supply networks in emerging economies due to the vulnerability of the road infrastructure.

■ WA-23

Wednesday, 8:30-10:00 - Y307

Additional educational activities for OR-Analytics - the link to Development 1

Stream: Additional educational activities for OR-Analytics - the link to Development
Invited session
Chair: *Milagros Baldemor*
Chair: *James Cochran*

1 - Application of Malmquist Productivity Index with Technical Change and Efficiency Change in Higher Education: 2016-2020 Case
Erhan Berk

Turkey's higher education has experienced substantial growth over the recent years, but few studies have been analyzed about their technology and productivity changes efficiency. This paper uses Malmquist productivity index to assess the technology and productivity performance of 56 Turkey universities during the period of 2016 through 2020. The findings indicated that the efficiency and productivity of the Turkish universities increased during the period under investigation. However, in the period of 2018-2019, a significant decline was observed in efficiency. With regards to the Malmquist productivity index, the productivity of universities was influenced by a technical change index (TCI) rather than efficiency change index (TECI). Technical change is greatly affected by external factors such as new university establishments while the efficiency change is influenced by an idle capacity of the university personnel's resources and an allocation of the budget. Due to increasing number of universities and its negative effect on the financial resources and university personnel's usage, we discovered that an overall productivity of the universities has decreased by 6.5% from 2016 to 2020.

2 - Human Rights of the Humans Left: Integration of Human Rights Education in the Curricula of SUCs in Region I
Rozzanne Victoria Buccat-Villamin, Lady Mae Calderon

As human rights violations abound, Human Rights Education (HRE) seems to be failing amid efforts of state universities and colleges (SUCs) in the Philippines to fulfill the constitutional mandate of teaching it. This study shows the integration of HRE in the curricula through mixed method, using validated survey, interview, and inspection of instructional mechanisms (IMs). Respondents included 165 teachers handling Readings in Philippine History, Contemporary World, and NSTP in all Region 1 SUCs. The IMs were examined in terms of HRE topics and time allotment. In the survey, HRE was included as a topic in the syllabi and learning plans, and said to be completed every semester, with lecture-discussion method as the most common pedagogy used. However, the IMs revealed varying degrees of integration: 0-9 hours per course per semester. This means that HRE is not after all being integrated mandatorily, considering various factors. The interviews support this finding. The top five constraints in HRE are: lack of reference materials, insufficient time, lack of training of teachers, lack of knowledge in constitutional rights, and students' detachment from news. HRE would improve through: more reference materials, training for teachers, making HRE a separate General Education course, encouraging students to be aware of news, and engaging students in interactive classroom activities. With these, a policy statement and a syllabus for the improvement of HRE were produced.

3 - LET Readiness of Mathematics Pre-Service Teachers in DMMMSU NLUC: a basis for a LET Review Material in Mathematics
Nora Oredina

One of the major determinants for a Higher Education Institution to be considered as a Center of Excellence is its overall performance in the licensure examinations. This study aimed to determine the level of LET readiness of the pre-service Mathematics teachers in DMMMSU as well as identify their strengths and weaknesses. This in turn will become a basis in crafting a LET Review Material. This study utilized the descriptive research design. The population of the study included the fourteen pre-service teachers of the College of Education in BSED major in Mathematics. The study utilized researcher-made tests in the various areas of Mathematics. The level of LET readiness is obtained by using the mean scores of the respondents Test of normality and dependent T-test were also used to determine differences in the LET readiness before and after the implementation of the LET intervention. The identified strengths are Trigonometry, College Algebra, Probability and Statistics, Problem Solving Abstract Algebra, Advanced Algebra and Calculus. This implies that they perform very good in these subjects. On the other hand, the pre-service teachers have not yet established a strong knowledge and mastery of the other subjects such as Analytic Geometry, Linear Algebra, Solid Geometry, Instrumentation in Mathematics, Investigation, History and Modeling. There is an improved performance after the administration of the LET Intervention Program.

4 - Assessing performance of Institutions of Higher Education in India (2016-2021): A DEA-based approach
Jinal Parikh

While India's education sector is sprucing up with dynamic transformational reforms whether it be through its recently (2020) announced National Educational Policy (NEP) or it be through its more recently (2022) announced proposed digital University, it is characterized by constrained resources on the other. Given this background, assessing performance of Institutions of Higher Education in India based on their efficiency can provide interesting insights to academia, researchers and policy makers. The present study uses a DEA approach to assess the efficiency of Higher Educational Institutions in India for the period of 2016-2021 based on the secondary data and reports available in the public domain which include reports of the Ministry of Human Resource Development (MHRD), UGC Reports, Economic Survey of India, Reports of the All India Survey on Higher Education (AISHE) and various Higher Educational rankings published by Ministry of Education which include National Institute Ranking Framework, etc. The efficiency results indicate the impact of the variables by determining their weights considering them as input/output variables in contrast to rank-based approaches which assign them apriori-weights.

Keywords: OR in education, Data envelopment analysis; higher education, efficiency, India

■ WA-24

Wednesday, 8:30-10:00 - Y307a

Price and Demand Planning

Stream: Demand and Supply in Consumer Goods and Retail
Invited session
Chair: *Winfried Steiner*
Chair: *Martin Waitz*

1 - A flexible heterogeneous sales response model with price dynamics to improving profits for consumer goods
Winfried Steiner, Philipp Aschersleben

We propose a Hierarchical Bayesian semiparametric dynamic store sales model to improve the pricing of brands and related profits for a retail chain. Using Bayesian P-splines as a nonparametric technique to estimate price effects allows us to dispense with the specification of a functional form for own and cross-price response a priori and to identify possibly exceptional pricing effects (like distinct threshold or saturation effects) directly from data. Heterogeneity of price effects across stores is accommodated via scaling factors for the P-splines which serve as random effects parameters to scale the price functions up- or downwards for individual stores while preserving their overall shape. Price dynamics are accounted for via lagged own prices, which allows us to address stockpiling or customer holdover effects. Optimal price paths for brands are determined by a discrete dynamic programming algorithm. We further introduce the Continuous Ranked Probability Score as a new measure to assess the predictive model performance and demonstrate in an empirical application that the proposed model outperforms simpler store sales models in predictive accuracy. Our findings further suggest that expected losses from not using the new model can be large if price dynamics are ignored, and that a retailer should at a minimum consider price dynamics even if only a parametric model would be used.

2 - Returns handling in wholesale price contract with nonnegative demand
Milena Bieniek

Additive uncertainty is interesting due to its special feature, namely, that the models with such uncertainty allow negative demand realizations. The negative demand realizations may occur for high values of price or small realizations of uncertainty parameter. Restricting the set of possible parameters lead to incomplete characterization of the optimal price. Provided that negative demand occurs at this price, the nonnegativity requirement on demand will considerably influence the optimal price. The negativity of demand is often neglected in many existing Operations Research models, which implies loss of generality and incompleteness of the results. Therefore, we plan to supplement the wholesale price contract with returns with the nonnegativity constraint and carry out the optimization as if it is a new task. Moreover, we derive the optimal solutions for supply chain with multiplicative demand. This research was funded by the National Science Centre, Poland, grant no. 2019/35/D/HS4/00801.

3 - Data-Driven Submodular Set-function Optimization: Theory and Applications in Assortment Planning and Recommender Systems
Jigar Patel, Christos Zacharias

Recommender systems and informed assortment planning facilitate the display of goods or services tailored to individual customer needs/characteristics, promote the visibility of assorted products, and revenue growth. We address the problem of optimal assortment and display of online search results for goods or services. The objective is to maximize the platform's revenue and customer engagement by leveraging the menu of displayed search results to users, subject to catering to their individual search criteria or characteristics. Our analysis is based on a detailed data set from a leading online platform. Assortment planning involves optimization over a utility set-function. For example, a supermodular utility function is related to complementary goods, and a submodular utility function is related to substitutes. By analyzing our data, we identify properties of our utility function and implement the proper optimization algorithm tailored to individual users. Recent advances in the discrete optimization field has enabled us to provide optimal or near-optimal algorithms in polynomial time to tackle the difficult problem of submodular function optimization

4 - Factors affecting consumers' acceptance of agricultural products e-commerce platforms (apeps) in China
Weiwei Wang, Mahmoud Abdelrahman, Sebastian Kapser, Firas Masri

The rapid development of e-commerce and the challenges facing the supply and marketing of agricultural products have led to the inevitable demand for the development of agricultural product e-commerce platforms (APEPs). People believe that with the help of APEPs, the supply and marketing of agricultural products will gradually expand from offline to online and the emergence of a full-marketing model will greatly improve the development status of agricultural products. This research proposes a theoretical model that is based on the Unified Theory of Acceptance and Use of Technology (UTAUT2) by investigating the factors that influence the acceptance of APEPs by Chinese users. An online questionnaire survey was conducted to collect research data with a total of 200 responses. Partial Least Squares Structural Equation Modelling (PLS-SEM) approach was used for data analysis. The results show that performance expectancy, social influence, and hedonic motivation have a significant positive impact on consumers' willingness to accept APEPs (i.e., behavioural intention to use APEPs); whereas no effect could be found for facilitating conditions and effort expectancy. The findings of this research provide guidance for future implementations of e-commerce in the APEPs in China.

■ WA-25

Wednesday, 8:30-10:00 - Y308

Novel Approaches for Order Picking Solutions

Stream: Warehouse Design, Planning, and Control
Invited session
Chair: *Serhat Saylam*

1 - Dynamic Routing of Multiple Pickers in Dark Stores and Urban Warehouses
Melih Celik, Arsham Atashi Khoei, Vaggelis Giannikas

With the current trends towards ever faster fulfilment and deliveries through e-commerce and the need for ever more predictable fulfilment and delivery times for better synchronisation, there has been increased pressure on efficient management of warehouses. The resulting demand for increased warehouse space, along with the need for social distancing, has meant that many retailers have converted locations into dark stores and urban micro-fulfilment centres. These new types of warehouses operate in an environment where the order pattern is dynamic and lead time requirements are very stringent.

In collaboration with an industrial partner developing innovative Internet-of-Things technologies and platforms for smart warehousing, we consider a warehouse setting with multiple pickers and dynamic order arrivals in this study. Given the need to address decisions in short timescales and the complexities of the orders associated with urban fulfilment, we propose a heuristic approach that extends those designed for single-picker environment by decomposing the problem into the batching, pick list updating, picker assignment, and re-routing decisions. We present our initial results using computational experiments on randomly generated instances to assess the quality of our solutions, derive managerial insights and perform sensitivity analyses.

2 - Arc Routing of Order Pickers in a Warehouse: A Compact Formulation for the Single-Picker Order Picking Problem

Serhat Saylam, Melih Celik, Haldun Sural

Order picking is the most costly and labor-intensive warehouse activity. The objective of order picking problem is to collect the items on the pick list in a sequence to ensure a route that minimizes the travel time. This problem has always been modelled as a special case of TSP. In this study, we study it as a variant of arc routing problem and present a solely warehouse-specific mathematical model. By taking into account the special properties of rectangular, parallel-aisle warehouse layout, we aim to find a strongly connected closed walk with the minimum length, and we present a compact and efficient mathematical formulation, which only depends on the number of aisles. The focus of our approach is to clear all picking aisles in the shortest possible time. To do that, we assign the best combination of intra-aisle movements and complementing cross-aisle movements such that it results in the minimum length-strongly connected closed walk while all picking aisles are cleared. The computational experiments and the comparison with the ones of recent literature show that it outperforms the previous TSP-based models in terms of size and computing times. The disconnectivity elimination constraints presented in the study significantly reduces the integrality gap with the increase in the number of pick locations and the number of aisles. Another noteworthy side of the formulation is that it can be the new basis for the future research directions on order picking operations.

3 - Energy Minimizing Order Picker Forklift Routing Problem

Arsham Atashi Khoei, Haldun Sural, Mustafa Kemal Tural

The material handling systems used in warehouses involve important operations such as the usage of order picker forklifts. The order picker forklifts provide efficient utilization of the storage space by their ability in moving in narrow aisles and picking items from high racks. Routing the order picker forklifts to pick ordered items belongs to operational decision level done in high frequency. Therefore, finding energy-efficient routes for order picker forklifts can yield significant savings in energy consumption in warehouses and the resulting CO2 emission. We introduce and study the energy minimizing order picker forklift routing problem (EMFRP) which aims to find energy-efficient routes for order picker forklifts to pick given list of items. We calculate the forklift's energy consumption in both horizontal and vertical moves considering the effects of friction forces, the acceleration and deceleration of the forklift, and its load. A mixed integer programming formulation and a dynamic programming approach are developed to solve small size instances of the EMFRP exactly. To solve larger instances, we provide tour construction and tour improvement heuristics and integrate them into a single solution approach. Computational results show that the proposed heuristic approach finds high quality solutions. Moreover, it is observed that significant energy savings can be achieved by solving the EMFRP instead of the classical distance minimization problem.

4 - Decision Model for Selecting Robotized Order Picking Solutions

Fabian Schäfer, Fabian Lorson, Alexander Hübner

Enabled through recent advances in technology, coupled with the advent of new system providers and decreased price points, automated and robotic order picking solutions (e.g., autonomous mobile robots) evolved as a surging market. Such systems aim at reducing labor costs, using available space more efficiently, and increasing throughput rates. As implementation projects and the variety of solutions are rising, managers face the decision which ones to select for their specific business case. However, appropriate decision models for this strategic problem are missing. We contribute by proposing a mathematical optimization approach that assigns each stock keeping unit the most suitable solution under space constraints. In particular, we minimize investment, running and error costs while adhering to product and solution related characteristics (e.g., space and physical constraints), which previous research has been neglecting, but are of outermost concern. We feed our model with decisive input factors and necessary constraints identified through expert interviews and warehousing literature. We conduct a case study and complement our findings by running numerical experiments. We find significant cost reduction potential compared to both manual picking and an experienced-based allocation. Our results give new insights into which solutions are best suited for different configurations.

■ WA-26

Wednesday, 8:30-10:00 - Y309b

OR in Telecommunications

Stream: Applications of OR

Invited session

Chair: *Gopika Premsankar*

Chair: *Bissan Ghaddar*

1 - Optimizing energy-efficient service placement for latency-sensitive applications in edge computing

Gopika Premsankar, Bissan Ghaddar

Edge computing is a promising solution for hosting AI applications that enable real-time insights on user-generated data. Edge computing deployments require a large amount of energy to run as their resources are typically over-provisioned to flexibly meet the needs of time-varying user demand with a low latency. Moreover, AI applications rely on deep neural network (DNN) models that require vast compute resources to support high accuracy. These DNN models must be efficiently stored and transferred, so as to minimize their energy consumption. We model the problem of energy-efficient placement of DNN models for AI applications as a multi-period mixed integer optimization problem. The formulation jointly places models and schedules requests such that the overall energy consumption is minimized and user-experience latency is low. We propose a heuristic that efficiently solves the problem while taking into account the impact of placing services across time periods. We assess the quality of our heuristic by comparing its solution to a lower bound of the problem, obtained by formulating and solving a Lagrangian relaxation of the original problem. Extensive simulations show that our heuristic outperforms baseline approaches in achieving a low energy consumption, while at the same time keeping the average latency of served requests below a configured threshold in nearly all time periods.

2 - Bayesian Learning for Resource Orchestration in Virtualized Mobile Networks

George Iosifidis

Virtualized base stations (vBS) constitute the main building blocks of next-generation of mobile networks. These fully softwarized nodes can be implemented in diverse commodity platforms and are expected to bring unprecedented operational flexibility and cost efficiency to communication systems. However, their widespread adoption is hampered by their complex configuration repertoire that affect in a non-typical fashion their operation and their power consumption. Following an in-depth experimental analysis in our testbed, we characterize the vBS power consumption profile and reveal previously unknown couplings between their various control knobs. Motivated by these findings, we develop a Bayesian learning framework for the orchestration of vBSs and design two bespoke algorithms: (i) BP-vRAN, which employs online learning to balance vBS performance and energy consumption, and (ii) SBP-vRAN, which augments our optimization approach with safe controls that maximize performance while respecting hard power constraints. We show that our approaches are data-efficient, i.e., converge an order of magnitude faster than state-of-the-art Deep Reinforcement Learning methods, and achieve optimal performance. We demonstrate the efficacy of these solutions in an experimental prototype using real traffic traces.

3 - Lyapunov Optimization for Dynamic Resource Allocation in Wireless Communication
Chen-Feng Liu

Guaranteeing the wireless communication performance is affected by the stochastic features of the data traffic demand, channel quality, etc. Due to the intrinsic randomness, the data lacking sufficient communication resources will be stored in the queue buffer and experiences a queuing delay. Besides the delay in information delivery, the up-to-date/fresh update of the available information at the receiver plays another crucial role in intelligent transportation systems and industrial automation. Information freshness can be measured by the age of information (AoI). For the queuing delay and AoI, the performance of the precedent data will affect the allocated resources to the upcoming ones. Thus, using deterministic transmission mechanisms will fail to ensure the performance in some situations. To tackle this concern, Lyapunov optimization provides a low-complexity approach which allocates communication resources by taking into account the influences of the precedent transmissions. In ultra-reliable low latency communication (URLLC), the extreme event with a very low occurrence probability is the critical concern. Therefore, enabling URLLC mandates a further examination on the tail distribution. In this regard, extreme value theory is a powerful framework to characterize the tail behavior of a distribution and the statistics of the extreme event. We incorporate extreme value theory with Lyapunov optimization and propose a resource allocation framework for URLLC system design.

■ WA-27

Wednesday, 8:30-10:00 - Y313

Recent advances in large-scale optimization

Stream: Numerical Optimization Methods with Inexact Evaluations of Objective Functions and/or Derivatives
Invited session
Chair: *Pierre-Cyril Aubin*

1 - Kernel representation of non-negative functions with applications in non-convex optimization and beyond
Pierre-Cyril Aubin

Many problems in applied mathematics involve non-negative functions. While linear models are well suited to represent functions with real output, being at the same time very expressive and flexible, the situation is different for the case of non-negative functions where the existing models are much more restrictive. In this talk we present a rather flexible and expressive model for non-negative functions based on kernel Sum-of-Squares . We will show direct applications in probability representation and non-convex optimization. In particular, the model allows to derive an algorithm for non-convex optimization that is adaptive to the degree of differentiability of the objective function and achieves optimal rates of convergence. Finally, we show how technique extends to other interesting problems in applied mathematics (optimal transport, shape constraints) that can be easily expressed in terms of inequalities.

2 - Global optimisation of smooth functions using sum of squares with Reproducing Kernel Hilbert Spaces
Ulysse Marteau-Ferey

We consider the global minimization of smooth functions based solely on function evaluations. Algorithms that achieve the optimal number of function evaluations for a given precision level typically rely on explicitly constructing an approximation of the function which is then minimized with algorithms that have exponential running-time complexity. In this paper, we consider an approach that jointly models the function to approximate and finds a global minimum. This is done by using infinite sums of square smooth functions and has strong links with polynomial sum-of-squares hierarchies. Leveraging recent representation properties of reproducing kernel Hilbert spaces, the infinite-dimensional optimization problem can be solved by subsampling in time polynomial in the number of function evaluations, and with theoretical guarantees on the obtained minimum.

3 - Projection-free methods for machine learning and data science applications
Francesco Rinaldi, Immanuel Bomze, Damiano Zeffiro

Recently, projection-free methods have gained popularity thanks to their ability to efficiently handle structured problems. In this work, we focus on some specific machine learning and data science applications and describe tailored Frank-Wolfe variants that efficiently handle the related problems.

4 - A local analysis for eigenvalue complementarity problems
Mario Jelitte, Andreas Fischer, Klaus Schönefeld

Eigenvalue complementarity problems still have interesting theoretical properties that are not fully understood so far. Here, we are interested in local Lipschitzian error bounds. We derive conditions that characterize the existence of such an error bound for a special class of complementarity problems. These results are applied to eigenvalue complementarity problems. In particular, this allows us to prove the existence of a local Lipschitzian error bound for the symmetric linear eigenvalue complementarity problem.

■ WA-28

Wednesday, 8:30-10:00 - Y405

Novel Data Mining Methodologies for COVID-19 Data prediction incorporating spatial and socioeconomic information. Session I

Stream: Stochastic Dynamic Programming and Learning Policies
Invited session
Chair: *Michael Katehakis*
Chair: *Javier Cabrera*

1 - Novel Adaptive Pattern Extraction and Matching Algorithms for Forecasting COVID-19 Time Series
Michael Katehakis

We present a novel approach for forecasting COVID-19 time series that exhibit evolutionary structural changes and have limited past data. The method involves data preprocessing using modified smoothing and variance stabilizing transformations. Dynamic change point analysis is performed to segment the original time-series into shorter distinct structural patterns. The extracted patterns are made scale invariant by further linear transformations. Finally, an approximate pattern matching approach is used to identify similar patterns for forecasting the future trend by weighted interpolation.

2 - COVID-19 Daily Case and Death Prediction using Deep Learning Models with Time-lag Features
Yajie Duan, Javier Cabrera, Dhammika Amaratunga, Michael Katehakis, Jin Wang, Nuria Diaz-Tena, Chun Pang Lin, Michalis Xyntarakis, Wenting Wang, Debopriya Ghosh

This talk presents a new methodology to predict COVID-19 daily cases and deaths, considering the reporting delays during data collection and the relationship between cases and deaths. The algorithm applies a deep learning model with novel pre-processing methods and time-lag features. To address reporting delays, pre-processing techniques are developed to obtain smoothed daily data using accurate weekly data. After applying variance stabilizing transformations, LSTM models are trained to predict cases and deaths jointly. The prediction model for cases utilizes time-series case data, and the model for deaths is trained based on both death data and the cases with a time lag in the past to consider the time difference between them. With the proposed techniques, the performance of deep learning models is improved to predict COVID-19 daily cases and deaths.

3 - Voucher Effect in Sequencing Arrivals of Appointment-Based Queues
Boray Huang

Sequencing arrivals is known to be important but exceedingly challenging in appointment systems. Up to date, very few structural results have been derived to depict the dynamics in sequencing customer/job arrivals. Most researches therefore turn to the shortest expected processing time first rule (SEPT) or the smallest variance first rule (SV) by conjecturing or proving their optimality under strict assumptions. The intuition behind the SEPT/SV rule is a snowball effect: A delay of an early job would cause a late start of its subsequent job and build up the tardiness. In the appointment-based queues, however, we found a voucher effect which counteracts the snowball effect in minimizing the total waiting time, making the SEPT/SV rule sub-optimal in general. The voucher effect is further investigated in an appointment-based queue with two classes of customers whose excessive service times are stochastically ordered. We prove structural properties of the optimal sequence and the impact of the voucher effect. We then extend the analysis to a system where customers differ in their no-show probabilities instead of the excessive service times. With a goal to minimize the total waiting time of the customers who show up, the same structural results still apply. Our results shed light on the dynamics in sequencing heterogeneous customers or services, which may help in the development of efficient solution algorithms.

4 - Forecasting COVID-19 deaths using time series model with changes points
Chun Pang Lin, Javier Cabrera, Dhammika Amaratunga, Yajie Duan, Michael Katehakis, Jin Wang, Wenting Wang

SARS-CoV-2 virus (COVID-19) or other viruses in general constantly change through mutation. Such mutations can result in a new variant of the virus, causing recurrent waves. We explored the COVID-19 cases and deaths data in the states of New Jersey, Florida, and California of the USA and discovered different cross correlations between cases and deaths at different waves or variants. Based on those observations, we applied a time series model with change points on different waves or variants for forecasting the deaths. The motivation comes from the expectation that the time series characteristics are different at different phases of the pandemic or with different virus variants. The modeling framework is generic and can be extended to other states and countries, and possibly to other recurrent seasonal diseases such as influenza.

■ WA-29

Wednesday, 8:30-10:00 - M1

Complex Scheduling II

Stream: Industrial Production, Planning and Inventory Management
Invited session
Chair: Ignacio Eguia

1 - Optimization strategies for Scheduling in Container Terminals
Sameh Haneyah

Container terminals are crucial links in the global supply chain. These facilities operate in a highly dynamic environment. In this context, a main logistic challenge is scheduling the container handling equipment to execute the container transport and handling operations efficiently and effectively. The aim of this study is to determine the appropriate optimization strategies to deploy in scheduling and dispatching container handling equipment, in large-scale automated container terminals. To this end, we review literature on scheduling and dispatching in container terminals and point to key elements that are not adequately addressed, e.g., waiting times at quay cranes, which is a crucial KPI in practice. In addition, we formulate the container terminal scheduling problem. We model the problem both as a Vehicle Routing Problem and as a Hybrid Job Shop and Parallel Machine scheduling problem, highlighting the recommended modelling approach. We address different solution methods and provide recommendations for the optimization strategies to deploy, considering different algorithmic aspects. In this effort, we weigh the value of optimality versus robustness. Finally, we also recommend strategies to schedule the secondary operations, such as recharging Automated Guided Vehicles (AGVs). This study is based on a representative container terminal, which includes quay cranes, yard cranes, and AGVs as container handling equipment.

2 - Automatic Dispatching Rule Generation for the Dynamic Flexible Job Shop Scheduling Problem via Genetic Programming
Nuno Marques, Gonçalo Figueira, Luis Guimarães

In recent years, the arrival of new technologies has substantially increased the complexity, flexibility and dynamism of manufacturing facilities. The Dynamic Flexible Job Shop Scheduling Problem is at the core of many of these settings. Traditional methods for Scheduling problems such as mathematical programming, theory of constraints and metaheuristics do not cope well with uncertainty, and struggle to find a good solution in the short period of time available in highly dynamic environments. Therefore, Dispatching Rules became a popular choice due to their reactive capabilities as well as their interpretability and simplicity. Designing a good Dispatching Rule manually requires domain knowledge and is a trial-and-error process. This process becomes harder as the complexity of the problem increases. Thus, research has been conducted on the automatic generation of new dispatching rule, namely by using Genetic Programming due to its search prowess. The goal of this work was to generate better DRs than the ones in the literature. Different penalties were applied to rule size, as smaller rules are preferred. Moreover, different terminal sets were used, as rules should have as little terminals to avoid unnecessary complexity. The best rules that were obtained render tardiness values that are on average over 20% lower than the best existing Dispatching Rules.

3 - Distributional reinforcement learning for online optimization of chemical production schedules and supply chains
Max Mowbray, Dongda Zhang, Antonio del Rio Chanona

Reinforcement Learning (RL) has received significant attention from the process systems engineering, control and operations research communities. Recent works have investigated the application of RL to identify optimal scheduling and supply chain management decisions under uncertainty. Here, we explore the application and development of an RL methodology to address uncertain online production environments and supply chain optimization. We consider restrictions on scheduling problems, including precedence and disjunctive constraints, which are not naturally handled by RL algorithms. Further, the work enables the use of risk-sensitive formulations, such as the conditional value-at-risk, which are essential to hedge risk in many applications. The strategy is investigated in a production scheduling environment, and in a multi-echelon supply chain optimization problem. Performance is benchmarked against policy gradient RL and mathematical programming. We show that the policies identified by our method account for uncertainties, with expected performance comparable to optimization methods, but with improvements in worst case performance. Additionally, the framework enables identification of online decisions orders of magnitude faster than the most efficient optimization methods. As a result, the methodology promises means to handle practical issues associated with online decision making, and ease in handling uncertainty in online production environments and supply chains.

4 - A MILP model for production planning in Additive Manufacturing with alternative part orientations
Ignacio Eguia, Jose Carlos Molina, Jesus Racero, Sebastián Lozano

In this work, the production planning in Additive Manufacturing (AM) with multi-part grouping in the presence of alternative orientations for each part is presented. AM, commonly referred to as 3D printing, is a new and emerging technology for realizing complex geometries designed in computers. AM allows batch processing of multiple parts within the same build volume, so the planning of parts to be processed on a set of non-identical AM machines is essential in reducing time or production cost. Some authors have analysed the multi-part AM planning problem with different objective functions related to production cost, makespan or tardiness. The problem solved in this work considers a set of parts with alternative orientations to be grouped in jobs for being performed in non-identical AM machines considering solutions with minimum production cost. The problem is modelled with linear programming techniques and then solved using optimization software for small-medium size instances. A set of benchmark cases adapted from 1-orientation instances for this problem are proposed and solved. In order to validate the model, solutions are compared for 1-orientation instances, and results for 2- and 3-orientations show a significant cost reduction.

■ WA-30

Wednesday, 8:30-10:00 - M237

Vector and Set Optimization II

Stream: Vector and Set Optimization
Invited session
Chair: *Gabriele Eichfelder*

1 - Differential properties to the weak optimal value mapping in convex vector optimization
César Gutiérrez

This talk focuses on differential properties of the optimal value mapping concerning weak efficient solutions of an unconstrained convex vector optimization problem. Specifically, formulas for the ϵ-subdifferential of that optimal value mapping are obtained by linear scalarization, which work in the case when the weak efficient solution set is empty. These results are based on the notion of cone proper set, a concept of infimal set and an ϵ-subdifferential for convex vector functions introduced by Taa

2 - New results on the weak property (pi) in locally convex spaces
Fernando García Castaño, Miguel Angel Melguizo Padial, Giovanni Parzanese

The concept of cone plays an important role in vector optimization. Some properties of cones have been extensively studied in the settings of normed spaces and locally convex spaces. In this talk, we will see some new results regarding cones (in locally convex spaces) that have weak property (pi). We will also compare them with their corresponding versions for normed spaces.

3 - Lagrange Multipliers, Duality, and Sensitivity in Set-Valued Convex Programming via Pointed Closed Convex Processes
Miguel Angel Melguizo Padial, Fernando García Castaño

In this talk present a new kind of Lagrangian duality theory for set-valued convex optimization problems whose objective and constraint maps are defined between preordered normed spaces. We introduce a new dual program whose dual variables are pointed closed convex processes, and we present a new set-valued Lagrange multiplier theorem from which we derive a strong duality result that guarantees the existence of dual solutions (even if we do not assume that the optimal value of the primal program is achieved in a feasible solution). We finally show that the set of solutions of the dual program is closely related to the sensitivity of the primal program. The pointed nature assumed for the processes is essential for the derivation of the main results presented in the talk.

4 - Computing an enclosure for multi-objective mixed-integer convex optimization problems
Gabriele Eichfelder, Leo Warnow

In multi-objective mixed-integer convex optimization multiple convex objective functions need to be optimized simultaneously while some of the variables are only allowed to take integer values. In this talk, we present a new approach to compute an enclosure of the nondominated set of such optimization problems. We decompose the multi-objective mixed-integer convex optimization problem into several multi-objective continuous convex optimization problems, which we refer to as patches. Then, we iteratively compute and improve coverages of the nondominated sets of those patches to finally combine them to obtain an enclosure of the nondominated set of the multi-objective mixed-integer convex optimization problem. Additionally, we introduce a mechanism to reduce the number of patches that need to be considered in total.

■ WA-31

Wednesday, 8:30-10:00 - M240

Quantitative stability in continuous optimization

Stream: Variational analysis and optimization
Invited session
Chair: *Juan Parra*
Chair: *Maria Josefa Cánovas*

1 - A calmness approach to Hoffman stability of linear semi-infinite inequality systems
Juan Parra, Jesús Camacho, Maria Josefa Cánovas

In this talk we focus on different -global, semi-local and local- versions of Hoffman type inequalities expressed in a variational form. In a first stage our analysis is developed for generic multifunctions between metric spaces and we finally deal with the feasible set mapping associated with linear semi-infinite inequality systems (finitely many variables and possibly infinitely many constraints) parameterized by their right-hand side. The Hoffman modulus is shown to coincide with the supremum of Lipschitz upper semicontinuity and calmness moduli when confined to multifunctions with a convex graph and closed images in a reflexive Banach space, which is the case of our feasible set mapping. Moreover, for this particular multifunction a formula –only involving the system's left-hand side– of the global Hoffman constant is derived, providing a generalization to our semi-infinite context of finite counterparts developed in the literature. In the particular case of locally polyhedral systems, the paper also provides a point-based formula for the (semi-local) Hoffman modulus in terms of the calmness moduli at certain feasible points (extreme points when the nominal feasible set contains no lines), yielding a practically tractable expression for finite systems.

2 - On the Lipschitz upper semicontinuity of the argmin mapping in linear optimization
Jesús Camacho, Maria Josefa Cánovas, Juan Parra

This talk is focussed on computing the Lipschitz upper semicontinuity modulus of the argmin mapping for canonically perturbed linear programs. The aimed modulus is expressed in terms of a finite amount of calmness moduli, previously studied in the literature. Despite the striking resemblance of the obtained formula with its counterpart for the feasible set mapping, the methodology followed to study the Lipschitz upper semicontinuity of the argmin mapping differs notably from the former as far as the graph of the argmin mapping is not convex. Specifically, a new technique based on a certain type of local directional convexity is developed.

3 - Projection-based local and global Lipschitz moduli of the optimal value in linear programming
Maria Josefa Cánovas, Maria Jesús Gisbert Francés, Diethard Klatte, Juan Parra

In this talk we firstly review some exact expressions or estimations for the Lipschitz modulus of the optimal value function ,restricted to its domain, in linear programming under different types of perturbations. Then we use a geometrical approach to sharpen a given lower bound for such a modulus under tilt perturbations of the objective function. The key geometrical idea comes from orthogonally projecting general balls on linear subspaces. Our new lower bound provides a computable expression for the exact modulus (as far as it only depends on the nominal data) in two important cases: when the feasible set has extreme points or when we deal with the Euclidean norm. In these two cases we are able to compute or estimate the global Lipschitz modulus of the optimal value function in different perturbations frameworks.

4 - Optimality conditions for mathematical programs with orthogonality type constraints
Vladimir Shikhman, Sebastian Lämmel

We consider the class of mathematical programs with orthogonality type constraints (MPOC). Orthogonality type constraints appear by reformulating the sparsity constraint via auxiliary binary variables and relaxing them afterwards. For MPOC a necessary optimality condition in terms of T-stationarity is stated. The justification of T-stationarity is threefold. First, it allows to capture the global structure of MPOC in terms of Morse theory, i.e. deformation and cell-attachment results are established. For that, nondegeneracy for the T-stationary points is introduced and shown to hold at a generic MPOC. Second, we prove that Karush-Kuhn-Tucker points of the Scholtes-type regularization converge to T-stationary points of MPOC. This is done under the MPOC-tailored linear independence constraint qualification (MPOC-LICQ), which turns out to be a generic property too. Third, we show that T-stationarity applied to the relaxation of sparsity constrained nonlinear optimization (SCNO) naturally leads to its M-stationary points. Moreover, we argue that all T-stationary points of this relaxation become degenerate.

■ WA-33

Wednesday, 8:30-10:00 - F102

Game Theory, Solutions and Structures III

Stream: Game Theory, Solutions and Structures
Invited session
Chair: Peter Sudhölter

1 - A Monotone Operator Approach to Convex Nash Equilibria
Patrick Combettes, Minh Bui

We investigate a modular convex Nash equilibrium problem involving nonsmooth functions acting on linear mixtures of strategies, as well as smooth coupling functions. An asynchronous block-iterative decomposition method is proposed to solve it, which is shown to converge under minimal assumptions and provides unprecedented flexibility relative to the state of the art.

2 - TU-Games with Utility: The Prenucleolus
Zsófia Dornai, Miklós Pintér

A generalization of the prenucleolus - the u-prenucleolus - can be defined by using the so-called utility function on the excesses. A special case for this is the per-capita prenucleolus, where the utility function is the function which divides the excess by the cardinality of the coalition. We focus on which coalitions are to be considered essential in order to calculate the u-prenucleolus. The goal of this approach is to show the connection between the different results on the subject of essentiality.

3 - Axiomatic characterizations of the core without consistency
Stéphane Gonzalez, Sylvain Béal, Philippe Solal, Peter Sudhölter

A TU game is totally positive if it is a linear combination of unanimity games with nonnegative coefficients. We show that the core on each cone of convex games that contains the set of totally positive games is characterized by the traditional properties Pareto efficiency, additivity (ADD), individual rationality, and the null-player property together with one new property, called unanimity requiring that the solution, when applied to a unanimity game on an arbitrary coalition, allows to distribute the entire available amount of money to each player of this coalition. We also show that the foregoing characterization can be generalized to the domain of balanced games by replacing ADD by "ADD on the set of totally positive games plus super-additivity (SUPA) in general". Adding converse SUPA allows to characterize the core on arbitrary domains of TU games that contain the set of all totally positive games. Converse SUPA requires a vector to be a member of the solution to a game whenever, when adding a totally positive game such that the sum becomes totally additive, the sum of the vector and each solution element of the totally positive game belongs to the solution of the aggregate game. Unlike in traditional characterizations of the core, our results do not use consistency properties.

4 - Set-valued expansions of Hart-Mas-Colell consistency and the core on convex games
Peter Sudhölter

For a set-valued solution the Hart-Mas-Colell reduced game w.r.t. a sub-coalition N' of N and a solution element x of the TU game assigns to each coalition in N' the amount that remains if the set of outside players (NN') joins and is paid according to an element of the solution of the subgame on this joint set of players. Consistency requires that for each element x of the solution of a game on N there exists an allocation scheme that assigns to each sub-coalition a solution element of the sub-game such that the restrictions of x are in the solutions of the reduced games. It is known that, for convex games, the Shapley value and the egalitarian solution only satisfy weak consistency (i.e., consistency for 1- and 2-person games), which was, together with converse consistency and some standard axioms, used by Dietzenbacher and Sudhölter (2021) to characterize the homothetic images with ratios in the unit interval and their relative interiors of the core with the Shapley value as center. They also showed that the core does not satisfy even weak consistency on slightly larger domains of games. In the present paper we show by means of a convex game derived from the 7-person projective game that consistency is not satisfied by a solution that satisfies the null-player property and Pareto efficiency. We also show that on the sub-domain of positive games (a game is positive if it is a non-negative linear combination of unanimity games), the core satisfies uniform consistency.

■ WA-35

Wednesday, 8:30-10:00 - T004

Air transport planning, operations and forecasting in turbulent times

Stream: Transportation
Invited session
Chair: Niklas Pöch

1 - Electric Aircraft Charging Network Design for Regional Routes: A Novel Mathematical Formulation and Kernel Search Heuristic

Sebastian Birolini

The uptake of electric aircraft appears faster today than predicted. Given the prominent electric aircraft technologies, short-and medium-haul routes are the ones that will benefit first, with the promise to revolutionize regional aviation at short notice. This paper proposes an optimization model to support the strategic design of charging networks for electric aircraft as a key enabling factor to prepare for and take full advantage of aviation electrification. The proposed model defines a network of airports and flight paths to optimally trade-off the number of charging bases with connectivity and population coverage targets typical for regional routes serving remote regions. Due to computational challenges in large problem instances, we propose a Kernel Search heuristic and illustrate how it can deliver high quality solutions for large cases in a shorter computational time than the branch-and-cut algorithms. A real-world application to Sweden then demonstrates the practical insights of the proposed approach; e.g., leveraging the many currently under-utilized regional airports has connectivity and investment benefits (on average +5.6% in population coverage and -8.4% reduction of travel times). Furthermore, increasing the maximum aircraft range on a single charge implies significantly fewer charging bases and more feasible travel options, thus favoring network resilience and granting higher flexibility for later planning stages.

2 - An integrated air cargo routing problem with environmental considerations: a metaheuristic approach

Mattia Cattaneo

In this research, we consider an integrated flight scheduling, fleet assignment, and cargo routing model for a full-cargo carrier where economic and environmental sustainability are simultaneously considered in the decision-making process. We employ a metaheuristic approach based on a path-based mathematical programming formulation that iteratively computes promising paths for the cargo requests using a shortest path approach and adds them to the master problem—modelled as a set-partitioning problem. For small instances, we compare the performance of such algorithm with an exact arc-based formulation. We divide our findings into two categories, namely numerical and managerial findings. In the former case, we expect our metaheuristic to outperform the exact formulation for large instances, where computational complexity should be a bottleneck for the arc-based formulation. In the latter case, we expect to identify trade-offs between economic and environmental sustainability that can guide the current de-carbonization policies of airlines. Our contributions are three-fold. First, we present a novel path-based model together with an ad-hoc algorithm to generate new promising paths for cargo requests. Second, we consider both economic and environmental sustainability in our model, where extra fuel burns due to requests being carried are endogenized to provide more meaningful results. Finally, we tackle large instances contrary to current air cargo models in the literature.

3 - An efficient exact algorithm for the airport slot allocation problem

Sergio García Quiles, Paula Fermín Cueto, Miguel F. Anjos

Airport coordination is a demand control mechanism that maximizes the use of existing infrastructure at congested airports. Aircraft operators submit a list of regular flights that they wish to operate over a five to seven-month period and a designated coordinator is responsible for allocating the available airport slots, which represent the permission to operate a flight at a specific date and time. This problem is a special class of the Resource Constrained Project Scheduling Problem where the objective is to minimize the difference between the allocated and requested slots subject to airport capacity constraints and other operational restrictions. Most studies on the topic focus on developing complex models and fast heuristics. Little attention has been paid to exact methods despite their potential to obtain higher quality solutions with better airline acceptability and fewer slot rejections. In this paper, we present an efficient column-and-row generation algorithm to solve the single airport slot allocation problem. We also present a problem-specific preprocessing scheme that can identify more redundant constraints and fix variables than a commercial solver in a fraction of the time. We solve instances originating from some of the most congested airports coordinated by Airport Coordination Limited in the United Kingdom significantly faster than the best exact method in the literature to date, and we also conduct experiments on a set of synthetic, realistic instances.

4 - Planning Inductive Charging Infrastructures on Airport Aprons

Niklas Pöch, Justine Broihan

The electrification of the ground vehicles on the airport apron can be a measure to reduce CO2 emissions in the aviation sector. Dynamic inductive charging, in which vehicles are charged wireless while in motion, is particularly suitable for airport apron vehicles. Compared to conductive charging, there is no downtime due to the charging of the vehicles. However, planning such a charging infrastructure is very challenging, as various technical and economic aspects must be considered. For this reason, we present a strategic model for allocating the components of charging infrastructures on airport aprons with minimum investment.

■ WA-36

Wednesday, 8:30-10:00 - U006

Supply Chains and Production in Healthcare

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: Kris Braekers

1 - Rolling Horizon Scheduling of Biopharmaceutical Therapies via a Two-Step Lookahead Heuristic

Siamak Naderi, Juergen Branke

This paper deals with scheduling in biopharmaceutical manufacturing involving uncertain process durations and no-wait constraints, i.e., once the production of a batch has been started, it must go through all tasks without delays. This is general practice for products with highly sensitive raw and work in progress materials. We address the problem of maximising throughput by assigning operators and equipment to a task whenever one is required for a biopharmaceutical firm who produces Chimeric Antigen Receptor T-cell therapies. This therapy is extremely expensive, thus even a slight increase in utilisation and throughput would significantly increase profits. The company produces the therapy using patients' own T-cells which are taken in an associated clinic. The cells are then modified to be re-injected to the patients. The underlying problem is formulated as a mixed-integer linear programming model and Gurobi is used as the solver. However, due to the complexity of the problem only solutions for small size instances are obtained. We develop a two-step lookahead heuristic to tackle real-world size instances. We test the proposed algorithm in a simulation considering the uncertainties in process durations and availability of the raw materials (T-cells from the patient). The results show applying the proposed algorithm on a rolling horizon after realisation of mentioned uncertainties improves resource utilisation and throughput significantly.

2 - Reducing cost and waste in hospital inventory management: A demand-driven replenishment strategy
Gaspard Hosteins, Allan Larsen, Dario Pacino, Christian Sørup

Logistics represents a large share of hospitals' operating budgets. However, it only holds a supporting role in hospitals' primary task of providing care to patients. Hospital inventory strategies typically rely on high safety stocks instead of data-driven methods, thus leaving potential for optimisation. Hospitals are organised in medical departments, with separate storage and budgets. Hospital inventory management deals with various medical products of diverse criticality and uncertain demand inside a complex multi-echelon storage structure. Public hospitals require a service-oriented approach that differs from classic industry profit-based inventory management. Data-driven decision support systems are widely spread in the private sector, whereas medical practitioners without advanced analytical backgrounds often take the inventory decisions in hospitals. Operational data are becoming increasingly available in hospitals, raising the potential for industry-inspired data-driven approaches. This paper offers a case-based analysis using data from a Danish public hospital. Our goal is to understand and model the hospital's demand for drugs and devise a demand-driven replenishment system. This work is inspired by state-of-the-art industry Collaborative Planning, Forecasting and Replenishment systems (CPFR) and tailored to hospitals' service-oriented nature. The proposed approach aims to reduce on-hand inventory, cost, and waste while maintaining or improving service level.

3 - A location-inventory model for the cooperative hospital supply chain
Lien Vanbrabant, Lotte Verdonck

A traditional hospital SC is designed as a multi-echelon inventory system, consisting of external suppliers, a central hospital warehouse, point-of-use locations and the patients as final users. In a cooperative SC, there is one central warehouse that operates for multiple hospitals and replaces the warehouse of each individual hospital. Moving from a traditional to a cooperative hospital SC results in logistic efficiency improvements. In order to fully benefit from a cooperative SC where inventory is pooled, it is desirable to integrate decisions on different levels of control (operational, tactical, strategic). On the strategic level, a decision should be made regarding the design of the hospital networks (e.g. number of hospitals per network, location of central warehouse within a network). In order to maximise the advantages of inventory pooling, tactical inventory management decisions should be included in the location-allocation problem. This integration between the strategic and tactical decision level results in a location-inventory problem (LIP). In this research, a LIP is formulated and solved to determine the optimal location and inventory levels of a central warehouse within a Belgian hospital network. The goal is to minimize logistic costs, while preserving a high quality of care. Therefore, real-life features are included in the problem formulation to realistically represent the healthcare setting, such as stochasticity, service level and emergency deliveries.

4 - An inventory-routing problem for cooperative hospital supply chain operations
Silia Mertens, Kris Braekers, An Caris, Lien Vanbrabant

Improvements in logistic efficiency can be made in the healthcare sector, which can help to reduce costs while maintaining or even improving the service quality. In this study, a traditional hospital supply chain (i.e. a multi-echelon inventory system) is compared with a cooperative hospital supply chain where a care hub (i.e. a single central warehouse) operates for multiple hospitals and replaces the central warehouse of each individual hospital. The goal of this study is to solve an inventory-routing problem for both supply chain configurations to examine whether efficiency improvements can be achieved when making use of a care hub. The problem is applied to a case study in collaboration with a Belgian University Hospital. Real-life features are included to make the case realistic: multiple products, uncertain demand, emergency deliveries, inventory pooling and time windows. A multi-period rolling horizon approach is proposed. At the start of each planning period, total expected costs are minimized by a mixed integer programming model. When the actual demand is observed inventory levels are updated accordingly and possible shortages are corrected using emergency deliveries. Total actual costs are calculated based on the actual demand. This procedure is repeated until the end of the planning horizon. First insights on the performed numerical experiments will be presented.

■ WA-37

Wednesday, 8:30-10:00 - V001

Machine Learning Guided Optimization for Demand Responsive Transport

Stream: Vehicle Routing and Logistics
Invited session
Chair: Marc Sevaux
Chair: *Flavien Lucas*

1 - Meta-Analysis of Operators in ALNS for Vehicle Routing Problems
Stefan Voigt, Heinrich Kuhn

This presentation systematically reviews the literature on adaptive large neighborhood search (ALNS) to gain insights into the operators used and their efficiency. The ALNS has been successfully applied to a variety of optimization problems, most notably variants of the vehicle routing problem. The basic idea of the ALNS is to gradually improve an initial solution by modifying it via destroy and repair operators. The selection of operators depends on their historical performance during the search. Authors usually propose a large set of destroy and repair operators and rely on the adaptive component of the ALNS to select the most efficient operator. In addition, authors often conduct experiments to identify operators that benefit to the solution quality or to identify (and remove) detrimental operators. This process is mostly cumbersome, as there exists a wide variety of operators, sometimes same operators under different names, or - vice versa - different operators under the same name. The goal of this article is twofold: Firstly, it aims to classify operators with a consistent wording, and secondly to analyze their performance and establish a common basis for future works. We analyze the performance via a meta-analysis of 58 articles that meet our criteria. Furthermore, we re-implement the most commonly used operators and test their performance on well-known instances for the VRP and the VRP with time windows.

2 - A simulation environment for training reinforcement learning algorithms for dynamical vehicle routing in last-mile logistics
Zisis Maleas, Dimitris Vrakas

The distribution and routing in last-mile Logistics services is a high priority problem of the modern supply chains as it is estimated that it is responsible for near the half of the distribution costs of a final product. The continuous increase of cities' size, along with the e-commerce trend, and the goal of distribution companies for faster delivery, impose the management of the fleet in a dynamical manner. The shift of the distribution models from static to dynamic, is an important advantage that can increase productivity, and performance. At the same time, the progress in software and algorithms in Deep Reinforcement Learning (RL), along with hardware advancements in technologies such as the IoT and cloud computing enables new innovative solutions. At first, the authors introduce the problem of dynamic fleet routing in the last mile distribution processes. The aim of this study is to develop a simulation environment for training and validation of reinforcement learning algorithms in the dynamic vehicle routing operations. The environment introduces a novel method of representing the problem in a way that can be easily extended to other instances of routing problems. Moreover, the environment is engineered to take advantage of Graph Convolutional Network architectures for Deep RL algorithms. Through a series of experiments, which compare four routing strategies, the deep RL emerges as the most promising solution.

3 - A Reinforcement Learning approach for lead vehicle routing in a semi-autonomous last-mile transportation system
Avital Shamir, Mor Kaspi

In semi-autonomous transportation systems, vehicle autonomy capabilities are utilized in a partial manner, so as to adhere to current regulations. The multi-layered personal transit system is a special design in which convoys composed of human-driven lead vehicles and autonomous trailers provide station-to-station transportation. At the proximity of stations, trailers can detach from the convoy and travel autonomously to enter/exit the stations. In a previous study, the assignment of passengers to trailers and the routing of the trailers was determined dynamically, while static circular routes were determined for the lead vehicles. In this study, we introduce for each circular lead vehicle route a potential shortcut, with the aim of determining dynamically when a lead vehicle should take shortcuts. We present an abstraction of the system and formulate the resulting decision problem as a Markov Decision Process in which the state represents the trailer workload on each route, an action represents the shortcut decisions, and the penalty represents the number of trailers waiting to be served. We develop an event-based simulation framework to represent the system's dynamics and employ a Reinforcement Learning approach to dynamically decide upon the lead vehicle shortcuts. The obtained policies are shown to outperform fixed lead vehicle route plans and simple-rule based dynamic shortcut policies.

4 - How linked are routing and inventory in IRP? A data mining study
Flavien Lucas, Romain Billot, Philippe Lacomme

AI-related methods have become very popular to help solving optimization problems. However, there are still some challenges linked to the volume of data needed and the capability to scale up to real world applications. The idea of Vendor-Managed Inventory has been developed in many companies for a decade: in this framework, there are no dedicated places for inventory and each product is directly available for sale. In this way, inventory costs are considerably reduced but companies remain dependent on the reactivity of their suppliers. In this work, the problem studied is the Inventory Routing Problem, in which we have to deliver customers in multiple periods of time considering both traveling costs and inventory costs of the customers. In the state of the art, many authors have decided to split the problem with two alternative strategies: either fixing the quantity to be delivered to each customer in each period and then decide to solve the routing associated with each time period, or on the contrary fixing the routing and choose the quantity to be delivered in a second phase. Thus, most of the existing attempts only consider one part of this problem at a time. Our main objective is to use data mining techniques to understand the link between the two parts and to develop new algorithms to solve both parts at once.

■ WA-38

Wednesday, 8:30-10:00 - V002

Shared Mobility III

Stream: Shared Mobility
Invited session
Chair: Frederik Schulte

1 - A generalized disjunctive programming model for the bike sharing rebalancing problem
Teemu Ikonen, Keijo Heljanko, Iiro Harjunkoski

Bike sharing systems offer a flexible and independent mode of transport in many urban areas in the world. Due to the asymmetric demand patterns in the different regions of the system, the operators typically transport bikes between the stations by trucks. This poses an optimization problem of finding the minimum cost route of the trucks while meeting the demand at the stations. In this work, we study a variant of the problem where the demand is specified by intervals, adding flexibility to the routing of the rebalancing vehicles. We propose a generalized disjunctive programming (GDP) model to represent the problem, its reformulation into a mixed-integer linear programming (MILP) model, and a branch-and-cut algorithm to solve the resulting MILP model. We use demand splitting to duplicate stations that require multiple visits. The model is designed for single-vehicle routing but can be used jointly with a clustering model [1] for multi-vehicle routing. The model can solve 387 of 400 benchmark instances [2] with 60 stations. On test cases based on real process data from Helsinki, the model is more than two orders of magnitude faster than a reference model [1].

References [1] Schuijbroek J, Hampshire RC, Van Hoeve W-J (2017). Inventory rebalancing and vehicle routing in bike sharing systems. Eur J Oper Res, 257, 992-1004.

[2] Erdoğan G, Laporte G, Wolfler Calvo R (2014). The static bicycle relocation problem with demand intervals. Eur J Oper Res, 238, 451-457.

2 - A decomposition-based hybrid metaheuristic for large scale pickup and delivery problems with time windows
Gerhard Hiermann, Maximilian Schiffer

Increasing mobility demand in the realm of urbanization has led to increasing demand for ride-hailing services, which nowadays complement existing mass transit options. In this context, it is of utter importance to efficiently operate the underlying ride-hailing service. Here, operators often face large vehicle routing problems with fleets of several hundred vehicles and several thousand customer requests during a day. With this work, we focus on analyzing an idealistic, full information day-ahead planning problem of such a system to derive upper bounds on a system performance that can potentially be derived in a realistic online setting. Accordingly, we focus on efficiently solving large-scale instances of a pickup and delivery problem with time windows. We develop a novel decomposition-based algorithmic framework that comprises three steps: 1) generating a solution using a large neighborhood search metaheuristic, 2) identifying and extracting promising request poolings, and 3) optimally sequencing poolings to vehicles. Additionally, we show how to leverage adaptive temporal and spatial restrictions to limit the search space and develop efficient caching mechanisms to avoid unnecessary repeated search space exploration. Experimental results on existing large benchmark instances and newly created instances show that our approach constitutes a new state-of-the-art that allows solving large-scale instances with up to 20000 requests and 1000 vehicles.

3 - Staggered Routing in Autonomous Mobility on Demand Systems
Antonio Coppola, Gerhard Hiermann, Dario Paccagnan, Maximilian Schiffer

Rapid and partially uncontrolled urbanization has led to soaring congestion in road networks, leading to discomfort for citizens, as well as to economic and environmental damage. With recent technological advances, Autonomous Mobility on Demand (AMoD) systems emerge as a novel paradigm to complement traditional personal and public urban transport modes. In AMoD systems, a central operator controls a fleet of self-driving vehicles picking up passengers and transporting them to their intended destination. In this setting, serving each request as early as possible minimizes the user's waiting time but may prolong its driving time due to local congestion, which may arise during peak times on some road segments. Here, it can be beneficial to delay the departure of a ride - as long as the user's desired arrival time window is met - to reduce both the system's congestion and a passenger's driving time. We refer to the underlying decision problem as the Staggered Routing Problem, in which an AMoD operator minimizes road blockage by delaying trip departures within the maximum time shift that a customer accepts. We formulate the problem as a mixed-integer linear program on a road network subject to congestion and present numerical experiments on medium- and large-scale real-world instances. Our results show that delaying departures can decrease congestion and travel times while ensuring punctual arrival for passengers.

4 - Learning-Based Optimization For Shared Autonomous Mobility: Modeling Service Classes and On-Demand Hiring of Idle Vehicles
Frederik Schulte, Breno Alves Beirigo

With the rise of transportation network companies (e.g., Uber, Lyft) and autonomous vehicles (AVs), the shared mobility industry increasingly focuses autonomous mobility-on-demand (AMoD) services. To challenge classic vehicle ownership, these service need to offer consistent service quality, considering individual expectations. Existing approaches, however, mostly do not actively control service quality, which may result in significant delays and user rejections. In this work, we model an AMoD system that considers the service expectations of heterogeneous user classes. We formalize the problem as the dial-a-ride problem with service quality contracts (DARP-SQC) and present a multi-objective matheuristic for real-world user requests from Manhattan, New York City. Furthermore, we propose a learning-based optimization approach that uses the dual variables of the underlying assignment problem to iteratively learn the marginal value of vehicles at each time and location. These values are used in the objective function of the optimization problem to dispatch, rebalance, and occasionally hire idle third-party vehicles. In this way, we improve user satisfaction (in terms of reached service-level expectations) by 53% on average, compared to conventional ridesharing systems. Moreover, our results show that the proposed learning-based optimization policy outperforms a reactive benchmark approach while hiring fewer vehicles.

■ WA-39
Wednesday, 8:30-10:00 - U8

MAI: Excellence in practice

Stream: Making an Impact
Invited session
Chair: *Ruth Kaufman*
Chair: *Tuomas Lahtinen*

1 - What is 'Excellent' practical OR?
Ruth Kaufman, Thorsten Koch

OR people are generally strivers, never satisfied with 'good enough' and always looking for 'excellent', not just with our optimisation models but with our performance - our service to the customer and the community. When judging if an OR/data science/analytics project is 'excellent', what are the factors we consider? Is it the quality of the analysis, the complexity of the problem and the fitness of the solution, the relationship with the customer, the inspiration and learning that it gives to others in the profession or in the organisation, the size of the impact on the bottom line? Are any more important than any others?

Are there some "secret ingredients" to be added? Can we systematise the measurement of excellence? Or is it just something "in the air"?

This round-table discussion will bring together a number of senior OR figures who aim to provide excellent practical applications of OR/analytics/data science and to enable their teams to do the same, to share their views and encourage audience members to do the same.

Confirmed panellists include Matti Vuorinen, Director of Advanced Analytics at forestry giant UPM; Matteo Pozzi, Partner and General Manager at optimisation consultancy Optit; Christian Timpe from the chemicals conglomerate and consultancy BASF; and Alessio Trivella of the University of Twente, one of the finalists from the 2021 EURO Excellence in Practice Award. The panel will be chaired by Tuomas Lahtinen, Chief Analytics and AI Officer at Loihde, and Ruth Kaufman, whose past roles include President of the UK OR Society, Chair of the UK Government's OR Service, and Chair of the UK's Heads of OR and Analytics Forum.

Wednesday, 10:30-12:00

■ WB-01
Wednesday, 10:30-12:00 - A

Claudia Archetti [EUROYoung]

Stream: Keynotes
Keynote session
Chair: *Valentina Morandi*

1 - How to deliver a successful research work in 2022: Focus on routing and logistics
Claudia Archetti

Research is challenging and fascinating. It requires knowledge, skills, creativity. In this talk I will present a discussion on the key ingredients for a successful research work in Operational Research, with a focus on routing and logistics problems. Specifically, I will start from a general perspective on research work: how to choose the topic, how to convince readers (and general audience) that your research is relevant, how to present your research - with a focus on quantitative research. Then, I will move to successful research on routing and logistics. The analysis will start from detecting what are current hot research topics and how to identify them. It will then continue with presenting some recent challenging trends that are attracting high interests, both in terms of scientific contributions and of real applications. The emphasis will be on practical impact, modelling and methodological contributions and relevance of the research work for the scientific community, funding entities and industrial stakeholders.

■ WB-03
Wednesday, 10:30-12:00 - C

Numerical methods in/for Machine Learning (II)

Stream: Machine Learning and Mathematical Optimization
Invited session
Chair: *Adil Bagirov*
Chair: *Emilio Carrizosa*

1 - Nonsmooth optimization algorithm for semisupervised clustering
Adil Bagirov, Sona Taheri

In this talk, using a nonconvex nonsmooth optimization approach, we introduce a model for semisupervised clustering where the objective function is represented as a sum of three terms: the first term reflects the clustering error for unlabeled data points, the second term expresses the error for data points with must-link constraints, and the third term represents the error for data points with cannot-link constraints. We develop a eurnonsmooth optimization algorithm to minimize it. This algorithm is based on the combination of the nonsmooth optimization method and an incremental approach. The performance of the algorithm is evaluated and compared with four benchmarking algorithms on synthetic and real-world datasets.

2 - Optimization Approach Towards Improving Compactness and Separability of Clusters
Sona Taheri, Adil Bagirov, Najmeh Hoseini Monjezi

The objective functions in optimization models of the sum-of-squares clustering problem reflect intra-cluster similarity and inter-cluster dissimilarities and in general, optimal values of these functions can be considered as appropriate measures for the compactness of clusters. However, the use of the objective function alone may not lead to the finding of separable clusters. To address this shortcoming in existing models for clustering, we introduce a new optimization model where the objective function is represented as a sum of two terms reflecting the compactness and separability of clusters. Based on this model we develop a two-phase incremental clustering algorithm. In the first phase, the clustering function is minimized to find compact clusters and in the second phase, a new model is applied to improve the separability of clusters. Starting cluster centers are generated using data points located on the boundary of clusters. The Davies-Bouldin cluster validity index is applied as an additional measure to compare the compactness of clusters and silhouette coefficients are used to estimate the separability of clusters. The performance of the developed algorithm is evaluated using some synthetic and real-world data sets.

3 - Machine Learning for the Per-Instance Configuration of MILP Solvers
Daniel Schermer, Oliver Wendt

Mixed-Integer Linear Programming (MILP) is a fundamental tool of Operations Research. Both academic and commercial MILP solvers have made remarkable advancements and continue to incorporate and refine algorithmic techniques that stem from several decades of research. Due to the complexity and feature-richness of these solvers, in principle, most of them allow the execution of the inherent branch-and-cut framework to be configured in various ways that influence the optimization, which can lead to performance gains. However, because it is not trivial to make such adjustments sensibly a priori, it is common to rely on a default configuration, which is generally attributed to work well for a wide range of applications. In this work, we attempt to bridge this conflict through a two-phase approach. First, using the well-known MIPLIB as our dataset, we learn the relationship of a given solver's performance as a function of MILP instance features and several solver configurations. To describe this relationship, we employ Random Forest (RF) regression as a Machine Learning model. Afterwards, we formulate an optimization problem that is derived from the structure of the learnt RF. This problem can be encoded as a MILP and solved on a per-instance basis to efficiently select a solver configuration that is predicted to do well. Using this methodology, we show that significant performance improvements can be achieved with respect to the default and single-best solver configuration.

4 - Convex Support Vector Regression
Zhiqiang Liao, Sheng Dai, Timo Kuosmanen

Convex regression is a popular nonparametric regression subject to convexity or concavity constraints on the regression function. Such regression problems are common in economics, statistics, operations research, and finance, but the conventional convex regression, based on the least squares estimator, often suffers from overfitting and data errors. In this paper, we propose a convex support vector regression (CSVR) method for reducing overfitting in prediction. It combines support vector regression with classical convex regression, retaining the merits of both. As a by-product of our analysis we drive an interesting connection between CSVR and Lipschitz convex regression. Numerical experiments demonstrate the robustness of CSVR in prediction accuracy that compares favorably with other state of the art methods.

■ WB-04

Wednesday, 10:30-12:00 - D

Interpretable Machine Learning

Stream: Machine Learning and Mathematical Optimization
Invited session
Chair: Connor Lawless

1 - Counterfactual Explanations with OptiCL
Donato Maragno, Tabea E. Röber, Ilker Birbil

The increase in deployment of machine learning models in practice comes with societal concerns including ethics and fairness. These concerns call for an explanation of machine learning models, and many interpretability approaches have been proposed in recent years. Insights from social sciences suggest that humans find counterfactual explanations intuitive and easy to understand. Previous work has established a set of criteria that counterfactual explanations should adhere to: validity, proximity, sparsity, actionability, diversity, data manifold closeness. We propose an approach for generating counterfactual explanations that respect these criteria using OptiCL, which is an end-to-end framework for mixed-integer optimization with data-driven learned constraints. We can leverage OptiCL and its definition of a trust region to generate a set of counterfactual data points that respect the criteria identified in the literature. Moreover, when a structural causal model, capturing all inter-variable causal dependencies, is available, we further put OptiCL in use to learn and embed the structural functions describing how endogenous variables can be obtained from exogenous variables. We test the performance of our approach on a collection of datasets and compare its results against other approaches from the literature.

2 - Integer Programming for Causal Structure Learning in the Presence of Latent Variables
Rui Chen, Sanjeeb Dash, Tian Gao

The problem of finding an ancestral acyclic directed mixed graph (ADMG) that represents the causal relationships between a set of variables is an important area of research on causal inference. Most existing score-based structure learning methods focus on learning directed acyclic graph (DAG) models without latent variables. A number of score-based methods have recently been proposed for the ADMG learning, yet they are heuristic in nature and do not guarantee an optimal solution. We propose a novel exact score-based method that solves an integer programming (IP) formulation and returns a score-maximizing ancestral ADMG for a set of continuous variables that follow a multivariate Gaussian distribution. We generalize the state-of-the-art IP model for DAG learning problems and derive new classes of valid inequalities to formulate an IP model for ADMG learning. Empirically, our model can be solved efficiently for medium-sized problems and achieves better accuracy than state-of-the-art score-based methods as well as benchmark constraint-based methods.

3 - Interpretable Bayesian classification under negative dependence with applications to wireless interference
Sander Aarts

This research develops an interpretable Bayesian model for binary classification under negatively dependent outcomes. Negative dependence is present in many settings where positive outcomes display a degree of mutual exclusivity. One motivating example is the study of wireless interference. In this setting, two radio transmissions that overlap in both time and frequency are rarely both successfully received, while receiving one of the two can be likely. In this case erroneously assuming independence can lead to overestimation of the number of successful transmissions. However, modeling and inference under negative dependence is non-trivial. This work exploits known results on determinantal point processes to develop a tractable model for negatively dependent binary classification. The determinantal model is shown to be amenable to standard Bayesian inference. Moreover, the model naturally decomposes into interpretable quality and a similarity sub-models, that highlight the trade-off between observations' individual likelihood of being positive as well as the mutual exclusivity between observations. Finally — as showcased in a case study on interference in LoRaWAN networks — the sub-models themselves can be specified to yield interpretable insight about the underlying system.

4 - Interpretable Clustering via Multi-Polytope Machines
Connor Lawless

Clustering is a popular unsupervised learning tool often used to discover groups within a larger population such as customer segments, or patient subtypes. However, despite its use as a tool for subgroup discovery and description few state-of-the-art algorithms provide any rationale or description behind the clusters found. We propose a novel approach for interpretable clustering that both clusters data points and constructs polytopes around the discovered clusters to explain them. Our framework allows for additional constraints on the polytopes including ensuring that the hyperplanes constructing the polytope are axis-parallel or sparse with integer coefficients. We formulate the problem of constructing clusters via polytopes as a Mixed-Integer Non-Linear Program (MINLP). To solve our formulation we propose a two phase approach where we first initialize clusters and polytopes using alternating minimization, and then use coordinate descent to boost clustering performance. We benchmark our approach on a suite of synthetic and real world clustering problems, where our algorithm outperforms state of the art interpretable and non-interpretable clustering algorithms.

■ WB-05

Wednesday, 10:30-12:00 - E

Machine Learning: Recent Advances and Applications

Stream: Data Driven Decision Making
Invited session
Chair: Sebastian Maldonado

1 - Burglary prediction via machine learning and crime report app data
Sebastian Maldonado, Joaquín Roa, Richard Weber, Carla Vairetti

Predictive policing is a fruitful research line that uses analytics to identify potential criminal activities. The goal of this work is to construct a learning machine that can predict, in a given area, the occurrence of a certain crime type based on past data. The main purpose of this model is to provide a tool for municipalities and police departments that help them to deploy patrols and other resources efficiently. Information from a Chilean crime report app was collected, which includes different criminal events and suspicious activities reported by ordinary people. Under the assumption that past reports are good predictors for future criminal activities, we define a classification problem to predict burglary and motor vehicle theft in a given area. We obtained promising results with traditional statistical and machine learning methods, such as logistic regression, decision trees or gradient boosting, reaching a balanced accuracy above 80%. We propose directions for future developments by considering spatio-temporal machine learning models.

2 - Improving crime report categorization and prioritization via text analytics and deep learning
Carla Vairetti, Matías Ponce, Sebastian Maldonado, Richard Weber

Deep learning has become the "de facto" method for text analytics thanks to its ability to model language from large datasets, and then transfer this knowledge to specific tasks. In this work, we apply deep learning to improve the labeling of public security reports made by ordinary people on a Chilean mobile application. The users select a category to report an incident from a wide variety of possible options ranging from lost pets or disturbing noises to accidents with injured people or burglary. They also have the option to accompany the report with a description of the incident. The main issue is that the users often report the events in the wrong category; usually in the first category presented in the app. The app has been a great help for municipalities and police departments in order to deploy resources and patrols efficiently to attend the incidents and to deter crime occurrence. However, they have a prioritization scheme that relies on the category provided by the user. This work presents a machine learning solution in which BERT and other Transformer architectures are used to learn from the description of the incident and to infer the right label, leading to a better event prioritization. Our preliminary results show the model's excellent predictive capabilities. The model also has the potential to capture additional information from the descriptions, enriching the priori

3 - Named entity extraction as a tool to enrich crime investigation
Richard Weber, Florencia Signorini, Santiago Valdivieso, Sebastian Maldonado, Carla Vairetti

Investigating organized crime often faces the challenge that only very few information on the respective criminals is available. Examples are car theft, robbery in inhabited places, among others. Apart from some structured information, such as day and time of the crime, victims' crime reports provide useful information, but in an unstructured way. Relevant information on the modus operandi, number of involved delinquents, use of weapons, etc. is often present in the respective narrative but difficult to be used for a systematic analysis. Natural language processing and particularly Named Entity Recognition (NER) has been applied to crime reports in order to enrich crime investigation performed by the Chilean Prosecutor. The results obtained underline the added value NER provides; e.g., we could establish that one criminal group is responsible for several raids initially assumed to be independent of each other. By using our model in daily crime investigation we expect that the crime investigators' work will be more efficient and effective (FONDEF ID20I10230ANID).

4 - Finding Criminal Groups in Suspect Networks Using a Steiner Tree Approach
Fredy Troncoso, Richard Weber, Alex Barrales-Araneda

The behavior of criminal groups has been studied using social network analysis and decision support systems. Several quantitative models to identify the members of such a group responsible for certain crimes have been proposed and used successfully. The existing models to identify crime associations require at least two suspects to be connected using modified shortest-path algorithms or more sophisticated models. However, many crime investigations start with just one suspect, thus making existing approaches inapplicable.

We present an optimization model based on a particular case of Steiner trees to detect criminal associations when only one confirmed suspect is available. An application of our model to a real-world case highlights its potential to support decision-making in crime investigation. The proposed model opens new avenues for applied research in crime investigation. It is concluded that starting a police investigation considering a single suspect using this model allows us to obtain results as good as those obtained by applying existing approaches that begin with two suspects individuals.

■ WB-06

Wednesday, 10:30-12:00 - U1

Combinatorial Optimization applications

Stream: Combinatorial Optimization
Invited session
Chair: Baruch Mor

1 - Combining heuristics with MILP to speed up the solution of the security-constrained unit commitment problem
Iiro Harjunkoski, Marco Giuntoli, Jan Poland

One of the optimization problems of today with increasing importance is related to the power grids management. The very common problem, also discussed within the OR-field, is the Unit Commitment problem, which basically determines a schedule for a set of generation units to fulfil the electricity demand at all times (typically 24 hours) considering network outages and power flow limitations. Why it is of increasing importance relates to the development of the electrical grids involving much more generation units as the traditional large power plants (nuclear, coal) are being replaced by small renewable generation units (solar and wind parks).

In this work we discuss the solution of large-scale unit commitment problems, specifically we are applying an LP-based heuristics to fix part of the binary variables. In earlier work we showed speed-ups between 2-5 for large-scale problems for individual unit commitment runs. In some cases there was a significant worsening of the objective function value. In this work, we solve iterative security constrained unit commitment problems, where at each iteration network constraints are added to the problem. The results are promising as we can show more stable performance improvements and lower quality losses owing to the fact that repeated solution steps balance out the earlier observed "outliers".

2 - The parliament seating assignment problem

Bart Vangerven, Dirk Briskorn, Dries Goossens, Frits Spieksma

A key institute in old and modern democracies is the parliament: a collection of persons that have been elected to represent the people and whose main task is to control legislative power. To exercise their right and duty of controlling power, there is a physical location where the elected representatives meet, discuss, and vote: the parliament. Typically, the parliament is a building where locations of seats are given, and hence, after an election, the question arises: who sits where? Motivated by evidence that parliament seatings are relevant for decision making, we consider the problem to assign seats in a parliament to members of parliament. We prove that the resulting seating assignment problem is strongly NP-hard in several restricted settings. We present a Mixed Integer Programming formulation of the problem, we describe two families of valid inequalities and we discuss symmetry-breaking constraints. Further, we design a heuristic. The outcomes of the Mixed Integer Programming formulation are compared with the outcomes of the heuristic in a computational study. Finally, we discuss the seating of the Dutch House of Representatives as a case study.

3 - Optimization aspects of wireless network design

Alice Calamita, Pasquale Avella, Laura Palagi

The design of wireless networks consists of configuring a set of radio base stations to provide service coverage to the users in a target area. Wireless networks are growing denser as a result of technological developments and increased traffic, demanding the employment of optimization approaches to reduce cost and meet user-demanded service quality criteria. We discuss the modeling of this problem and reveal the major optimization issues that arise when dealing with large-sized instances of this problem. Indeed, realistic wireless network design problems turned out to be large problems affected by strong ill-conditioning due to the intrinsic nature of the data, as evidenced by the results of several tests.

4 - Scheduling with step-deterioration and rejection

Baruch Mor

This research focuses on scheduling problems with step-deteriorating job processing times. This phenomenon reflects various real-life settings where the processing time of the jobs, processed after their pre-determined and job-dependent deterioration-date, is defined by a step-function. A single machine setting is assumed and optional job-rejection considered. The scheduling measure focused on is makespan, and three variants of the basic problem are considered: (i) minimizing the total integrated cost of the scheduling measure and total rejection cost; (ii) minimizing the scheduling criterion, given an upper bound on the total rejection cost; and (iii) minimizing the total rejection cost, subject to a constraint on the scheduling measure. As minimizing the makespan on a single machine with step-deterioration is known to be ordinary NP-hard, even if all jobs share a common deterioration-date, all presented problems are NP-hard. For all problems, pseudo-polynomial time dynamic-programming (DP) algorithms are presented, establishing that they remain ordinary NP-hard. Furthermore, an extensive experimental study was conducted to determine the efficiency of the proposed algorithms.

■ WB-07

Wednesday, 10:30-12:00 - U3

Urban and Territorial Planning in MCDA 2

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Francesca Abastante*
Chair: *Isabella Lami*
Chair: *Marta Bottero*

1 - A multi-domain evaluation methodology to assess building performance based on real-time monitored data

Giulio Cavana, Anthony Suppa, Giulia Vergerio, Federico Dell'Anna, Cristina Becchio, Marta Bottero, Sara Viazzo, Stefano Corgnati

To advance the European Green Deal's pledge for climate neutrality by 2050, 97% of buildings in the EU need deep energy retrofits to decarbonize, requiring significant private investment.

When making energy efficiency investments, co-benefits arise in economic, environmental, and social domains, such as improved air quality, increased asset value, enhanced occupant comfort and well-being, reduction of environmental impacts. Quantification of these co-benefits could become a lever toward new habits and investment decisions.

This contribution proposes a multi-criteria and multi-domain (energy, environmental, financial, and socio-economic) methodology to assess building performance, based on Key Performance Indicators using monitored data. The evaluation framework is based on the Multi-Attribute Value Theory, built on the standardization of the various indicators by means of so-called value functions, defined through a benchmarking process. This approach enables the translation of data from an established building monitoring system into simple, aggregated metrics to support building management and retrofit decision-making.

The methodology has been applied to the STAR project, where an office building in Ivrea (Northern Italy) serving as a pilot case is currently being tested. For explanatory purposes, a focus on the standardization and aggregation process of the indicators composing the socio-economic domain is presented as well as their planned weighting procedure.

2 - The application of multi-criteria methodology in spatial planning. The case study of Greece.

Vasiliki Charalampidou

This proposal refers to the application of the multi-criteria methodology in the field of spatial planning in the case study of Greece. As a part of a wider PhD research, the aim is to examine the investments' location optimally, to deploy the competitive advantages and to have geographical targeting, both at national and regional level. Undoubtedly, there is a spatial concentration of investments in the Metropolitan areas of Athens and Central Macedonia, due to the availability of infrastructure, accessibility to raw materials, competitiveness phenomena and participation in economies of scale. Having studied the spatial and development model of the country under the current conditions, the criteria and alternatives (investment sectors) emerge. The criteria were put up for discussion and enrichment by different backgrounds experts (Central and Local Administration, spatial planners, Professors, investors etc.), and they were asked to give the weighting factors. The location of investments is important to be based on certain criteria, so that they are directed to the optimal area and to achieve their desired decentralisation. This multi-criteria methodology is a tool of decision support in spatial planning, as it could update and enhance the location process and available spatial plans. In conclusion, the multi-criteria methodology is essentially a tool of both economic and spatial policy, although there is no relevant institutional framework in Greece.

3 - Autocracy vs "Solidarchy". The Territories of Energy and Shapes of Landscape in the Environmental Accountability
Salvatore Giuffrida, Maria Rosa Trovato, Cheren Cappello, Ludovica Nasca

This study frames within the prospect of the progressive abandonment of fossil fuels in favour of the RETs. Some points concerning the main ethic-environmental claims are summarized about the negative externalities of the fossil sector, mainly affecting the underdeveloped countries. In such issue, "solidarchy" arises as the opposite of autocracy of the developed countries, which create and keep unbearable asymmetries in the allotment of advantages and disadvantages related to the control of the fossil energy sources. Solidarchy can be defined as the most accountable arrangement of the energy system, imposing a settled community to produce the energy it needs, by using only its own territory and polluting only its own habitat. The study carried out in the province of Enna (Italy) concerns the prospect of the energy self-sufficiency by means of a widespread system of wind farms covering the part of territory allowed by the Territorial Landscape Plan. 1. A landscape analysis was carried out to outline the location pattern of the wind farms; 2. the calculation of the investment and operating costs, as well as the energy potential production, estimated according to the anemometric maps available over the territory were carried out; 3. a DCFA aimed at ranking the profitable windfarms; 4. the map of the intervisibility of each wind farm was drawn to measure their landscape impact; 5. a MAVT model was applied to choose the most profitable and less impacting windfarms

■ WB-08

Wednesday, 10:30-12:00 - U4

Transportation problems

Stream: Combinatorial Optimization
Invited session
Chair: M. Grazia Speranza

1 - Tactical and Dynamic Technician Routing and Scheduling
Clara Chini Nielsen, David Pisinger

We consider the tactical planning aspect of a dynamic technician routing and scheduling problem with a time horizon of several days. In this problem study, some tasks are known beforehand, while others arrive dynamically. The tactical planning is to schedule the known tasks, such that we minimise the overall driving distance while ensuring short service times of the dynamic tasks. Without tactical planning, the known tasks would be spread throughout the whole area as they are scheduled based on a first-come-first-serve principle. In this study, we partition the area into some disjoint areas covering the full plane. Every day we schedule the known tasks corresponding to one area in a round-robin fashion. The partitioning of the areas will be constructed with a balanced sweep algorithm using two approaches: The first is based on a sweep-line following a given angle, while the second is based on a rotating sweep-line around a given origin. To guide the partitioning, we aim to minimise the degree of dynamism, which in our case is defined by the number of dynamic tasks, the distance from known tasks to dynamic tasks, and the tightness of the time windows. The tactical planning is evaluated using dynamic instances based on the Solomon test instances, where some of the tasks are known, and some are dynamic. We benchmark the two partitioning approaches against the default strategy of just serving all known tasks on a first-come-first-serve basis. Computational results are reported.

2 - A Benders decomposition approach for a maximum coverage location-routing problem with minimum workload
Vera Fischer, Sanne Wøhlk, Meritxell Pacheco Paneque

In most Swiss municipalities, a curbside (pick-up) system is used for non-recoverable waste collection. Due to the many stops of the trucks, this strategy causes high fuel consumption, emissions and noise. These effects can be alleviated by requesting residents to bring their waste to collection facilities, from which it is then picked by the vehicles. We formulate this problem as a maximum coverage location problem (MCLP) with two particular features. First, a facility must collect a minimum amount of waste that justifies its opening. Second, we take into account residents' preferences when allocating them to collection facilities. To consider the routing aspect of the problem, we favor solutions accommodating vehicles able to visit up to two collection facilities in each route. We propose a mixed-integer linear programming (MILP) formulation for the complete problem and apply a Benders decomposition approach to handle practically relevant instances. We formulate the subproblem as a multi-period minimum weight perfect matching problem, in which for each day of the planning horizon we form pairs of facility locations that are visited by the same vehicle. The goal is to identify a subset of candidate locations to place the facilities such as to maximize the amount of waste assigned to acceptable locations while defining for each day of the planning horizon pairs of locations with minimum total cost.

3 - Branch-price-and-cut with partial dominance for the split delivery vehicle routing problem with time windows
Sarah Machate, Stefan Faldum, Timo Gschwind, Stefan Irnich

Given a homogeneous fleet of vehicles and a set of customers, the split delivery vehicle routing problem with time windows (SDVRPTW) consists of finding a set of routes with minimal routing costs such that customer demands and time windows, vehicle capacities and the fleet size are respected. Contrary to classical VRPs, customers may be served through multiple visits, which provides opportunities to logistics companies to reduce routing costs and fleet size, while it significantly complicates the planning process. In this talk, we propose a branch-price-and-cut (BPC) algorithm for the SDVRPTW, in which the subproblem is a combination of an elementary shortest path problem with resource constraints and the linear relaxation of a bounded knapsack problem. The key novelty of our approach is a new labeling algorithm using partial dominance. In the classical labeling algorithm, a label is only discarded if it is infeasible or fully dominated by another label. Our algorithm additionally discards a label if it is fully dominated by a set of labels that each only partially dominate it. Moreover, we integrate several acceleration techniques e.g. bidirectional labeling, ng-route relaxation, capacity cuts and subset-row inequalities. Computational tests show that the proposed method leads to a significant speedup resulting from a reduction in the number of generated labels. These results may be adaptable to other VRP variants with subproblems that feature a tradeoff between resources.

4 - Optimization models for fair horizontal collaboration in demand-responsive transportation
M. Grazia Speranza, Enrico Angelelli, Valentina Morandi

The advances in information and communication technology are changing the way people move and companies operate. Companies that offer demand-responsive transportation services have the opportunity to reduce their costs and increase their revenues through collaboration, while at the same time reducing the environmental impact of their operations. We consider the case of companies that offer a shared taxi service and are involved in a horizontal collaboration initiative. We present mixed integer linear programming (MILP) models for the optimization of their routes that embed constraints aimed at balancing the workload exchange to ensure that the collaboration is fair to all the companies involved. The constraints bound the imbalance in terms of traveled time and/or served customers to be less than thresholds agreed in advance by the companies. We also present a heuristic algorithm for the solution of the MILP models. The computational results show the good performance of the heuristic and the benefits of the collaboration.

■ WB-09

Wednesday, 10:30-12:00 - U5

Computational Mixed Integer Linear Programming

Stream: Mixed Integer Linear Programming
Invited session
Chair: Gregor Hendel

1 - Adaptive Cut Selection in Mixed-Integer Linear Programming
Mark Turner, Thorsten Koch, Felipe Serrano, Michael Winkler

Cut selection is a subroutine used in all modern mixed-integer linear programming solvers with the goal of selecting a subset of generated cuts that induce optimal solver performance. These solvers have millions of parameter combinations, and so are excellent candidates for parameter tuning. Cut selection scoring rules are usually weighted sums of different measurements, where the weights are parameters. We present a parametric family of mixed-integer linear programs together with infinitely many family-wide valid cuts. Some of these cuts can induce integer optimal solutions directly after being applied, while others fail to do so even if an infinite amount are applied. We show for a specific cut selection rule, that any finite grid search of the parameter space will always miss all parameter values, which select integer optimal inducing cuts in an infinite amount of our problems. We propose a variation on the design of existing graph convolutional neural networks, adapting them to learn cut selection rule parameters. We present a reinforcement learning framework for selecting cuts, and train our design using said framework over MIPLIB 2017. Our framework and design show that adaptive cut selection does substantially improve performance over a diverse set of instances, but that finding a single function describing such a rule is difficult.

2 - Feasibility Pump 3.0: Using Multiple Reference Vectors and New Objective Scaling
Gioni Mexi, Timo Berthold, Domenico Salvagnin

The Feasibility Pump (FP) is one of the best-known primal heuristics for mixed-integer programming (MIP): more than 15 papers suggested various modifications of all of its steps. So far, however, no variant considered information across multiple iterations, but all maintained the principle to optimize towards a single reference integer point. In this paper, we present a new FP version that uses multiple reference vectors in all stages of the algorithm. In particular, we use LP-feasible vectors obtained during the main loop to tighten the variable domains before entering the computationally expensive enumeration stage. Moreover, we consider multiple integer reference vectors to explore further optimizing directions and introduce alternative objective scaling terms to balance the contributions of the distance functions and the original MIP objective. Our computational experiments demonstrate that the new method can improve performance on general MIP test sets and make a big difference when solving specific application instances. In detail, our modifications provide a 27.8% solution quality improvement and 5.2% running time improvement in an embedded setting, needing 15.8% fewer iterations over a large test set of MIP instances. In addition, the method's success rate within the first few iterations increases considerably. In a standalone setting, we also observe a moderate performance improvement, which makes our version of FP suitable for all use-cases of the algorithm.

3 - On Global Information Transfer Across Restarts in MIP
Gregor Hendel, Timo Berthold

Restarting a solver gives us the chance to learn from things that went good or bad in the search until the restart point. The benefits of restarts are often justified with being able to employ different, better strategies and explore different, more promising parts of the search space. In that light, it is an interesting question to evaluate whether carrying over detected structures and collected statistics benefits the subsequent search or counteracts the anticipated diversification from the previous, unsuccessful search provided by a restart.

In this talk, we will discuss four different types of global information that can potentially be re-used after a restart of a mixed-integer programming (MIP) solver, present technical details of how to carry them through a represolve after a restart, and show how such an information transfer can help to speed up the state-of-the-art commercial MIP solver FICO Xpress by 7% on the instances where a restart is performed.

4 - Innovating Kernel Search: some new directions
Renata Mansini, Roberto Zanotti

Kernel Search is a general-purpose method for the solution of mixed integer linear programs (MILP). In recent years, it has been successfully applied to many combinatorial problems such as knapsack, facility location, portfolio selection, and routing problems. The method is based on the solution of a sequence of restricted problems (RPs) obtained by selecting a subset of variables of the original problem, while setting the remaining ones to zero. To build RPs, the algorithm uses information provided by continuous relaxation (value of basic variables, reduced costs) to sort variables and identify the most promising ones (most likely to be selected in an integer optimal solution). The first variables in the ordered list define the kernel set, whereas the others are partitioned into groups called buckets. Each RP is constructed using the kernel set and one bucket at a time, while its solution contributes to updating the kernel set in a learn-and-adjust way. A central role in the solution of RPs is played by MILP solvers on which the method strongly depends. We propose some new directions to innovate the method including the analysis of the role of variables (integer, binary, continuous) in constructing RPs, the impact of different sorting rules based on alternative relaxation methods, the parallelization of RPs solution, the hybridization of the framework with metaheuristic algorithms and machine learning techniques, and the evaluation of its potential use as primal heuristic.

■ WB-10

Wednesday, 10:30-12:00 - U6

Portfolio Risk Management II

Stream: Financial Risk Measurement and Management
Invited session
Chair: Nina Lange

1 - Jump-Diffusion Risk-Sensitive Benchmarked Asset Management with Traditional and Alternative Data
Sebastien Lleo

Parameter uncertainty is widely considered the Achilles' heel of continuous-time portfolio selection models. A standard approach postulates that stochastic factors explain expected asset returns. The problem is then to estimate these factors from observed asset prices via filtering. Recent advances have also combined asset prices with expert opinions to improve the estimates. Individually, stocks prices favor momentum strategies, and expert opinions require careful debiasing. However, using stock prices and debiased opinions simultaneously improves portfolio performance, highlighting the importance of diversifying the sources of observations. Our paper shows how alternative data complement asset prices and expert opinions in a jump-diffusion risk-sensitive benchmarked asset management model. This model admits a unique classical solution and an optimal investment policy in quasi-closed form. We find that investors construct their portfolios from a passive core and an active satellite. The passive core adds considerations for jump risk to a simple benchmark replication. The active satellite blends security selection and factor tilts with event-driven strategies unique to jump-diffusion problems. Furthermore, our improved expert forecast model combined with new alternative data provide factor tilters with new tools to sharpen their asset allocation. Thus, our model explains the most popular investment strategies, from passive index replication to active hedge fund strategies.

2 - Integrating multiple ordinal information into portfolio optimization
Eranda Cela, Stephan Hafner, Roland Mestel, Ulrich Pferschy

Active portfolio management tries to incorporate any source of meaningful information into the decision process. We consider total orders of the expected asset returns and discuss robust optimization approaches (ROA) and order aggregation approaches (OAA) to incorporate these orders as inputs in a mean-variance portfolio optimization model (MVO). In ROA's first step, each total order is used to compute a posterior expectation of asset returns by means of the Black-Litterman (BL) framework adapted so as to process ordinal information. Then, in its second step, the posterior expectations of asset returns are considered as possible input scenarios for different robust optimization variants of the MVO (max-min robustness, min regret robustness and soft robustness). In OAA the total orders are first aggregated in a single "consensus order" by applying methods known in social choice theory (Borda, Footrule, Copeland, Best-of-k and MC4). Then the "consensus order" is used to compute a posterior expectation of asset returns by means of the adapted BL framework. Finally, the later posterior expectation of asset returns is passed as an input to the MVO. Using data from the EUROSTOXX 50 and the S&P 100, respectively, we empirically compare the success of ROA and OAA in the context of portfolio performance analysis. We observe that in general OAA outperfms ROA for both data sets and for different settings of input orders varying in quality, quantity and level of confidence.

3 - Hidden Markov Model Utilization in Financial Modeling
Marian Reiff, Juraj Pekár, Ivan Brezina

The hidden Markov model is a mathematical model in which a hidden Markov property can describe the analyzed system, i.e., states modeled by the Markov chain, which cannot be directly observed. Model parameters are unknown and must be estimated based on observable data. The main idea behind the hidden Markov model is that the latent states of the system and other invisible information are hidden in the observed process, which is damaged by some noise. In the context of financial modeling, an observable process can be time series of financial data containing hidden information whose dynamics can be described by a Markov chain with a finite number of hidden states. This information can be extracted using hidden Markov model techniques. In the case of financial modeling, it is possible to interpret Markov hidden states, for example, bull and bear markets. The presented paper aims to develop integration ideas in portfolio management and propose innovative approaches that will contribute to the use of financial analyses on the asset market based on hidden Markov model theory and optimization models. The idea is to describe the price asset movements using a hidden Markov model and select the optimal portfolio. The paper assesses existing formalized approaches in time series analysis using a hidden Markov model, financial asset allocation planning, and elaborate portfolio selection models based on statistical and econometric methods and mathematical programming approaches.

4 - Trade-off between correlation and trading costs in proxy-hedging
Nina Lange, Michael Coulon, Diana Prinzbach

Uncertainty in the value of a spot contract is often hedged using a proxy instrument. The effectiveness of the hedge depends on the correlation of the proxy instrument and the spot contract. Forward contracts written on an underlying closely related to the spot offer a better correlation than futures contracts written on a less related underlying. On the other hand, trading costs for futures are much lower than the trading cost for forward contracts. Trading costs can be of further importance when hedging an instrument that needs frequent rollover. Hence, there is a tradeoff between correlation and trading costs when choosing hedge. We propose a pragmatic approach to handle the hedging decision while considering the trading costs occurring both when hedging and at a future rollover.

We conduct an empirical analysis using data from the shipping industry, specifically bunker fuel. We analyze the effectiveness of different proxy hedges with oil futures as well as OTC forwards for the bunker fuel market. When disregarding trading costs, the forward contracts' higher correlation yields better hedging results. However, given the high amount of trading costs for OTC products combined with the added rollover trading costs, the oil futures contracts can deliver higher utility. We explore the tradeoff between costs and correlation to determine when futures oil futures with low trading costs are a better choice than higher correlated forwards contracts with high trading costs.

■ WB-12
Wednesday, 10:30-12:00 - U9

Solving complex energy problems

Stream: OR in Energy
Invited session
Chair: Karlo Šepetanc

1 - Convex Relaxations for the Multi-period Natural Gas Storage Optimization Problem
Bahar Okumusoglu, Burak Kocuk

In power systems, natural gas has certain advantages over other non-renewable energy resources since it is the cleanest-burning and the cheapest one and moreover, it can be stored in larger amounts compared to renewable energy resources in a safe and more efficient way. In particular, the recent advances in power-to-gas technologies have made natural gas storage more substantial to balance supply and demand. In our work, we focus on a multi-period natural gas storage optimization problem including the switching decisions of active elements, such as compressors and valves, and the well-known nonconvex Weymouth equations governing the gas transportation in pipes. We formulate this problem as a nonconvex mixed-integer nonlinear programming problem under steady-state conditions. We present an alternative formulation of the resulting problem by introducing auxiliary variables and removing the absolute values from the nonconvex constraints induced by the gas network. Using second-order cone representability of the convex hull of these nonconvex constraints, we obtain a convex relaxation of our problem in order to obtain high-quality feasible or globally optimal solutions for large-scale instances. We design a computational study on small- and large-scale GasLib test instances taken from the literature, and compare these formulations to illustrate the computational efficiency of our approach.

2 - Exact solution of the OPF problem based on compact quadratically constrained convex relaxation
Amélie Lambert

We consider the optimal power flow (OPF) problem which consists in determining the power production at each bus of an electric network by minimizing the production cost. Our contribution is an exact solution algorithm for the OPF problem. It consists in a spatial branch-and-bound algorithm based on a compact quadratically constrained convex relaxation. This compact relaxation is computed by solving the rank relaxation once at the beginning of the algorithm so that the lower bound at the root node of the tree is equal to the rank relaxation value. Then, at every sub-nodes of the branch-and-bound, the lower bound is obtained by solving a quadratic convex problem. To construct this compact relaxation, we add only O(n) variables that model the squares of the initial variables, where n is the number of buses in the power system. Since the relations between the initial and auxiliary variables are non-convex, we relax them to get a quadratic convex relaxation. Finally, in our spatial branch-and-bound algorithm, we have only O(n) equalities to force to prove global optimality.

3 - Strengthened Linear and SOCP Relaxations for the Generalized Pooling Problem
Mosayeb Jalilian, Burak Kocuk

The pooling problem is a classical NP-hard problem in the chemical process and petroleum industries. It involves mixing raw materials with different specifications in such a way that end products with certain specifications are obtained. This problem is modeled as a nonlinear, nonconvex network flow problem with a three-layer network in which the layers are called the input tanks, pools, and output tanks.

In particular, the raw materials in input tanks are mixed in the pools and these intermediate products are mixed one more time at the output tanks. The analysis of the pooling problem is a quite active research area and there are different exact formulations and relaxations proposed. However, the state-of-the-art does not perform very well on generalized pooling problem instances in which flow streams between pools are allowed. In this work, starting from a recently proposed rank-based formulation, we introduce strengthened (mixed-integer) linear and second-order cone programming relaxations. These relaxations involve convexifying a nonconvex set defined by a rank constraint on the matrix variable and bounds on the row and column sums. We also use Optimization-Based Bound Tightening (OBBT) to produce strong upper and lower bounds on pool and arc capacities. Testing these methods on challenging instances from the literature shows that the OBBT helps to improve the relaxation quality and reduce the computational time of a commercial global optimization solver significantly.

4 - Solving Bilevel AC OPF Problems by Smoothing the Complementary Conditions

Karlo Šepetanc, Hrvoje Pandzic, Tomislav Capuder

The existing research on market price-affecting agents, i.e. price makers, neglects or simplifies the nature of AC power flows in the power system as it predominantly relies on DC power flows. This talk shows a novel bilevel formulation based on the smoothing technique, where any price-affecting strategic player can be modeled in the upper level, while the market clearing problem in the lower level uses convex quadratic transmission AC optimal power flow (AC OPF), with the goal of achieving accuracy close to the one of the exact nonlinear formulations. Achieving convexity in the lower level is the foundation for bilevel modeling since traditional single-level reduction techniques do not hold for nonconvex models. The formulation is transformed into a single-level problem and solved using multiple techniques such as the primal-dual counterpart, the strong duality theorem, the McCormick envelopes, the complementary slackness, the penalty factor, the interaction discretization as well as the proposed smoothing techniques. We use a strategic bidding of energy storage as an example of a suitable upper-level problem. The superiority of the proposed algorithm and smoothing techniques is demonstrated in terms of accuracy and computational tractability over multiple transmission networks of different sizes and different OPF models. The case study also shows economic benefits of reactive power bids for the storage and the system.

■ WB-13

Wednesday, 10:30-12:00 - U119

Discrete mathematical optimization @ OJMO

Stream: OR Journals
Invited session
Chair: Michael Poss

1 - The Referenced Vertex Ordering Problem: Theory, Applications, and Solution Methods

Jérémy Omer

The referenced vertex ordering problem (revorder) is a combinatorial decision problem generalizing several vertex ordering problems that appear in the scientific literature under different guises. Given a simple undirected graph G = (V, E), revorder basically asks whether the vertices of G can be sorted in a way to guarantee that every vertex is adjacent to a minimal number of its predecessors in the order. Previous works show that revorder, as well as its optimization counterpart, denoted in our work as min revorder, are NP-hard. We give a survey of methods and algorithms that can be applied to the solution of min revorder, and we develop a new enumeration scheme for its solution. Our theoretical analysis of this scheme yields several pruning techniques aimed at the reduction of the number of enumeration nodes. We then discuss how upper and lower bounds can be computed during the enumeration to design a branch-and-bound algorithm. Our branch-and-bound outperforms other existing solution methods: among 180 instances with 60 vertices, it solves 179 instances to optimality whereas the best existing method is only able to solve 109 of them. Moreover, our tests show that our algorithm can solve medium-scale instances up to 500 vertices, which opens the perspective of handling new real-life problems. Our implementation of the branch-and-bound algorithm is publicly available on GitLab.

2 - Efficient optimization of the Held-Karp lower bound

Giovanni Righini

This paper presents and analyzes an algorithm that allows to compute all the alternative edges that are needed to rebuild a minimum cost spanning tree when a vertex is deleted from a given weighted undirected graph. This goal is achieved with the same worst-case computational complexity required by the computation of a single minimum spanning tree of the same graph. As a by-product, the algorithm allows to efficiently compute the largest possible Held-Karp lower bound for the traveling salesman problem.

3 - Estimating Scenarios for Discrete Robust Optimization

Marc Goerigk, Jannis Kurtz, Stefan Lendl

This talk has two parts, which are both connected by the overarching topic of creating suitable uncertainty sets for discrete robust optimization models.

In the first part, I present recent results on locally budgeted uncertainty sets, published in OJMO. I show that the additional flexibility of locally budgeted sets in comparison to their classic counterpart can considerably improve the quality of resulting robust solutions. This is joint work with Stefan Lendl.

In the second part, I consider the task of finding a representative set of scenarios that can be used as a starting point for the well-known scenario generation iterative solution procedure in robust optimization. I demonstrate that using a training set of already solved robust optimization problems, it is possible to predict the most relevant scenarios, which results in strong lower bounds and improved solution times over alternative, reasonable methods of choosing starting scenarios. This is joint work with Jannis Kurtz.

■ WB-14

Wednesday, 10:30-12:00 - U261

Analysis of metaheuristics

Stream: Metaheuristics, Matheuristics
Invited session
Chair: Kenneth Sörensen

1 - When to stop a heuristic algorithm? An application of extreme value theory

Lissa Melis, Kenneth Sörensen

Heuristic algorithms are frequently used to solve large-scale combinatorial optimization problems, e.g., vehicle routing problems, variants of the knapsack problem, etc. Heuristics are particularly useful for such problems because they find good solutions within a relatively small amount of computation time. However, one often does not know when and if a heuristic algorithm will find the optimal objective function value. Consequently, the decision on when to stop a heuristic algorithm is frequently based on intuition or simple stopping criteria instead of it being a rationally substantiated decision. This results in algorithms being terminated right before finding a better solution or in an unnecessary long algorithm execution time. This work aims to give some guidelines on how determine the stopping criterion objectively by applying extreme value theory to the time series of heuristic outcomes, i.e. the found objective function values throughout the iterations of the algorithm. We will estimate the exceedance probabilities and return periods of extreme objective function values empirically and by fitting them to the generalized extreme value distribution (GEVD). These metrics are consequently used to forecast the additional amount of computation time needed before finding a better solution. We test our ideas on benchmark instances of the traveling salesman problem.

2 - Genetic algorithm with search reduction using neighborhood in Bi-objective Network
Natsumi Takahashi, Tetsushi Yuge

In the real world, many infrastructures, for example, Internet, power supply and traffics, are required high reliability. Independently, in these systems, cost may be needed for the construction or maintenance of components in the networks. In this study, we consider a bi-objective network with objectives of maximizing all-terminal reliabilities and minimizing costs. In general, these objectives are in trade-off relation, and cannot be optimized simultaneously. Therefore, solving the problem is to find the set of all Pareto solutions. On the other hand, the problem of evaluating all-terminal reliability of a given network is computationally intractable. Therefore, we thought a Genetic Algorithm obtaining a set of quasi-Pareto solutions. In this study, we consider the evaluation procedure of individuals. When a reliability of a network is evaluated for obtaining its fitness value, reliability of its subgraph is also evaluated.[U+3000]In addition to generated individuals, proposed algorithm evaluates their subgraphs which are generated in the reliability calculation process and adds them to the population. After that, based on network structure and distributions of non-dominated solutions, we conduct select parents and generate offsprings that inherit characteristics of "good" solutions. And then, we evaluate the accuracy of our proposed algorithm by comparisons with other algorithms.

3 - Progressive filtering for the location-routing problem
Kenneth Sörensen, Florian Arnold

In location-routing problems, two decisions are made simultaneously: the opening of facilities, and the planning of the vehicle routes to deliver goods to customers from those (opened) facilities. This problem is challenging because it consists of a hierarchy of optimization problems where the solution of the upper level problem (the location of facilities) can only be evaluated by solving a lower level optimization problem (the routing problem) which is itself NP hard. We present a performant heuristic for this problem that we have called "progressive filtering". This heuristic starts from a large set of potential solutions to the upper-level problem and iteratively removes (filters) solutions by solving the lower-level problem to an increasing level of precision. We demonstrate that this approach does not only perform better than the state-of-the-art, but also that it is flexible and can be easily adapted to solve several variants of the location-routing problem.

■ WB-15

Wednesday, 10:30-12:00 - U262

Decision Support Systems Technologies, Infrastructures, and Processes

Stream: Decision Support Systems
Invited session
Chair: Pavlos Delias

1 - Charging Strategies and Infrastructure Policies Supporting the Adoption of Electric Vehicles in Fleet Utility Operations
Vidura Sooriyaarachchi, Anne Liret, Jiyin Liu, Rupal Rana

In order to support the widespread adoption of Electric Vehicles, the charging infrastructure required to support such vehicles must first be installed and prepared. Large fleet operators may wish to install a private network of such chargers and in this work the case of such an operator is examined. The fleet in question will be used for a service application rather than a delivery application and will rely on the private network wherever possible. The private network has the additional condition that the charging points may only be installed at pre-existing private sites. These sites must be chosen based on various constraints relating to the power grid, as well as operational constraints. A method of reducing the capacity requirements is also examined in order to reduce the initial investment required. The use of a private network has operational and economic advantages which are discussed with respect to different charging strategies and infrastructure policies, including exploring the potential for utilising the network to create a separate revenue stream by itself.

2 - The System Dynamics model of recovery of inhabited areas
Anna Selivanova, Igor Krejci, Tereza Sedlářová Nehézová

Considering radioactive contamination of inhabited areas, the System Dynamics recovery model has been developed. The model contains sequences of countermeasures (or scenarios) selected for predominant types of urban/rural objects. The decontamination methods used for the simulation are chosen from the handbooks and official manuals. Objects of interest are located in an emergency planning zone (EPZ) of a chosen nuclear power plant (NPP). Assessments of affected areas were carried out in the JRODOS tool. For these purposes, historical data on weather conditions are used. Inputs for the model were obtained using data from the State Administration of Land Surveying and Cadastre of the Czech Republic. Thereafter, decontamination scenarios of the model designed were filled with data required and simulated over a selected time period in the Vensim software. The mathematical model provides the estimation of costs of recovery and financial expressions of health detriment for each scenario. Hence, simulated results were used for cost-benefit analysis, allowing to assess the suitability of countermeasures chosen. The following steps lead to the demography structure implementation. For these purposes, the census from 2021 will be used.

3 - Dynamic Supply Chain Mapping: Backbone of a Tailored Intelligent Decision Support
Sahar Validi

Effective management of Supply Chains (SCs) in today's increasingly complex & and complicated business environment requires a different approach. The digital revolution is well underway with all the opportunities it offers to SCS. Despite all the benefits & advantages the digital transformation can offer, adaption to the changes remains a major risk & struggle for businesses. The recent ongoing pandemic highlighted the vitality of SCs, their increasing global & interconnected nature, & their capabilities in facing major disruptions, & exposed their vulnerabilities & their strengths. In dealing with such risks, SCs of future need to be capable of planning proactively, minimising damage during distribution & put together recovery plans quickly and efficiently. Flexibility, transparency, traceability, resilience, & responsiveness are some of the main elements required for this purpose, & technology is a major enabler in realising this transformation efficiently. This transformation won't be achievable without access to a dynamic SC wide related data. This paper is reporting on SC mapping & its vital role in developing a tailored efficient Intelligent Decision Support System (IDSS) This paper is a part of an ongoing interdisciplinary research project and is focused on the nature and the key role of supply chain mapping and its contribution to developing efficient and tailored IDSS, capable of providing diagnostic, predictive, prescriptive decision support.

■ WB-16

Wednesday, 10:30-12:00 - U264

Stochastic Dominance in Risk Management

Stream: Risk Management in Finance
Invited session
Chair: Tommaso Lando
Chair: *Idir Arab*

1 - Second-order stochastic dominance of k-out-of-n systems, with applications
Tommaso Lando, Idir Arab, Paulo Oliveira

We deal with the problem of comparing the lifetimes of k-out-of-n systems by relying on the theory of stochastic orders. If we assume that the lifetime of each component is distributed according to a common parent distribution, say F, then the lifetime of the system is represented by the order statistic X_k:n, corresponding to a random sample of size n from F. Similarly to most decision problems in other research fields, the "best" performance of a k-out-of-n system may be represented by larger magnitude and smaller risk or dispersion, since lifetime predictability is always preferable. The second-order stochastic dominance (SSD) enables comparisons of random variables in terms of magnitude and dispersion, therefore combining both aspects into a single preorder. We determine sufficient conditions for SSD between order statistics, from the same or from different parent distributions, based on two related aspects, namely, i) ranks and sample sizes and; ii) information available on the parent.

2 - Monotonicity properties of some exceedance probabilities
Paulo Oliveira, Idir Arab

We characterize the family of Beta random variables with respect to the convex transform order, obtaining a full description of the comparability. As an application, we prove that the probability of a Beta random variable exceeding its mean has reversed monotonicity with respect to each of the parameters. An analogue of Jensen's inequality also allows to describe the behaviour of exceedances with respect to the mode.

3 - Properties of a new ageing class
Idir Arab, Tommaso Lando, Paulo Oliveira

We study a family of distributions characterized by the convexity of their odds function, or equivalently by the increasingness of their corresponding odds rate (IOR), showing that this is a necessary condition for the increasing hazard rate property (IHR) and coherent with the notion of "adverse aging", in other words, the class of IOR distributions is larger than the one of IHR distributions. We prove some preservation properties of this class under several transformations that are often considered in reliability and life testing problems, including the formation of order statistics. Moreover, the IOR assumption enables the derivation of survival bounds and tolerance limits, extending the scope of applicability of some known results for IHR distributions.

4 - Risk and reward-based schedule optimisation for underground mining
Fanie Terblanche

Traditional underground mine planning involves the scheduling of mining activities to derive the most economical value, while satisfying constraints related to resource availability and infrastructure capacity. Advances in computing technology and algorithmic approaches paved the way for optimisation of large-scale underground mining operations, which brought the mining community closer to the ideal of having on-demand decision support. In addition, the emergence of enterprise platforms allows for the amalgamation of enterprise-wide data and the ability to consume the data for advanced analytics and data-driven decision-making. There is, however, still too much focus on the reward-side of the decision-making process and not enough consideration for a risk-based approach. In this paper, a risk and reward-based optimisation approach is proposed, which incorporates elements of detailed operational decision-making with the ability to determine an acceptable trade-off between risk and return. Computational results are based on simulated data based on mining characteristics of a typical deep level South African mining operation.

■ WB-17
Wednesday, 10:30-12:00 - U356

AI in South African Economic Development

Stream: OR for Development and Developing Countries
Invited session
Chair: *Gordon Dash*
Chair: *Simanti Bandyopadhyay*

1 - AI Infused FinTech: Achieving National Sustainability for South African SMEs
Amos Mpofu, Helper Zhou, Gordon Dash, Nina Kajiji

Small and Medium Enterprises (SME) sustainability approaches for investment and growth are a key result area for progressive governments worldwide, especially for those operating in developing regions like Africa. However, SMEs in countries like South Africa continue experiencing a high failure rate within their first year of operation. There is a need for artificially intelligent mechanisms to diagnose, predict, and manage the key performance drivers of SME success. Our studies focusing on South Africa established that the fundamental driver behind the continued failure rate in the SME sector is the lack of efficient decision-making tools to assist owners in optimizing the deployment of their limited resources. To address this end, we developed an Artificial intelligence application, Exponento, to intercept this challenge. Application Programming Interfaces (APIs) are designed to auto harvest data from both local and external sources. Radial Basis Artificial Neural Networks (K4-RANN) and Support Vector Machines (SVM) are deployed to predict SMEs' sales and growth. The app enables business owners to access and attend to their real-time challenges requiring urgent attention while providing other stakeholders with insights on the health of the overall SME sector. Real-time data is also available to assess the impact of interventions received to address problem areas to improve SME sustainable performance.

2 - A Radial Basis Function Approach to Corporate Distress Modelling in Zimbabwe
Louisa Muparuri, Nina Kajiji, Gordon Dash, Victor Gumbo

Zimbabwe was once a thriving economy and considered Africa's food basket. However, years of industrial mismanagement, food shortages, a collapsed currency, rampant corruption, and hyperinflation have led to an economic collapse. While the new government has made significant in-roads in economic recovery, the continued drought and now COVID-19 have delayed the economic progress. Corporations are still faced with financial distress and the possibility of closure. This research is premised on prior work by the authors in filling knowledge gaps in distress modeling in underdeveloped nations like Zimbabwe. Specifically, we use a Bayesian enhanced regularised radial basis function neural network (K4-RANN) to determine the importance (or weight) of each feature for determining the probability of corporate distress. Annual financial data from 2014 to 2021 was obtained for the 61 companies listed on the Zimbabwe Stock Exchange. Akaike Information Criterion (AIC) and the MSE were used to establish model performance. The results show that the K4-RANN model had a 99.28% measure of R-squared while AIC was -2292.54, suggestive of a good learning algorithm. The total assets to debt ratio reported the largest contribution towards distress while debt to equity has the smallest contribution. This research will be invaluable to policymakers in various capacities such as governments, corporates, investors as they seek to predict the financial health of institutions thus thwarting a crisis.

3 - Efficient Shallow Neural Network Methods for Mapping the Determinants of SMME Performance
Helper Zhou, Gordon Dash, Nina Kajiji

Various studies have been carried out to establish the key drivers impacting small enterprise performance in developing countries. Despite many policy-oriented studies to uncover the structure of SMME performance in emerging markets, SMMEs continue to demonstrate lagging performance. Guided by a history of linear- and log-linear econometric model estimation that ignores potential network effects, our study extends the literature by implicating SMME performance as a production network. Using an enhanced Radial Basis Function Artificial Neural Network (i.e., K4-RANN), performance (factor) elasticity coefficients are derived from the estimated nonlinear regression weights. We find urban-based SMMEs experience negative elasticity compared to their rural counterparts. Further, this study provides detailed evidence of how gender impacts SMME performance. A confirmatory analysis was conducted to establish how SMMEs are aware of the impact (magnitude) and effect (positive/negative) of the specified performance factors. Generally, we confirmed that SMME owners in South Africa's KwaZulu Natal province are not aware of the relative importance of key performance factors on their enterprises.

4 - AI Universal Approximation with Big Data to Model Bond Volatility Spillovers between SALT States and the South African Government Bond Market

Gordon Dash, Nina Kajiji, Domenic Vonella

Under the Africa Growth and Opportunity Act (AGOA), South Africa (SA), an emerging market economy, recorded substantial exports. However, the recent political agenda could lead to a weakened AGOA, thus undermining SA financial stability and possibly propagate financial contagion between SA and U.S. capital markets. The identification of any volatility spillover effects is made more convoluted by the persistence of the COVID-19 pandemic. This paper studies the network effect of volatility spillover transmission to the State and Local Tax (SALT) impacted municipal bond markets from the South African government bond market. Spillovers and financial contagion are attributed to the government bond market of SA, the trade of precious metals, and the sovereign effects of COVID-19. In our research study, we implicate over 3.8 million state-level municipal bond trades. We then examine COVID-19's shock to spillover transmission among impacted states using a supervised machine learning algorithm to map international volatility transmission into U.S. states. Preliminary results provide insights into SA volatility transmission's negative contribution into SALT states where the impact of the Tax Cuts and Jobs Act (TCJA) of 2017 was most felt. The states with moderate impact on personal income from TCJA exhibit a significant variation in spillover transmission and COVID-19 shock. Broadly, these states are geographically located in the south or mid-east part of the U.S.

■ WB-18

Wednesday, 10:30-12:00 - U358

Cutting and packing session 2

Stream: Cutting and Packing
Invited session
Chair: *Célia Paquay*

1 - A mathematical formulation for a Capacitated Vehicle Routing Problem with pickups, Time Windows and 3D packing constraints

Emeline Leloup, Célia Paquay, Thierry Pironet

Service providers have to respond to the growing demand from their customers, who offer increasingly widespread e-commerce services. Since the collection and delivery locations may be geographically spread, the route is carried out over two days: on the first day, the collection of the boxes, and on the second day, their delivery. While the last-mile delivery was intensively studied lately, the first-mile pickup, which corresponds to the first movement of the goods within the supply chain, has received less attention. Given the increasing number of parcels being transported, the packing plan is crucial. Thus, we face the 3D loading problem combined with the Capacitated Vehicle Routing Problem with Time Windows. Moreover, we consider the possibility to perform split pickups and to outsource some customers' requests. In this work, we aim to minimise the transportation and outsourcing costs while deciding (1) which vehicles will leave the depot and for those determine a route, a schedule, and successive packing plans, and (2) which customers to outsource. We developed a mathematical formulation with routing, time, and packing constraints (namely, geometric, vertical stability, orientation, fragility, and multi-load). Our next step, as the problem can be decomposed by nature, is to develop a constructive matheuristic such as an Insert-and-Fix.

2 - Lexicographic optimization for the multi-container loading problem with open dimensions

Manuel V. C. Vieira, Margarida Carvalho

Motivated by a real-world application, we present a multi-container loading problem with 3-open dimensions. We formulate it as a biobjective mixed-integer nonlinear program with lexicographic objectives in order to reflect the decision maker optimization priorities. The first objective is to minimize the number of containers, while the second objective is to minimize the volume of those containers. We present a heuristic that solves smaller linear mixed-integer programs. This algorithm is specifically tailored for the real-world application. The effectiveness and efficiency of the devised heuristics is demonstrated with numerical experiments.

3 - A Machine Learning approach for 3D Load Feasibility prediction

Ruggiero Seccia, Sarah de Wolf, Leendert Kok, Neil Yorke-Smith

When solving Vehicle routing problems (VRP), computed routes must be checked for feasibility. Among the feasibility checks to perform, we need to guarantee that all assigned products fit inside the truck (load plan feasibility). This involves solving a 3D Container Loading Problems (3D-CLP).

Since the check of load plan feasibility is performed frequently, a short computational time is important. Hence, this feasibility check is usually performed using approximation methods. However, if these approximations are conservative, the obtained routes are inefficient routes; if the approximations are opportunistic, the resulting load plans can turn out to be infeasible.

In this ongoing work, we explore to what extent supervised Machine Learning (ML) methods can be used to rapidly yet accurately classify whether load plans will be feasible or not. These predictions can then be exploited in VRP algorithms to improve efficiency and computation time.

Several ML methods are considered and benchmarked on synthetic data and real data from a major company in the beverage sector. Extended experiments in different settings are performed to check the effectiveness of ML in providing reliable load plan estimations and to extract insights on how load plan characteristics affect load feasibility. Preliminary results suggest the effectiveness of applying ML models, with random forest models reaching an accuracy above 93% on all different experiments considered.

4 - Loading Kitchens into Trailers: A Local Search Matheuristic

Jakob Schulte, Michael Römer, Kevin Tierney

We address a real-world single container loading problem (SCLP), arising from a large kitchen manufacturer involving packing sets of boxes containing partially assembled kitchen parts into a trailer. The boxes to be loaded into a trailer are considered as given, and thus, the task considered here is to check if they fit into the trailer or not, taking into account that all packages of a customer (a kitchen retailer) must always be loaded together and must not be spread over the entire loading area. In our work, we consider practically relevant features such as box orientation, package support and that the boxes must be delivered in different places (multi-stop). We present a novel local search matheuristic relying on a wall building approach. We decompose the problem into many small subproblems using a local search strategy and solve these subproblems with a MIP solver. In that context, it is crucial that subproblems are chosen small enough to be solved quickly by a solver, but at the same time consider a sufficiently large part of the solution space to guarantee high-quality solutions. The matheuristic is particularly characterized by the fact that information from the box structure is used to insert meaningful cuts and constraints, which significantly improve the speed of the solver. We show the performance of the algorithm on both benchmarks and real world instances provided by the kitchen manufacturer.

■ WB-19

Wednesday, 10:30-12:00 - Y228a

Queueing systems for services 2

Stream: Performance Evaluation of Queues
Invited session
Chair: Dennis Schol

1 - Bidding for initial level of priority in accumulating priority queue
Elisheva Zur, Binyamin Oz

We consider an unobservable accumulating priority M/G/1 queue with predetermined accumulation rates while customers bid for their initial level of priority. In particular, the instantaneous priority level of a customer present in the queue is an affine function of the time elapsed since his arrival. The slope of this accumulation function is given, while the intercept is determined by a payment of his choice, made upon arrival and without observing the queue. We show that, in contrast to other priority purchasing models, a pure equilibrium may does not exist. We further explore the best response function against an arbitrary symmetric pure strategy profile and motivate a conjecture that the unique equilibrium strategy is a mixture of zero, and some positive initial priority level.

2 - Charging more for priority via two-part tariff for accumulating priorities
Binyamin Oz, Shir Moshe

We consider an unobservable M/G/1 queue with accumulating priorities and strategic customers who bid for priority accumulation rates. We show that when affine pricing is introduced, multiple equilibria may exist. This is in contrast to the standard linear pricing case where the equilibrium bidding strategy is unique. Furthermore, a revenue-maximizing operator may generate more revenue under the optimal affine pricing than under linear pricing. In particular, we show that if the utilization level is not too high, no other combination of a priority scheme and pricing generates more revenue than the optimal affine pricing of accumulating priorities.

3 - Estimating customer delay and tardiness parameters from periodic queue length observations
Liron Ravner, Jiesen Wang

A single server commences its service at time zero every day. A random number of customers decide when to arrive to the system so as to minimize linear waiting time and tardiness costs. Each customer's optimal arrival time depends on the others' decisions, thus the resulting strategy is a Nash equilibrium. This work considers the estimation of the ratio between the waiting time and tardiness cost parameters from queue length data observed daily at discrete time points, given that customers use a Nash equilibrium arrival strategy. A method of moments estimator is constructed from the equilibrium conditions. Remarkably, the method does not require estimation of the Nash equilibrium arrival strategy itself, or even an accurate estimate of its support. The estimator is strongly consistent and the estimation error is asymptotically normal. Moreover, the asymptotic variance of the estimation error as a function of the queue length covariance matrix (at sampling times) is derived. The estimator performance is demonstrated through simulations, and is shown to be robust to the number of sampling instants each day.

4 - Extreme-value theory for large fork-join queues, with an application to high-tech supply chains
Dennis Schol, Mirjam Meijer, Maria Vlasiou, Bert Zwart, Willem van Jaarsveld

We study extreme values in fork-join queueing networks: consider N identical queues with a common arrival process and independent service processes. All arrival and service processes are deterministic with random perturbations following Brownian motions. We prove a convergence result for the maximum queue length in this fork-join queue as the number of queues N goes to infinity. We explore repercussions of this result for original equipment manufacturers (OEMs) that assemble a large number of components, each produced using specialized equipment, into complex systems. Component production capacity is subject to fluctuations, causing high risk of shortages of at least one component, which results in costly system production delays. OEMs hedge this risk by investing in a combination of excess production capacity and component inventories. We formulate a stylized model of the OEM that enables us to study the resulting trade-off between shortage risk, inventory costs, and capacity costs. Our asymptotic extreme value results translate into asymptotically exact methods for cost-optimal inventory and capacity decisions, some of which are in closed form. We validate our asymptotic results with a set of detailed numerical experiments. These experiments indicate that our results are asymptotically exact, while for transient times they depend on model parameters.

■ WB-20

Wednesday, 10:30-12:00 - Y228b

Dynamical Systems and Mathematical Modeling 1

Stream: Dynamical Systems and Mathematical Modeling in OR
Invited session
Chair: Gerhard-Wilhelm Weber
Chair: *Emel Savku*

1 - Equilibrium and stability in imperfect competition
Nora Grisáková

Our aim is an extension of classical and well-known models of duopoly - Cournot and Bertrand duopoly models, by the third company on the market under the assumption of partially differentiated production of the companies. We create a mixed models of triopoly (Cournot-Bertrand and Bertrand-Cournot models), by which we approach theoretical models to the real situation on the chosen market. Since companies adjust their decisions in the time, we assumed in this work different companies expectations about the future. The aim of this work is also verifying the stability of founded equilibria under pure strategies. In last model we assume, that two companies created a cartel against the last one. As a practical application of analyzed models we selected the mobile phone network operators market in Slovakia in the time, when a new mobile operator came on the market. The result of our research is derivation of general equilibrium for Cournot, Bertrand, mixed strategies, strategy with cartel and derivation conditions for stability in Cournot and Bertrand strategies. The results are verified on the basis of the analysis of scenarios of possible changes in the starting model parameters and applications on the market of mobile phone network operators.

2 - Principal-Agent Problem in Dynamic Context
Mustafa Akan

The objective is to analyze the principal-agent problem concerning the investment behavior of the agent in the dynamic context using Optimal Control Theory. Two models were considered: 1. An agent has a contract with the firm for infinite horizon. The result was that the agent in a small firm would invest heavily in the Productive Capacity (PC) of the firm and gradually decrease it to the long-term equilibrium level while increasing the PC up to its long-term level. An agent will put more effort into the firm if his bonus high. Increasing the fixed salary will have a smaller but similar impact. However, his efforts will be always less than the efforts the shareholders would put into the firm if they were making decisions themselves. An opposite behavior will prevail if the firm was large. 2. An agent has a fixed duration contract with the firm. An agent working in a small firm will begin to put a high effort (higher than amortization of PC) at the beginning thus increasing the PC and begin to reduce his effort until he reaches the point where his effort is equal to the amortization of PC and then he continues to decrease his effort until both the effort and the PC of the firm vanishes at time T. The general conclusions of this study are: First, there is no optimal incentive (profit sharing ratio) or fixed salary to synchronize the objectives of the shareholders and the agent. Second, shareholders should always sign a fixed-long term contract with the agent.

3 - Equivalent formulations of optimal control problems with maximum cost and applications
Emilio Molina, Alain Rapaport, Hector Ramirez
We consider the optimal control problem which consists in minimizing the maximum over a time interval of a scalar function. This problem is not in the usual Mayer, Lagrange or Bolza forms of the optimal control theory, and thus does not allow to use directly numerical software based on direct or Hamilton-Jacobi Bellman methods.

In this talk I will present several reformulations of this problem in Mayer form and I will illustrate its application in some examples, one of them, minimization of the peak of infected on a SIR dynamic motivated by the covid-19 context.

4 - An Application of Stochastic Differential Games with Lagrange multiplier: Bancassurance
Emel Savku
We develop an approach for a two player constrained nonzero-sum stochastic differential game, which is modeled by Markov regime-switching jump-diffusion processes. We provide the relations between a usual stochastic optimal control setting and a Lagrangian method. In this context, we prove the corresponding theorems for two different type of constraints, which lead us to find real valued and stochastic Lagrange multipliers, respectively. Then, we illustrate our results for an example of cooperation between a bank and an insurance company, which is a popular, well-known business agreement type called Bancassurance. We developed a Nash equilibrium for this game and solved the adjoint equations explicitly for each state. By our formulation, we provide an insight to both of the bank and the insurance company about their best moves in a bancassurance commitment under specified technical conditions.

■ WB-21

Wednesday, 10:30-12:00 - Y229a

Methodological considerations

Stream: Behavioural OR
Invited session
Chair: Stephan Onggo

1 - Target-oriented utility, rank and status
Jeffrey Keisler
Target-oriented utility (TOU) functions equate a utility function for a variable to the probability that its value will exceed a target value drawn from a random distribution. We can apply this to a context where individuals are paired at random and the higher performing party receives a reward, so that an individual's expected utility for performance is based on the distribution of the others' performance. This allows us to apply machinery of TOU across a range of social and societal situations by varying the specification of who and what are compared.

2 - Spatial decision analysis under incomplete preference information
Mikko Harju, Juuso Liesiö, Kai Virtanen

Decision alternatives with geographically varying consequences can be compared with spatial value functions. However, determining such a function is difficult in practice since each location within a given geographical region must be taken into consideration. We consider approaches for comparing spatial alternatives based on incomplete preference information, which does not require precise specification of the relative importance of each geographical location. The approaches considered include the identification of non-dominated alternatives, the utilisation of decision rules, and the fitting of a value function to the available preference information. In each case, the region under consideration is partitioned into subregions. Then, the importance of each subregion as a whole and the relative importance of the locations within the subregion are considered. We also discuss a simulation study concerning the approaches. In this study, the elicitation of preference information from a decision maker is analysed in order to advance guidelines for efficiently representing the decision maker's preferences.

3 - An agent-based model to investigate how different agent behaviors affect a crowd
Carolina Crespi, Georgia Fargetta, Mario F. Pavone, Rocco Alessandro Scollo

Simulating crowd behaviors has become one of the most important topics, especially in emergency management in which, most of the time, we do not have enough information or real data to understand what will happen or to prevent fatalities. In the literature, there are several model crowd behavior, each of which focuses on different aspects of the problem, depending on the specific framework used. In this work, we present a hybrid crowd evacuation model in which we have merged macroscopic and microscopic study methods. In particular, we have realized an agent-based model in which the agents must find a specified safe location, starting from a chosen point, in a planar graph. The crowd is composed of two different kinds of agents: collaboratives that act helping others and defectors that act individually. The aim is to understand if and how the presence of defector agents may influence the behavior of the crowd. We have considered the number of agents evacuated, the path cost, and the evacuation times as evaluation metrics.

4 - GAM: Behaviour elicitation using games for agent-based simulation
Stephan Onggo

Games can be used to generate insights about human behaviours and perceptions in an engaging environment. Therefore, games have been used to elicit agents' behaviours in agent-based models. In this talk, we will review existing research that combines games with agent-based modelling. We have identified six ways in which they have been used in empirical studies. We propose to refer to the combination of games and agent-based modelling as GAM which stands for Games and Agent-based Models. In the seemingly lack of guidance about how and when to use a specific combination, we hope that the finding from our review could inform and inspire both novices and experienced researchers in choosing the right GAM design for applied research and improving the current GAM practice. We will end this talk with an example in which we use a role play game to elicit the behaviours of dairy farmers. The game is designed to identify which behaviour that is likely to contribute to the significant decline in the dairy production in West Java Indonesia. During this research we interviewed 153 farmers and 24 of them participated in the game. Our analysis shows that the data obtained from the game are valuable for the validation of agent-based models at the micro-level and, subsequently, improve the validity of the model at the macro-level.

■ WB-22

Wednesday, 10:30-12:00 - Y229c

Supply chain management

Stream: Supply Chain Management
Invited session
Chair: Franco Basso

1 - Dynamic Lot-Sizing with Financing Options and External Deposits in a Two-Stage Supply Chain
Oussama Kajjoune, Tarik Aouam, Tarik Zouadi

Dynamic lot-sizing has typically been studied in the context of optimizing the physical flow of goods to minimize supply chain costs, assuming there is always enough cash to finance operations. In practice, however, companies also need to manage cash flows and ensure that the supply chain is financially viable. We consider a supply chain with two capital-constrained firms, a supplier and manufacturer, and present a novel model to jointly optimize lot sizing and cash flows, which are both dependent on financial decisions and constraints. Our model determines the optimal quantities to supply or produce, the initial endowment and short-term amounts to borrow, the capital to subscribe from shareholders, and the deposits to invest, while satisfying operational and financial constraints. The objective is to maximize the total discounted external deposits net of capital subscriptions throughout the planning horizon. Structural properties of the optimal solution are derived, and a dynamic programming algorithm is developed to solve the problem. Through numerical experiments, we analyse the value of coordinating supplier and manufacturer decisions and study the effect of financial and operational parameters on the optimal operational and financial plans.

2 - Horizontal collaboration in the wine supply chain planning: A Chilean case study
Franco Basso, Guillermo Ibarra, Raul Pezoa, Mauricio Varas

The wine industry faces a highly competitive environment, making cost-effective management of the wine supply chain essential. Literature has shown that this objective can be achieved with the implementation of horizontal collaboration strategies in logistics. In this strategy, firms located at the same level of the supply chain cooperate to reduce costs, improve quality of service and mitigate environmental externalities. This paper analyses the implementation impacts of a horizontal collaboration policy in the wine supply chain. To do so, we propose a cooperative game with transferable costs, in which the characteristic function is obtained by solving a novel linear programming formulation that models the joint planning of the wine supply chain. To evaluate the benefits of collaboration, we conduct a case study involving three of Chile's largest wineries. The results show that the use of collaborative frameworks leads to significant reductions in the logistics costs of the wine supply chain. Furthermore, we find that the grand coalition reduces the costs by 9.83% compared to the non-collaborative case. This reduction comes mainly from a decrease in the bulk wine inventory cost.

3 - Sustainable Blood Supply Chain Network Optimization
Ana Torrado, Ana Paula Barbosa-Póvoa

A location-allocation problem involving healthcare facilities with blood services and related institutions is studied. An integrated multi-objective and mixed-integer linear programming model is proposed aiming to achieve strategic and tactical planning of the Blood Supply Chain (BSC) network. Firstly, and under a deterministic demand, geographical distribution for donors/patients is considered allowing the definition of supply/demand allocation of facilities as well as product flow calculations. Next, the model is extended to consider demand as an uncertain parameter. The objective functions consider a sustainable mindset, namely by addressing the minimization of transportation costs and the blood product loss costs. The application of the proposed model is demonstrated with a Portuguese case study with the respective scenarios. The results are analyzed, discussed and some conclusions are drawn.

■ WB-23

Wednesday, 10:30-12:00 - Y307

Additional educational activities for OR-Analytics - the link to Development 2

Stream: Additional educational activities for OR-Analytics - the link to Development
Invited session
Chair: Jinal Parikh
Chair: Gerhard-Wilhelm Weber
Chair: Simanti Bandyopadhyay

1 - From academia to industry
Maria Alejandra Castellini, Melany Ángeles Segarra Marinetti, Hernán Van Straaten

In this contribution, we present our trajectory from academia to industry, based on interdisciplinary experiences from the year 2000 to date. With the intervention of researchers, industrial engineers, chemists, economists, systems analysts and students in the last years of their respective university degrees, around 100 small organizations were assisted, collaborating in their decision-making processes to face problematic situations of different complexity. The teams worked, in the 1st decade, as analysts, studying the situations to improve in organizations through the application of Hard Operational Research models, Process and Organizations Management Tools, which allowed the approach of specific problems. In the last decade, the teams have worked as facilitators together with the stakeholders of the organizations, with a multi-methodological approach, based on Soft Operational Research tools, combining different methodologies, or part of them, in order to systematically address the problematic situations of the organizations. This evolution in the methodology of multidisciplinary intervention in small organizations has contributed, on the one hand, to the teaching-learning process by facing real problems, together with advanced students and researchers in training. On the other hand, it allows a comprehensive diagnosis of the organizations and the prioritization of the different situations to be resolved.

2 - Human Capital Formation, Employability and COVID 19: Insights from Indian Higher Educational Institutions
Simanti Bandyopadhyay, Aishna Sharma, Tushar Bhageria

We offer a framework to estimate human capital formation and employability through performances of Higher Educational Institutions (HEIs) and also assess the loss of human capital formation and employability in India due to COVID. Using Data Envelopment Analysis on the data published by National Institutional Ranking Framework for the years 2019-20 and 2020-21, the paper addresses the following questions: How efficiently can HEIs create human capital and employability? Are they more capable in utilizing resources to produce a targeted level of human capital and employability or in expanding human capital and employability with a given level of resources? How do performances of HEIs in generating human capital and employability vary across their locations, ownerships, specialisations in courses offered and age? How has Covid-19 impacted human capital formation and employability in India? We find that ownerships of HEIs, adaptability to changes, state of the art curriculum, innovation in pedagogy and investment in IT infrastructure impact overall performances. The loss of human capital formation and employability increased after COVID by 6 percentage points. In both the time periods, HEIs located in Southern region perform the best; loss of human capital formation and employability is higher in public HEIs; HEIs offering professional courses face higher losses as compared to those offering non-professional courses; young HEIs perform worse than the old.

3 - Collaborative Learning Strategy and Anticipation Reaction Guide in the Performance of Tertiary Students in Calculus
Milagros Baldemor

Collaborative Learning as an approaches involves the joint intellectual efforts of students, or students and teacher organizing them from a small group or a bigger one to maximize their own learning and each other's learning. The anticipation-reaction guide is a pre and post instructional technique in a tabular form which serves as the teacher's tool to assess and identify the knowledge on what the students know about the topic to be discussed. It was found out that: The experimental group had varied learning styles, They are dominated by auditory learners. The group had a favorable attitude towards Calculus. Most of the respondents performed low in Differential Calculus. On the other hand, there are more auditory learners in the control group compared with the rest who differ in learning styles. The group has positive attitude towards Calculus. In addition, most of the respondents performed low in Differential Calculus. The collaborative learning strategy and the anticipation-reaction guide enhanced the performance of the experimental group as compared with the performance of the control group. Both groups improved in their performance after the experiment. Learning styles has no influence to the performance of both groups. Performance in Integral Calculus exists not considering their learning styles. Grades in Differential Calculus influenced the performance of the two groups.The collaborative learning strategy and A-R Guide enhanced the respondent's performance.

■ WB-24

Wednesday, 10:30-12:00 - Y307a

Innovations in Retail Distribution

Stream: Demand and Supply in Consumer Goods and Retail
Invited session
Chair: Christian Fikar

1 - Sustainable Distribution in Alternative Food Networks: Evaluating the Potential of Crowd Logistics
Florian Cramer, Christian Fikar

Crowd logistics is a mostly unexplored concept to facilitate efficient deliveries in short food supply chains (SFSC). By employing agent-based modelling combined with elements from discrete event simulation, various crowd logistics scenarios for local food providers are explored in this work. Demographical data from Bavaria, Germany, such as population structure, employment rates, and available data on alternative food outlets, such as farmers' markets and farm shops, act as input. The computational experiments explore four settings: (i) a base scenario without any crowd logistics activity, (ii) a crowd logistics scenario, where shoppers at outlets are participating as occasional drivers (ODs), (iii) a crowd logistics scenario, where also non-shoppers participate as ODs, and (iv) a scenario that additionally considers the effect of introducing mobile transhipment nodes. The effect of changing the willingness to participate as ODs on an increase in market reach, food miles, and food waste is studied. Results show, among others, that by introducing mobile transhipment nodes, both the number of participating ODs and farmers' market reach can be increased with the additional benefit of providing intermediate cold storage options for perishables to facilitate a reduction in food waste.

2 - Fleet planning and demand-based pricing for Attended Home Delivery
Daniela Fernandes

Many firms have adopted Attended Home Deliveries (AHD), which require the retailer and the customer to agree on a delivery time window. Because some delivery times are more popular than others, lack of demand management leads to significant imbalances and, consequently, the need for dimensioning capacity for peak-load, which is costly or losing customers. Neglecting to plan delivery capacity might further lead to poor service quality. This work tackles the tactical problem of fleet planning under demand influenced by pricing decisions in AHD. The aim is to improve the profitability of online distribution without compromising service quality. Delivery capacity, determined by the fleet, should be aligned with demand, controlled by the delivery fees, so that cost-effective operations can be achieved. In tackling this problem, two major challenges arise: (a) deriving demand as a result of, among other factors, the pricing decisions, and (b) cost and capacity anticipation. To overcome (a) well studied discrete choice and machine learning models are applied in a bottom-up approach. For challenge (b), we explore scenario-based formulations considering a priori or consistent routes embedded as a proxy for capacity and routing costs. In a setup inspired by an industry partner operating in grocery retail, we perform a comprehensive computational study.

3 - A model and Analysis for Smart Parcel Locker Location and Distribution System Design Problem
Sorour Zehtabiyan, Kadir Ertogral

The fast expanding e-commerce market forced managers to improve their delivery operations in each step of the delivery process. The final part of this delivery process is bringing the goods to the doorsteps of the customers and it's called the last-mile delivery. The last mile delivery is a very costly part of the delivery process. A major factor that contributes to this high cost is the lack of economies of scale in last-mile delivery. To address this problem, parcel carrier companies started to use the solution of delivering goods to the nearest smart parcel locker locations to the customers, where customers come and pick up their packages from. This allows parcel carrier companies to eliminate the costs of delivering each packet separately to the doorstep of the customer. Motivated by this problem, we tackle a strategic level problem composed of locating smart parcel lockers, assigning lockers to distribution depots, and deciding the fleet size in the depots. The number of lockers and their locations affect both the amount of demand they serve and the distribution related costs. We propose a mathematical programming model of this problem where the objective is the minimization of sum of the ownership cost of the distribution fleet, locker establishment cost, and an approximate routing cost. We solve the problem with constraint programming heuristic using CPLEX and analyze different scenarios of randomly generated instances that are partly based on a real data.

4 - Single item periodic review inventory control with sales-dependent stochastic return flows
Enis Kayis, Esra Gokbayrak

Retailers have to deal with increasing levels of product returns as the shares of e-commerce sales soars and redesign their processes to manage the returned product flows. We study a retailer's optimal inventory control policy under stochastic product returns to maximize expected profit during a selling season. Returns are assumed to be stochastically dependent on the previous period's sales quantity. We compare the profits of a return-smart retailer who manages its inventory by keeping separate records of sales and returns and following our results and a return-naive retailer who does not track sales explicitly and simply uses the net demand approach. Incorporating sales-dependent returns increases expected profit by 23% on average. We find that this profit improvement percentage is most sensitive to the fixed ordering cost, backorder cost, and return rates. The return-smart retailer considers the possible incoming product returns and orders less frequently (thus saves from the fixed order cost) compared to the return-naive retailer. The latter option leads to lower order-up-to levels which increase backorders as the return rates increase.

■ WB-25

Wednesday, 10:30-12:00 - Y308

Scheduling order picking operations in warehouses

Stream: Warehouse Design, Planning, and Control
Invited session
Chair: Kris Braekers

1 - Order picking problem: Exact and heuristic algorithms for the Generalized Travelling Salesman Problem with geographical overlap between clusters.

Farzaneh Rajabighamchi, Stan Van Hoesel, Christof Defryn

The generalized traveling salesman problem (GTSP) is an extension of the traveling salesman problem (TSP) where the set of nodes is partitioned into clusters, and the salesman must visit exactly one node per cluster. In this research, we apply the definition of the GTSP to anorder picker routing problem with multiple locations per product. As such, each product represents a cluster and its corresponding nodes are the locations at which the product can be retrieved. To pick a certain product item from the warehouse, the picker needs to visit one of these locations during its pick tour. As all products are scattered throughout the warehouse, the product clusters not separated geographically. We propose an exact LP model as well as heuristic and meta-heuristic solution algorithms for the order picking problem with multiple product locations.

2 - An overview study for the development and evaluation of vision guided order picking systems in logistics operations

Nikolaos Chondromatidis, Anastasios Gialos, Vasileios Zeimpekis

The effective fulfilment of customers' requirements is one of the most important challenges for the modern warehouses. To this end, the aim of logistics managers is to design and implement efficient order picking systems in order to tackle customer requests for frequent and low volume order fulfillment as well as the need for faster response times. Over the last years a significant number of order picking technologies has already been developed yet there is still a need for better productivity and accuracy and vision guided order picking systems through smart glasses and augmented reality seems to be a promising technology. The latter is an innovative solution which uses wearable technology and may produce improved performance and perceive workload as compared to current order picking systems. To this end, the aim of this paper is to review a set of factors and performance measurement indices that can be considered for the development and evaluation of vision picking systems by using the Systematic Literature Review approach. Based on the reviewed papers, 27 factors and 3 performance measurement indices were identified and classified into three categories. The first category deals with the design and development of vision guided system, the second category concerns the testing of the performance of the system while, the last encompasses factors which are used for the comparison of vision picking system with other available picking systems.

3 - A data-driven analysis of route deviations in an order picking process

Aïcha Leroy, Kris Braekers, An Caris, Benoît Depaire

Order picking is recognized as the most expensive warehouse operation, especially for picker-to-parts systems in which order pickers travel through the warehouse to collect products following a planned route. In practice, order pickers often deviate from their planned route, leading to what is called maverick picking. A key phenomenon that causes maverick picking is picker blocking. An order picker cannot reach its next destination because another order picker is blocking the path, leading to deviations from the route (e.g., waiting times, alternative paths).

Existing literature has indicated the detrimental effect of picker blocking, and maverick picking in general, on operational performance. Yet, literature lacks a quantitative assessment of these aspects' prevalence in practice. At the same time, individual order picker data is readily available in many warehouses. Therefore, we propose a data-driven approach to quantify the occurence of order picker deviations.

As order picker deviations may manifest in different ways, the aim is to identify both deviations from the planned pick order of items (e.g., locations in a pick aisle were skipped because the aisle was congested) and deviations from the expected times at which picks are performed (e.g., delays due to picker blocking or pickers taking alternative travel paths). First insights based on a large real-life dataset will be presented.

4 - Storage location assignment in warehouses to minimise walking in order picking

Jiyin Liu, Wei Jiang, Yun Dong, Li Wang

Order picking is the costliest activity in distribution warehouses. Appropriate storage location assignment can help reduce the average walking distances in order picking and hence increase efficiency. We study a storage location assignment problem where a product may be placed in multiple storage locations. Order picking is usually done in waves - orders accumulated for certain period are released for picking. We define a correlation matrix to reflect the likelihood for each pair of products to be ordered in the same order picking period. The elements of this correlation matrix are used as weights for the walking distance between the two product locations. The storage location assignment problem is to allocate storage locations to each product so that the weighted sum of distances between the products is minimised. We formulate the problem as a mixed-integer linear programming model. To solve large problems a genetic algorithm (GA) and a basic particle swarm optimisation (PSO) algorithm, are applied. To improve solution quality, a new PSO algorithm based on the problem characteristic is designed and a hybrid algorithm combining it with GA is proposed. Experimental results show that the solutions of these algorithms are close to the optimal solutions for the small-sale problems. For larger problems, the specially designed new PSO greatly improves solution quality as compared to the based algorithms and the hybrid algorithm makes further improvement.

■ WB-27

Wednesday, 10:30-12:00 - Y313

Large scale optimization

Stream: BIGMATH - Mathematics for Big Data
Invited session
Chair: Natasa Krejic

1 - A harmonic framework for stepsize selection in gradient methods

Giulia Ferrandi, Michiel Hochstenbach, Natasa Krejic

We study the use of the harmonic Rayleigh quotient with target for the stepsize selection in gradient methods for nonlinear optimization problems. We show that this stepsize provides a framework to reinterpret existing stepsizes and select new ones. In particular, we analyze the adaptive Barzilai-Borwein stepsize (Zhou et al., 2006) and propose a target-based version of it. While existing stepsizes usually correspond to negative values for the target, positive targets are also considered. We extend the classical convergence analysis for quadratic problems (Dai and Liao, 2002) to these new stepsizes. Numerical experiments on quadratic and generic unconstrained problems show that the introduction of a target may decrease the computational cost of the gradient method alone, or combined with a nonmonotone line search.

2 - Alternating projection approach for cardinality-constrained optimization problems
Natasa Krejic, Marcos Raydan

We consider a continuous reformulation of nonlinear programming problems with cardinality constraints. In particular we are interesting in the case where the feasible set is defined is the intersection of a finite collection of convex sets plus the cardinality constraint. Using a continuous reformulation of the cardinality constraint by a linear constraint and a box constraint plus the Hadamar product we get an approximation of the feasible set that is also easy to project on except the Hadamar product. Therefore an alternating directions projection scheme can be successfully applied. The main method we consider is a low-cost constrained gradient method with a suitable penalization that ensures that the Hadamar product constraint is also satisfied. In particular we consider the portfolio problem with cardinality constraints and application of Dykstra's alternating projections in Spectral Projected Gradient Method.

3 - Non-monotone Line Search in Non-smooth Constrained Optimization Problems
Nataša Krklec Jerinkić, Tijana Ostojić

We consider optimization problems with possibly non-smooth objective function and convex constraints. Finding a descent direction in non-smooth optimization is not an easy task, especially if a large scale problem is at hand. Although possible in some applications, checking the descent property can be a challenging problem itself. Moreover, a search for the descent direction usually employs a subroutine, and finitely many inner iterations may produce non-descent direction. On the other hand, it is known that the line search can be beneficial, even in the non-smooth environment. Thus, non-monotone line search seems to be a suitable choice in this setting and we investigate different strategies within this framework, devoting a special attention to the case where a spectral coefficient is employed.

4 - An Inexact Levenberg-Marquardt Method for Sparse Least Squares Problems
Greta Malaspina

We present an Inexact Levenberg Marquardt method for the solution of large scale sparse least squares problems that arise in Network Adjustment and Localization Problems. Each iteration of classical LM method involves the solution of a linear system which can be prohibitively expensive when the number of variables and residuals is large. The method we propose employs an approximate solution of the linear system computed through a fixed-point strategy that relies on the decomposition of the coefficient matrix into its block diagonal and non-diagonal part, based on the structure of the underlying problem. The resulting method can be effectively applied to solve large sparse problems and it is suitable for parallelization. We present the convergence analysis of the method and we compare the necessary assumptions and the convergence behaviour with those of classical LM. Moreover, we present a set of numerical results for both the sequential and the parallelized version.

■ WB-28

Wednesday, 10:30-12:00 - Y405

Novel Data Mining Methodologies for COVID-19 Data prediction incorporating spatial and socioeconomic information. Session II

Stream: Stochastic Dynamic Programming and Learning Policies
Invited session
Chair: *Javier Cabrera*
Chair: *Michael Katehakis*

1 - Analyzing the impact of COVID-19 on spatio-temporal mobility patterns using mobile device data
Michalis Xyntarakis, Briance Mascarenhas

Urban human mobility and activity patterns are analyzed using smartphone-derived location-based services data during COVID-19. We identify smartphone trips by clustering transient GPS points between point-of-interest (POI) locations such as restaurants and retail stores. The projection pursuit guided tour and high-dimensional visualization algorithms are applied to trip flows between New York and New Jersey neighborhoods to analyze trip patterns during the pandemic. Data Nuggets, a data reduction technique, is used to represent oddly shaped low dimensional clusters. The findings of our case study provide evidence of the impact of COVID restrictions on neighborhood trip flows and POI popularity.

2 - Using fractal analysis to measure the dimensionality of a worldwide dataset for detecting countries with excess COVID deaths
Nuria Diaz-Tena

There is not a consistent method of collecting COVID deaths. Papers show how to detect excess deaths due to the lack of consistency and resources in different countries. The data don't catch everyone whose life was shortened by the pandemic and add other people whose primary reason for dying was not COVID even thought they were COVID positive. The paper will used excess COVID methods to identify the over and under reporting of COVID deaths, check the dimensionality of the data using fractals and identify the main drivers for the excess COVID deaths.

3 - The impact of socio-economic factors and commuter pattern between New York and New Jersey on the spread of COVID-19 cases and deaths
Wenting Wang

Socio-economic factors impact how epidemics spread. We investigated the possible effect of several local socio-economic factors on the case count and time course of confirmed Covid-19 cases and deaths across all New Jersey counties. And we studied the effect of commuter patterns, which provides by smartphone-derived location-based services data, between New York and New Jersey on the spread of disease. Multiple predictive models were applied to study the effect of various socio-economic factors and commuter patterns on the time course of Covid-19 cases and deaths. Our study found that the evolution of the epidemic was influenced by certain socio-economic factors, which could be helpful for the formulation of public health policies. In addition, using data from cellphone locations we will discuss the patterns of commuting and how are they relate to the pandemic transmission from New York to New Jersey.

4 - SEIR Filter: A Stochastic Model of Epidemics
Martin Smid

There are many epidemiological models at hand to cope with the present pandemic; it is, however, difficult to calibrate these models when data are noisy, partial or observed only indirectly. It is also difficult to distinguish relevant data from noise and to distinguish the impact of individual determinants of the epidemic.

In mathematical statistics, the tools to handle all of these phenomena exist; however, they are seldom used for epidemiological models. The goal of this paper is to start filling this gap by proposing a general stochastic epidemiological model, which we call SEIR Filter.

Technically our model is a heterogeneous partially observable vector autoregression model, in which we are able to express closed-form formulas for the distribution of compartments and observations, so both maximum likelihood and least square estimators are analytically tractable. We give conditions for vanishing, explosion and stationary behaviour of the epidemic and we are able to express a closed form-formula for reproduction number.

Finally, we present several examples of the model's application. We construct and estimate an age-cohort model of the COVID-19 pandemic in the Czech Republic. To demonstrate the strengths of the model, we employ it to analyse and compare three vaccination scenarios.

■ WB-29

Wednesday, 10:30-12:00 - M1

Line Balancing

Stream: Industrial Production, Planning and Inventory Management
Invited session
Chair: *Seyyed Ehsan Hashemi Petroodi*

1 - Workload Smoothing and the Robustness of Assembly Line Balancing: A Simulation Analysis
Oncu Hazir, Maher Agi, Jeremy Guerin

We investigate whether workload smoothing has impacts on the robustness of assembly lines. Specifically, we study the relationship between the distribution of the workloads of the workstations and the probability to achieve the target cycle time under several uncertainty scenarios. For this purpose, we conduct simulation and correlation analyses on a diverse assembly line balancing problem set. Our results show that the solutions with even workload distributions are in general less sensitive to deviations in task times. We also test the impacts of several problem characteristics on the correlation results. Our results constitute a basis to develop expert systems that will support to improve assembly line performance in various industries.

2 - Robust optimization for mixed-model assembly line balancing with dynamic task assignment and walking workers
Seyyed Ehsan Hashemi Petroodi, Simon Thevenin, Sergey Kovalev, Alexandre Dolgui

Nowadays, the manufacturing industry faces rapid changes in customer preferences, short life cycles of products, and demand fluctuations. As a result, manufacturers tend to adopt mixed-model assembly lines that produce multiple types of products instead of a single one, and they need these lines to be as flexible as possible to handle market changed. A mixed-model assembly line can enhance its flexibility through dynamic task assignments and walking workers. In such a line, the assignment of tasks and workers to stations change in each takt depending on the product unit entering the line. In this work, we consider the design of a mixed-model assembly line with moving workers and dynamic task assignments, and our objective is to minimize the number of workers and equipment costs. We study the robust optimization problem where we minimize the cost for the worst sequence of products. We formulate the problem as a scenario-based Mixed Integer Linear Programming (MILP). In addition, we propose a simulation-based optimization approach to obtain the most robust solution compared to the one found by MILP for a set of given sequences. Moreover, we develop a local-search algorithm to find the most robust solution faster. Some benchmark instances are solved. The results show that the dynamic task assignment significantly reduces the costs when compared to the model-dependent and classical fixed task assignments which have been studied in our previous papers.

■ WB-30

Wednesday, 10:30-12:00 - M237

Vector and Set Optimization III

Stream: Vector and Set Optimization
Invited session
Chair: *Daniel Dörfler*

1 - On convex polyhedron computations using floating point arithmetic
Andreas Löhne

Convex polyhedra are not necessarily finite sets but they can be finitely represented. Thus they play an important role for various types of set computations, for instance in set optimization. Most of the computational techniques for polyhedra rely in some sense on vertex enumeration, which means to compute the vertices and extremal directions of a polyhedron which is given by (finitely many) linear inequalities. The inverse problem, which is equivalent by polarity, is called convex hull problem. In practice it is quite common to implement vertex enumeration and convex hull methods by using floating point arithmetic. However, in most situations there is no proof of correctness of the methods when inexact arithmetic is used. In particular, there is no correct practicable floating point algorithm known for polytopes of dimension larger than 3.

We demonstrate by examples that inexact computations can produces results which are far away from the correct ones. We present an approximate vertex enumeration method, which is shown to be correct for polytopes of dimension 2 and 3. We discuss why a generalization to any higher dimension is, if possible, not trivial.

2 - Performance Space Supported Design of Analog Electronic Circuits Using Multi-Objective Optimization
Christopher Schneider

In this talk, we present a method for approximating so-called performance spaces of analog electronic circuits. Performance spaces as representations for attainable image spaces of analog electronic circuits are well-suited for supporting their conventional design process. The design task can be formulated as non-convex multi-objective optimization problem. Our approach is based on the well-known Normal Boundary Intersection method for Pareto optimization with modifications to get an approximation of the complete image space of the problem. The thereby resulting models provide accurate information about all valid compromise solutions of the competing circuit performances.

A selection of examples demonstrates how this approach can help analog system designers to make reliable topology decisions, even without detailed knowledge about the underlying circuit. Furthermore, we present a concept for visualizing active constraints on the performance space boundary to directly identify responsible circuit parts.

3 - On unbounded polyhedral convex set optimization problems
Niklas Hey

A polyhedral convex set optimization problem is given by a set-valued objective function which maps from the n-dimensional space to the q-dimensional space where the graph of the objective is a convex polyhedron. In [Löhne, Schrage: 2013] a solution concept for bounded polyhedral convex set optimization problems was introduced: The solution concept is based on two conditions, infimum attainment and minimality. We generalize the solution concept to unbounded polyhedral convex set optimization problems. It can be shown that infimum attainment in the unbounded setting can be obtained analogous to the bounded case by solving a vector linear program. Furthermore we discuss two extensions of the definition of minimality and the problems arising from this extensions.

4 - A notion of polyhedral approximation of unbounded convex sets and its application to convex vector optimization problems
Daniel Dörfler

There are various solution concepts for vector optimization problems in the literature. Given a convex vector optimization problem (CVOP) it is in general only possible to compute an approximation of a solution. One of these approximate solution concepts considers a finite set of weakly efficient points that generate a polyhedral approximation to the so-called upper image, a convex set associated with a given CVOP, in the sense that the Hausdorff distance between the two sets is small. It has recently been established, that approximate solutions to a CVOP exist if and only if it satisfies a condition known as self-boundedness. We investigate the problem of approximating an unbounded convex set by a polyhedron from a geometric perspective and conclude that the Hausdorff distance is inadequate to quantify an approximation error. We further introduce a new notion of polyhedral approximation that is dependent on two parameters and takes the recession cones of the involved sets into account. We show that polyhedral approximations under this notion are suitable to approximate line-free convex sets in the sense that a sequence of polyhedral approximations converges to the set as the parameters tend to zero. We apply this notion to propose an approximate solution concept for CVOPs.

■ WB-31

Wednesday, 10:30-12:00 - M240

Splitting methods in convex optimization III

Stream: Variational analysis and optimization
Invited session
Chair: *Aviv Gibali*

1 - Convergence of an Asynchronous Block-Coordinate Forward-Backward Algorithm for Convex Composite Optimization
Saverio Salzo

In this talk, I will present a study on the convergence properties of a randomized block-coordinate descent algorithm for the minimization of a composite convex objective function, where the block-coordinates are updated asynchronously and randomly according to an arbitrary probability distribution. I will discuss several convergence properties: almost sure convergence of the iterates, general sublinear rate of convergence in expectation, and a linear rate of convergence in expectation under an error bound condition of Tseng type.

2 - Alternating proximal-gradient steps for (stochastic) nonconvex-concave minimax problems
Axel Böhm

Minimax problems have attracted increased interest largely due to advances in machine learning, in particular generative adversarial networks and adversarial learning. These are typically trained using variants of stochastic gradient descent for the two players. Although convex-concave problems are well understood with many efficient solution methods to choose from, theoretical guarantees outside of this setting are sometimes lacking even for the simplest algorithms. In particular, this is the case for alternating gradient descent ascent, where the two agents take turns updating their strategies. To partially close this gap in the literature we prove a novel global convergence rate for the deterministic and stochastic version of this method for finding a critical point in a setting which is not convex-concave.

3 - Strengthened splitting methods for computing resolvents
Francisco Javier Aragón Artacho, Rubén Campoy, Matthew Tam

The resolvent of a monotone operator is an integral building block of many iterative algorithms. In this talk we present a systematic framework for computing the resolvent of the sum of two or more monotone operators which only activates each operator in the sum individually. The key tool in the development of this framework is the notion of the "strengthening" of a set-valued operator, which can be viewed as a type of regularization that preserves computational tractability. We derive various iterative schemes through this framework and demonstrate their applicability in different settings.

■ WB-33

Wednesday, 10:30-12:00 - F102

Game Theory, Solutions and Structures IV

Stream: Game Theory, Solutions and Structures
Invited session
Chair: *Josep Freixas*

1 - Bilevel Optimization Games with a Mixed Measure Space of Agents
Ludovic Julien

In this paper, we consider an extension of the bilevel optimization game in which all agents behave strategically, i.e., a multiple leader-follower game in which the price function is endogenous. The main objective is to study the equilibrium and welfare properties of this model. To this end, we consider an exchange economy with large agents, represented as atoms, and small agents, represented by an atomless part. Within this framework, we define a sequential noncooperative equilibrium concept, namely the Stackelberg-Nash equilibrium. To highlight the main features of the model, we investigate the equilibrium and welfare properties, which we compare with those obtained in the usual bilevel optimization multiple leader-follower game in which the price function is given, an also with the simultaneous move version of the game.

2 - Power indices in cooperative games with supporters and enemies
Xavier Molinero, Fabian Riquelme, Maria Serna

Cooperative games are decision models of players, individuals, or agents that can associate in groups or coalitions to achieve a common goal. A simple game is a cooperative game in which a coalition's benefit is binary, i.e., a coalition can either win or lose. Simple games are monotonous in the sense that if a coalition wins, any superset of that coalition will also win. Voting power or the ability to influence the formation of winning coalitions can be measured through power indices. In simple games, it is assumed that all players vote or decide to join a coalition independently. However, in voting or decision processes, it is common for players to have previous relationships as supporters or enemies. For example, members of the same political party will always vote the same, while two politicians with very different ideologies will always vote differently. In this work, we propose a generalisation of simple games in which additional information about these relationships among players is taken into consideration. We also analyse under which conditions these games lose the property of monotony, and how these relationships affect power indices. We further study the relationship of the games with respect to the structural equilibrium of social network analysis.

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3 - Algorithms for measuring indirect control in corporate networks and effects of divestment
Jochen Staudacher, Linus Olsson, Izabella Stach

This paper discusses algorithms for measuring indirect control in complex corporate shareholding networks and investigates the importance of mutual connections in the network in the sense of shareholdings of one firm in another. Our algorithms rely on the concept of power indices from cooperative game theory. We focus on a variant of the implicit power index by Stach and Mercik based on the absolute Banzhaf index. We extend this algorithm by determining the number of regressions in an adaptive network-dependent manner taking into account the maximal number of predecessors in each controlled company in the network and by a model for the float, i.e. the set of unidentified small shareholders. We compare our method with existing algorithms and discuss the importance of linkages by investigating divestment of shares for a theoretical network with 21 players.

4 - A method of aggregating judges' scores based on the binomial distribution
Josep Freixas

We propose a scoring system based on the binomial distribution to evaluate athletes' performances for some sports as diving, synchronized swimming, figure skating, rhythmic gymnastics, etc. The proposed method has several advantages. It discriminates, is consistent with all its variants, and is sparsely dependent on outliers. It also serves, in turn, to assess how judges judge athletes.

■ WB-35

Wednesday, 10:30-12:00 - T004

Vulnerability and resilience of transportation networks

Stream: Transportation
Invited session
Chair: Marcella Samà

1 - Risk evaluation of real-time Railway Traffic Management solutions under uncertain dwell times
Marcella Samà, Marco Pranzo, Carlo Meloni

While trains travel in railway networks, disturbances may arise and corrective decisions to minimize delay propagation may be necessary to solve conflicting track requests. This problem is known in the literature as the real-time Railway Traffic Management Problem (rtRTMP) and its solutions represent plans of operations that minimize delay propagation due to unexpected disturbances. However, uncertainty may still affect such plans and their expected quality. We propose a new approach for assessing the risk of onset or worsening of delays associated to an rtRTMP solution when dwell times are uncertain and only an interval representation of them is known to the scheduler. To this aim, the Conditional-Value-at-Risk of the maximum train delay is adopted as risk index. We address both modeling and computational issues, developing and testing a graph-based model to use with an innovative numerical method to obtain a real-time risk evaluation for rtRTMP solutions. The proposed approach is applied on a real case study analyzing the effects of uncertainties of different severity. Promising computational results enable to use the methodology to deal with the rtRTMP taking into account the uncertainty on the involved activities and the risk attitude of the decision-makers at operational level.

2 - Solving the train routing selection problem for different rescheduling solution approaches and objective functions
Bianca Pascariu, Marcella Samà, Paola Pellegrini, Andrea D'Ariano, Joaquin Rodriguez, Dario Pacciarelli

The Train Routing Selection Problem (TRSP) is the combinatorial optimization problem of selecting the best train route alternatives, for each train in a rail network. Solving the TRSP aims to limit the number of rerouting variables of the train rescheduling problem, formalized as the real-time Rail Traffic Management Problem (rtRTMP) and intended to minimize train delays. In the TRSP, the benefit of using specific subsets of routes in the rtRTMP is assessed by considering estimations of costs due to scheduling decisions. The impact of TRSP solution on the rtRTMP has been analyzed in the literature by using RECIFE-MILP, a rtRTMP solver based on a MILP model formulation. In this paper, we propose the extension of the TRSP validity for the rtRTMP, regardless the specific model and solution approach used for the rtRTMP, and the objective function optimized. In addition to RECIFE-MILP, we consider for the rtRTMP the decision support system AGLIBRARY, developed at Roma Tre University, which solves an alternative graph model of the problem. We then propose the formulation in the TRSP of a selection of rtRTMP objectives functions, such as the minimization of the cumulative consecutive train delay, the train travel time, the number of delayed trains, and the maximum consecutive delay. We study the extent to which the TRSP effectiveness depends on the correlation between the TRSP and rtRTMP objective functions. The computational analysis is performed on a real case study in France.

3 - Vulnerability of collaborative transport networks under disruptions
Rob Zuidwijk, Camill Harter, Otto Koppius

Collaboration in transport enables efficient use of transport resources operated by different organizations, but extensive collaboration between carriers also comes with dependencies, which can have an adverse impact under disruption. While the synergy potential of collaborative transport is widely addressed in literature, existing transportation research models are less able to capture the dependencies induced by collaboration and the concomitant vulnerability to disruption. We aim to fill this gap by establishing a novel multi-layer network model capturing the functional dependence between the physical transport network, which is impacted by the disruptions, and the network of carrier collaborations, which is being disrupted. The model is applicable to particular instances of collaborative transport networks generated from data or from random graph processes. Using the model on a mix of probabilistic network populations and realized random network instances, we show that market structure, represented by disparity in carrier sizes, has a non-trivial impact on the vulnerability of a collaborative transport network to targeted disruption at the collaborative level, resulting from the interplay between a system's dependence on collaboration and its susceptibility to targeted attack. Networks are most vulnerable if they have intermediate disparity in carrier sizes.

4 - The resilience of airlines during the early phase of the COVID-19 pandemic - a comparative study of airlines' performance in Hong Kong and the U.S. in 2020
Peter Lee, Wai Ming To

Resilience refers to the ability of an organization to cope with the disturbance caused by unexpected events, to stay operational, and to find ways to recover the loss it experiences. As the COVID-19 pandemic is entering the endemic phase in some regions, it is crucial to review and keep track of how airlines responded to the COVID-19 pandemic and how the COVID-19 pandemic influenced airlines performance in different parts of the world in 2020.

The objective of the study is to address the following research question: How resilience of airlines with respect to economic, environmental, and social performance is during the early phase of the COVID-19 pandemic? More specifically, the study aims to compare selected airlines' triple-bottom line performance in these two different regions. The study also discusses whether and how multiple criteria decision making (MCDM) tools such as data envelopment analysis (DEA) can be applied to evaluate the triple-bottom line performance of airlines.

This presentation does not intend to presenting the complete findings of this project. Instead, it primarily shares the project design and preliminary findings in an attempt to gather insights from scholars for further enhancement. We expect the final version of the paper will be finished and submitted to EJOR by the end of 2022.

■ WB-36

Wednesday, 10:30-12:00 - U006

Cancer Screening and Treatment Planning

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: Aurelio Oliveira

1 - Multistage Optimization of the Finnish Colorectal Cancer Screening Programme
Lauri Neuvonen, Mary Dillon, Eeva Vilkkumaa

In Finland, colorectal cancer (CRC) incidence rates have increased over the last decades, and as of 2017, CRC is the sixth most common cause of death. CRC is a crucial concern for the public health of Finland. Screening for CRC is often a multiperiodic process, where participants are screened in, e.g., 2-year intervals. The strategy applied to a single screening period will affect the starting prevalences of the following periods and, thus, the efficiency of later period-specific strategies. Therefore, prescriptive analytics applied to screening should account for effects rising from multiperiodicity. The Finnish program utilises faecal immunochemical testing (FIT) to filter participants for further examination: those whose FIT test result exceeds a cut-off level are invited for e.g., a colonoscopy. At the moment, the cut-off levels are not optimised per period, likely leading to inefficiencies. We apply a multistage optimization framework based on multiobjective influence diagrams to optimize a FIT based 5-period screening program, minimizing cancer prevalence in the total target population with given colonoscopy resources. The results represent optimal period specific FIT cut-off levels and invitation decisions for sex- and age-based target groups, with expected cancer prevalence and additional characteristics. We present a case example based on the Finnish CRC screening program with data found in the literature, and discuss data collection needs for the Finnish program.

2 - Optimization of combinatorial cancer drug-treatment using a large-scale mechanistic model
David R Penas, Christoph Wierling, Yu-Chieh Lin, Max Schelker, Torsten Kroll, Artur Muradyan, Moritz Schütte, Alejandro F. Villaverde, Jos Jonkers, Bodo Lange, Aspasia Ploubidou, Jan Hasenauer, Julio R Banga

Cancer remains a leading cause of death and one of the world's major healthcare challenges. Response to drug-based therapies is hampered by the high genetic heterogeneity and complexity of the disease. As a consequence, most patients do not respond well to pharmacological treatments. In recent years, personalised approaches are being investigated in order to reduce the fraction of patients refractory to drug interventions. The development of individual mechanistic models have been suggested as a key component for designing personalised drug-based therapies. Here we consider the problem of finding optimal interventions in pharmacological treatment of cancer using targeted drug inhibitors. Mathematically, we formulated this problem as a mixed-integer dynamic optimization problem, where the differential equations describing the signalling dynamics act as differential constraints, and where additional requirements (e.g. regarding drug toxicity) can be added as path inequality constraints. Specifically, we developed a computational pipeline to identify the interventions (combinations of drugs, and their concentrations) that optimise a predefined performance index; the latter represents a proxy for the desired therapeutic effect (i.e. inhibition of cell proliferation). The pipeline combined a discrete optimization approach with a large scale mechanistic dynamic model of cellular signal transduction networks, recently developed in the CanPathPro project (www.canpathpro.eu).

3 - Optimization of external beam radiation therapy
Vinicius Jameli Cabrera, Aurelio Oliveira

Teletherapy is a cancer treatment that uses ionizing radiation delivered via a linear accelerator, an instrument that rotates around the patient distributing radiation at every feasible angle. The treatment's goal is to use the smallest dose required to eliminate the tumour while sparing healthy organs. To accomplish this, the linear accelerator incorporates a tool called Multileaf Collimator (MLC), that shapes the format of the radiation field to match the borders of the target tumor. Allen Holder presented a linear programming model for the dosage delivery problem, which calculates the MLC's optimal arrangement for each treatment angle. However, the implemented data to test the model was a single handmade image for each plan. This project aims to validate Holder's model with CT scans of real patients and to introduce solution analysis tools used by medical physicists. Computational tests showed that the current bigger data slows down convergence significantly, and that some treatment plans are not attainable. Furthermore, the tests revealed new model limitations: insufficiency in the model's interpretation of the results, treatment angles unaccounted for, and unfeasible solutions for the MLC. These problems were addressed by using proper analysis routines and implementing new linear constraints that smoothen the resultant MLC's shape. With these major problems fixed, the authors' endeavor to create a specific interior points algorithm for the modified model.

4 - The intertwining of cost structure and prescription pattern: a case study of electronic medical records data mining
Praowpan Tansitpong

The aim of this study is to use data mining techniques to identify prescribing patterns in health care plans, as well as to determine whether variation in health insurance plans and benefits may affect health care treatment. Electronic health records were collected from regional hospitals in Thailand with the prescribing guidelines of the National Public Health Administration. Due to complexity of healthcare management with wide range of drug options and treatment protocols, the costs of treating patients in government-funded programs were significantly higher than with patients in out-of-pocket programs. This study has investigated the variation in benefit plans, which can make a difference in treatment outcomes when multiple options are available. The impact was significant on health service providers' profit margins. The study has showcased how big data and cloud technology can be integrated in practice, and how to support data migration from regional hospital databases to the cloud. By utilizing database technology that can help improve the performance of healthcare-related software, the process can ensure the delivery of healthcare services. The findings suggested that prescribing variability in diagnosed patients and chronic disease symptoms by mapping prescribing patterns were related to choice of brand preference for patients under universal coverage plans in which their healthcare costs was dropped due to government subsidy regulations and constraints.

■ WB-37

Wednesday, 10:30-12:00 - V001

Rich Routing and Logistics in Warehouses

Stream: Vehicle Routing and Logistics
Invited session
Chair: *Maxime Ogier*

1 - Multi-period scheduling for ready-mixed concrete trucks
Imadeddine Aziez, Jean-François Côté, Leandro Coelho

We study the problem of scheduling truck drivers over multiple periods for a ready-mixed concrete (RMC) company. Multiple production plants are available to satisfy the requests of several construction sites. A fixed fleet of heterogenous trucks is available each day to transport RMC from production plants to construction sites. The problem looks for a weekly schedule for drivers that minimizes travel times, waiting duration of trucks at construction sites, and idle durations of drivers. We propose a solution method based on an iterative two-stage approach. For each day and for each driver, we determine the starting working time in stage one, then we optimize the routes in stage two using a framework composed of a large neighborhood search and a local search. We assess our solution approach based on real data from an industrial partner. Computational results show that the proposed solution approach outperforms the approach used by the company.

2 - Minimizing earliness-tardiness costs in supplier networks - A Just-in-time Truck Routing Problem
Julian Baals, Simon Emde, Marcel Turkensteen

We consider a routing problem where orders are transported just-in-time from several suppliers to an original equipment manufacturer (OEM). This implies that shipments cannot be picked up before their release date when they are ready at the supplier and should be delivered as close as possible to their due date to the OEM. Every shipment may have a distinct due date, but all shipments loaded onto the same truck arrive at the same time. The performance of the transportation network is optimized by finding an allocation of shipments to trucks and routes for each truck that minimizes the total earliness-tardiness cost. These penalties are caused by deviations between the truck arrival times at the OEM and the due dates of the loaded shipments. To solve the problem, we introduce a metaheuristic approach based on large neighborhood search, which we combine with an efficient local search scheme that allows the evaluation of neighborhood solutions in worst-case logarithmic time despite the nonlinear objective function. Our algorithm can find high-quality solutions to large instances with 200 shipments in under 23 minutes of CPU time. From a practical perspective, our computational tests indicate that too small a truck fleet or too low a truck capacity can dramatically affect the punctuality of the deliveries.

3 - Integrating order picking and vehicle routing decisions in a dynamic e-commerce setting

Ruben D'Haen, Kris Braekers, Katrien Ramaekers

With the rising importance of e-commerce, companies try to compete by delivering as quickly as possible at the customer's home. After a customer places an order, the requested items first need to be picked in the warehouse. Once the order picking operations are finished, the goods need to be shipped to the customer's location. Nowadays, companies are often scheduling the order picking and delivery operations separately, leading to a fixed cut-off time between both scheduling problems. To shorten the delivery time, this cut-off time may be removed by integrating the problems of order picking and order delivery.

Previous research showed that solving the integrated planning problem can significantly improve operational efficiency. Only few studies exist on this topic, however, and in all of them a static problem setting is considered. Nevertheless, quickly responding to dynamic order arrivals is important to reduce the delivery time even more. While dynamic problems exist for both the order picking and vehicle routing problem separately, such a setting has not yet been considered for the integrated problem.

We propose a new metaheuristic algorithm, to solve the integrated order picking and vehicle routing problem in a dynamic context. This way, new orders are handled with minimal delay, while the operational performance is optimised.

4 - A bin-packing formulation for the joint order batching, picker routing and picker sequencing problem

Maxime Ogier, Olivier Briant, Hadrien Cambazard, Diego Cattaruzza, Nicolas Catusse, Anne-Laure Ladier

Picking is the process of retrieving products from inventory. It is considered the most expensive of warehouse operations. To reduce the picking cost, customer orders can be grouped into batches that are then collected by pickers who travel the shortest possible distance.

A column generation heuristic able to produce lower and upper bounds for the joint batching and routing problem was proposed in the literature. We show that the methodology can be extended to include the sequencing question, i.e. the additional assignment and sequencing of batches for each picker in order to meet the deadlines of the orders. This aspect is currently seen as a scheduling problem in the literature. We take a different view-point and propose a bin-packing formulation. As a result, the time aspect of the problem is considered indirectly with a drastical decrease of the number of needed variables. Moreover, we benefit from a strong family of cutting planes identified for packing problems and known as dual feasible functions. A stronger lower bound of the integrated problem can be therefore derived by adding such cuts in the formulation proposed for the joint batching and routing problem. Additionally, the bin-packing view-point provide new insights to design efficient heuristics.

Optimal solutions are obtained in few seconds for small size instances with thousand of feasible batches. We also provide some results for larger instances with a column generation procedure.

■ WB-38

Wednesday, 10:30-12:00 - V002

Shared Mobility IV

Stream: Shared Mobility
Invited session
Chair: *Josep Maria Salanova Grau*
Chair: *Zisis Maleas*

1 - E-scooter Rebalancing with En Route Charging Capability

Xiangyu Jin, Yufeng Cao, Yu Yang

Electric scooters (e-scooters) have been emerging as a popular means of transport, which are flexible and environmentally friendly to use and provide an alternative solution to the last-mile problem in public transportation. However, the rapid growth of the e-scooter riding demand imposes significant operational challenges, especially with the charging and rebalancing issues. Customers would get upset when they could not find an e-scooter nearby or run into e-scooters out of battery power. Meanwhile, hiring too many workers leads to soaring manual costs. Therefore, the service operators need to find efficient ways to accomplish the work while keeping their customers satisfied. We consider a setting where e-scooters can be charged on a rebalancing vehicle while being transported to other locations. The truck visits a list of sites in sequence, picks up energy-drained e-scooters, and drops off charged ones to meet service levels. E-scooters are charged on the truck en route or while the truck is waiting at each location. We formulated the joint charging and rebalancing problem as a mixed-integer linear program. Fixing the truck route and waiting times, we proved that the resulting problem is an integer program with a totally unimodular coefficient matrix that guarantees the integrality of its solution. We proposed an effective algorithm to solve the problem based on Benders decomposition. Further, we validated the proposed algorithm with extensive numerical experiments.

2 - Smart Charging of Electrical Vehicles: Coordinated energy consumption through a digital platform

Mario Guajardo, Endre Bjørndal, Mette Bjørndal, Jacob Dalton, Elisabet Kjerstad Bøe

With the penetration of electric vehicles (EVs) growing considerably, it is important to understand the implications of different charging mechanisms in the grid operation and in the budget of users. In collaboration with an energy aggregator which has created a fully digital energy platform, we conduct a study analyzing data on EVs charging. Our study is based in Norway, the country with the largest plug-in car segment market share in the world. We first develop an optimization model to compute an ideal scheduling plan. Then, we compare the realized schedules against this ideal solution, distinguishing users who use a smart-charging functionality of the digital platform from those who do not use it. Our findings indicate that the smart-charging behaviour conduces to considerably better results and close to the idealistic optimal solution. Also, the smart-charging strategy usually shifts the charging schedules towards off-peak times, which helps the grid to be less congested.

3 - Design and location of shared mobility infrastructure assets

Josep Maria Salanova Grau, Zisis Maleas, Georgia Ayfantopoulou

During the last decades, more and more cities adopt the scooter sharing systems as a reliable alternative micro-mobility solution that covers various aspects of citizen needs including daily work trips, leisure, or a leg of multimodal trips. The popularity of this mode lies in the simplicity of such services operational scheme, the familiarity of users with mobile apps and online payments, along with a relatively affordable and green solution. However, the free floating (park and pick-up everywhere) application of those services is responsible for undesirable situations both for pedestrians and the operators. To overcome this, public authorities adopt solutions that reform the operational models from free-floating to dock-based (pick up and drop only in predefined stations). This study uses real-world data provided by a company that operates in the municipality of Thessaloniki, Greece to define the optimal location and capacity of the dock-based scooter sharing network. The authors use classical ML methods for trip pattern recognition together with MIP and bioinspired formulations and algorithms to design the network. The intuition behind the models (variables, costs, physical constraints) and an extended experimental analysis also provided. Moreover, this study provides a framework about the way that different companies should operate to ensure that users, even in areas with low profitability, can find available scooters, ensuring thought that companies run in a profitable m

■ WB-39

Wednesday, 10:30-12:00 - U8

MAI: Our Identities: engaging with others

Stream: Making an Impact
Invited session
Chair: *Michele Quattrone*
Chair: *Slawomir Pietrasz*

1 - Share our new identities after the lockdown: recipes for engaging people in the post-Covid reality.
Michele Quattrone, Slawomir Pietrasz, Joaquim Gromicho

What if Covid19 constraint had finally overpowered our communication skills, after all? The covid situation forced us to communicate extensively using teleconferencing systems, and many new opportunities emerged: being able to meet and collaborate with people regardless of their location, being flexible and able to work in non-professional settings... and we have also learned to share more facets of ourselves.

What seemed like a big disadvantage may have brought us to new levels of effective communication and global engagement.

In this inspirational, collaborative MAI session, we will collectively discover and exchange communication recipes, acquired in those difficult times. Be prepared to engage and even surprise other people using conventional and unconventional means!

Wednesday, 12:30-14:00

■ WC-01

Wednesday, 12:30-14:00 - A

Athanasios Yannacopoulos

Stream: Keynotes
Keynote session
Chair: *Immanuel Bomze*

1 - Decision making under model uncertainty with applications in finance and insurance
Athanasios Yannacopoulos

The lack of a single stochastic model compatible with the available data initiates the need for developing robust decision making tools which account for the possibility of multiple stochastic models describing the phenomenon under consideration. Such questions have concerned the scientific community at least since the 1950's (starting by the seminal contributions of Alais and Elsberg) and have led to an important body of research, linked with a number of Nobel prize awards, with highlight the introduction of the robust control formulation of decision making models under uncertainty, using the technique of penalizing models in terms of the Kuhlback-Leibler entropy, by Hansen and Sargent in the turn of the 21st century. The aim of this talk is twofold: (a) To present some recent advances to the theory and applications of robust control for the study of problems in financial and actuarial risk management with concrete examples in portfolio management and pension fund management. (b) Present an alternative framework for quantifying model uncertainty, based on the theory of optimal transportation, by introducing of the concept of the Frechet risk measures or variational utilities and illustrating it in terms of applications in finance and insurance.

■ WC-03

Wednesday, 12:30-14:00 - C

Machine Learning, Mathematical Optimization and Health

Stream: Machine Learning and Mathematical Optimization
Invited session
Chair: *Emilio Carrizosa*

1 - Comparative Analysis of Breast Cancer by Logical Analysis of Data (LAD) and Supervised ML Techniques
Elnaz Gholipour, Béla Vizvári

Breast cancer is the most common type of cancer in the world among women mostly over the age of 50, but there is a good chance to be recovered if detection happens at an early stage. Therefore, the main scope of this study is the comparison of cancer detection by LAD and other ML techniques which all are supervised binary classification methods. The data set of a healthcare system which is under study is composed of three categories "recovered, died and under treatment". There are 1138 patients diagnosed with breast cancer that is grouped as 600 deaths, 187 recovered cases, and 351 under treatment. Cleaning and feature engineering on the dataset creates a normalized and balanced database for further steps of the study. The dead and recovered cases are grouped as the training set of the study while "under-treatment" patients are taken as a test set that is almost 30% of the whole data. The methodology of the study is performed by LAD and other ML binary classification techniques. Two classes are assigned for the dead as 0 and recovered as 1. There are 18 main features and independent variables. The final part of the study classifies the test set in the "dead" or "recovered" category and predicts the tumor as benign or malignant. Comparative analysis of binary classifications is the last part of the conclusion.

2 - Feature selection problem on Breast cancer classification using an Improved Grey wolf optimizer
Preeti Preeti, Kusum Deep

Breast cancer is the most common deadly disease in women worldwide. Extracting the appropriate feature information plays an important role for preventing the disease in early stages. This paper focus on enhanced Grey wolf optimizer wrapper feature selection method for diagnose of breast cancer. Grey wolf optimizer (GWO) is a population based swarm inspired algorithm well known for its superior performance compared to other well establish nature inspired algorithms(NIAs). To achieve a proper comprise between the local and global search process in GWO, a class of random walk called the Levy flights taken from the Levy distribution and a scaling factor are integrated in wolf hunting process. In order to determine the optimum subset of tumor features for accurate identification of benign and malignant tumor, the simulation of Levy Walk Grey Wolf based feature selection (LW-GWO) in combination with K Nearest Neighbor (KNN), Support Vector Machine (SVM), Naïve Bayes (NB), Classifier Tree (CT) and Logistic Regression (LR) is performed. Finding shows that LW-GWO yields better classification results on breast cancer data over GWO. The results indicate that the best accuracy is obtained by LW-GWO using logistic regression (LR) classifier.

3 - Machine Learning in Brain-Computer Interface (BCI): Classifying EEG Signals obtained with Portable Technology
Guadalupe Pascal, Andrés Redchuk

The first applications of brain-computer interface (BCI) systems from electroencephalography signals (EEG) took place in medicine, generating devices capable of solving motor and cognitive disabilities in people with healthy brain capacity. However, BCI presents new developments in the quality of life, alert systems, entertainment, games, experimentation, and learning. Therefore, studying the bridges between the brains and computers is increasingly expansive and exciting. In particular, the emergence of portable EEG devices has made it possible to improve the technology in terms of usability, promoting large-scale research and experimental studies in previously unexplored situations. The main fields of application are education, decision-making processes, health, and quality of life. Recent evidence shows that portable EEG technology supports increasingly applied research, and the methods used are constantly developing. This research aims to develop methods for analyzing and processing EEG signals obtained with portable devices. We compare different algorithms and machine learning techniques to classify signals obtained with the EMOTIV EPOC EEG device with 14 channels.

4 - Deep Learning Models for Pancreatic Cancer Detection in CT Images
Olga Kurasova, Gintautas Dzemyda, Viktor Medvedev, Aušra Šubonienė, Rokas Gipiškis, Kęstutis Strupas, Aistė Gulla, Artūras Samuilis, Džiugas Jagminas

Artificial intelligence-based algorithms are gaining increasing attention in medicine. Applying deep learning models to specific tasks in medicine enhances and simplifies the process compared to human approaches and is very useful for the early detection of diseases. Pancreatic cancer remains a diagnostic challenge since patients present with no or mild symptoms in the early stages of the disease. At present, unfortunately, pancreatic cancer is often diagnosed too late. The reason for this is partly because the pancreas is a small, soft, and flexible abdominal organ that shows high inter-individual anatomical variations in both shape and volume. Given the difficulty of early diagnosis, pancreatic cancer often metastasizes after diagnosis. Computed tomography (CT) is very powerful in diagnosing cancer. Obtained results by applying deep learning methods for pancreatic cancer detection in CT images are promising, however, the accuracy is not sufficient in diagnosing diseases. One of the aims of this study is to investigate the feasibility and effectiveness of deep learning techniques for detecting pancreatic cancer. The focus of the study is to develop a new approach to detecting pancreatic cancer on CT images with more accuracy than current methods allow. Combinations of several CT image databases of patients with confirmed pancreatic cancer are used for model training and testing. The developed approach can be useful to detect pancreatic cancer at an early stage.

■ WC-04

Wednesday, 12:30-14:00 - D

Bayesian Statistical Learning methods

Stream: Machine Learning and Mathematical Optimization
Invited session
Chair: Pepa Ramirez Cobo

1 - Fairness in multiple linear regression: a Bayesian approach
Rafael Jiménez, Emilio Carrizosa, Pepa Ramirez Cobo

In order to avoid discrimination against specific groups of populations, fair machine learning strategies have been considered recently. In this work, a Bayesian tool to obtain fair solutions in multiple linear regression is introduced. In analogous way to Empirical Bayes, the hyper-parameters of the Normal-Gamma prior distribution are selected so that the average posterior predictive difference between sensitive and non-sensitive attributes is less than a required threshold. Our method does not need for individual information regarding the sensitive classes, which may be unavailable for privacy issues. As numerical illustrations show, the method provides a solution that balances between the fairness degree and adequacy of the model to the data.

2 - Revisiting pitch framing using Bayesian Additive Regression Trees
Sameer Deshpande

The advent of high-resolution pitch tracking data (PITCHf/x) has facilitated many quantitative analyses of "pitch framing." Framing refers to the ability of Major League Baseball catchers to catch a pitch in such a way as to increase the chance that the umpire calls the pitch a strike. Multiple analyses, utilizing a range of modeling techniques, all suggest that framing can have an outsize effect, with a good framer able to save his team anywhere on the order of 20 - 50 runs over the course of a season, which can be worth as tens of millions of dollars in contract value.

In this talk, I will revisit one such analysis based on fitting a hierarchical Bayesian model that partially pooled between umpires. That is, in order to predict whether one umpire calls a particular pitch a ball or strike, I "partially pool" predictions about how all of the other umpires would call the same pitch. I will discuss some new refinements to this analysis, focusing, in particular, on new models for the called strike probabilities and the value of a called strike based on Bayesian additive regression trees. The new model discovers new ways to "borrow strength" across umpires and all players involved.

3 - Variational Inference and Sparsity in High-Dimensional Deep Gaussian Mixture Models
Lucas Kock, Nadja Klein, David J. Nott

Gaussian mixture models are a popular tool for model-based clustering, and mixtures of factor analyzers are Gaussian mixture models having parsimonious factor covariance structure for mixture components. There are several recent extensions of mixture of factor analyzers to deep mixtures, where the Gaussian model for the latent factors is replaced by a mixture of factor analyzers. This construction can be iterated to obtain a model with many layers. These deep models are challenging to fit, and we consider Bayesian inference using sparsity priors to further regularize the estimation. A scalable natural gradient variational inference algorithm is developed for fitting the model, and we suggest computationally efficient approaches to the architecture choice using overfitted mixtures where unnecessary components drop out in the estimation. In a number of simulated and two real examples, we demonstrate the versatility of our approach for high-dimensional problems, and demonstrate that the use of sparsity inducing priors can be helpful for obtaining improved clustering results.

■ WC-05

Wednesday, 12:30-14:00 - E

Business Analytics

Stream: Data Driven Decision Making
Invited session
Chair: *Kristof Coussement*
Chair: *Wouter Verbeke*

1 - Actionable Knowledge Discovery and Rule Mining in B2B Churn
Emil Guliyev, Kristof Coussement, Arno De Caigny

B2B enterprises seek to cultivate long-term relationship with customers which highly depends on customer engagement and trust building. It is recognized that the application of attrition models can be helpful to measure the health of business relationship and reduce churn by applying proactive targeting strategies on potential churners. Even if existing churn models help to identify such customers, the results don't directly provide an actionable solution for firms with proactive strategies and it often requires additional step to define preventive remedies on those potential churners. It is gaining more popularity among academic researchers that the paradigm shift from data-driven approach to domain-driven approach could close this gap between the discovery of knowledge from data and the needs of business domain. Actionable Knowledge Discovery is one the concepts that converts the knowledge into the concrete actions and helps firms in better decisions making process. Some researchers have provided Action Rule Mining models which not only provides the probability of churn, but also suggests set of actions that can lead to successful churn preventions. This novel study tests the potential implications of action rule mining in B2B churn context and compares it to traditional churn models. Our results suggest that building actionable churn models could bring more value to enterprises by providing direct retention intervention actions.

2 - The off-policy evaluation of Bayesian contextual bandit strategies in an e-commerce recommender system
Lukas De Kerpel, Dries Benoit

One of the main challenges in training a recommender system for display advertising is the changing nature of consumer behavior over time. Existing strategies try to address this issue by updating the recommendation models in a continuous training loop. However, this introduces algorithmic (or selection) bias, as the newly trained models typically act greedily upon frequently displayed items, thereby failing to explore promising alternative ad campaigns. In order to deal with this exploration-exploitation trade-off, the recommendation problem is formulated as a Bayesian contextual bandit. Bayesian learning establishes a principled approach to enforce exploration by sampling from the posterior distribution of click-through rates of the ad campaigns. As deploying an untested policy in a real-world situation is a risky gamble, an off-policy evaluation mechanism has been set up. This allows to estimate the performance of a new policy without requiring its execution in the online world and hence facilitates the implementation of a comparative study of multiple Bayesian and frequentist bandit algorithms on online advertising data.

3 - Influence in complex networks: Predicting churn in mobile gaming
María Óskarsdóttir, Ragnar Stefánsson, Kristín Eva Gísladóttir, Damian Aleman, Carlos Sarraute

Social networks have been shown to enhance the player experience in online games and to be greatly important for the players who often build complex communities. In online and mobile games, the behavior of players is bursty: they play intensively for a short time and then quit playing all together. Such players are known as churners. In the literature, several attempts have been made at predicting player churn in online and mobile games. The methodology typically depends on engineering representative and useful behavioural features from the games' player logs, and using them as input in supervised machine learning models. Based on our previous research on customer churn in telco, information from social networks provides alternative and significant information when predicting churn. The importance of networks has not been fully researched in mobile gaming. In this research, we study player churn in a mobile game with one-versus-one match-es. We build two types of networks based on how two players are matched and train churn prediction models with features extracted from the networks. Our goal is to evaluate whether information from the two social networks enhances the predictive performance of player churn prediction models. According to our results, there is con-siderable added value of including network variables. The results give an indication of which aspects of game playing are associated with churn and allow us to study influence and social factors in mobile games.

4 - Towards sustainable AI: the power consumption and carbon emissions of common data science
Bjorge Meulemeester, David Martens

Continuous development of AI has brought forth an exponential increase in complexity of AI models. Additionally, data science has become ubiquitous in the private market, and continue to grow in demand. Both of these trends are associated with an increase in power consumption and associated carbon footprint. The increasing carbon footprint of large-scale advanced data science has already received attention, but the latter trend has not. This work aims to estimate the contribution of the increasingly popular common data science to the global carbon footprint. To this end, the power consumption of several common data science tasks will be measured and compared to large-scale "advanced" data science, common computer-related tasks, and everyday non-computer related tasks.

■ WC-06

Wednesday, 12:30-14:00 - U1

Exact methods for combinatorial optimization problems

Stream: Combinatorial Optimization
Invited session
Chair: *Juan A. Mesa*

1 - Mixed-Integer Programming for Combinatorial Coalition Formation Problem
Sebastián Dávila, Martine Labbé, Vladimir Marianov, Fernando Ordonez, Frédéric Semet

Often the companies offer wholesale prices that reduced with a rise of the purchase size. However, the buyers not necessary wish or can buy a large size. Therefore, forming group buyer can improve bargaining power. In this work, we focus on a mathematical model to forming a buyer groups optimally where the products are offers in bundles. Mixed-integer programming for non-increasing price and step price function are presented. To solve large instances, a bender decomposition for step price formulation is proposed. Computational experiments showed the efficient method for synthetic instances.

2 - A renewed formulation for the p-median problem
Agostinho Agra, Cristina Requejo

A formulation for the simple facility location and p-median problems introduced by Cornuéjols, Nemhauser and Wolsey (1980) is revisited. Despite being the smallest known formulation regarding the number of variables, this formulation is barely used in the literature. We reintroduce the formulation for the p-median problem as the intersection of a selection problem with an additional family of optimality constraints to define the costs correctly. By exploring the optimality constraints we discuss approaches to derive bounds for large-size instances. These approaches are based on relaxations obtained by eliminating optimality constraints and can be seen as simple matheuristic to solve large size instances. In particular, we characterize relaxations which provide the optimal solution, and therefore, can be seen as new formulations for the p-medium problem. Additionally, we adapt this formulation for robust p-mediam problems. Computational tests are reported showing that the renewed formulation can be used efficiently to solve p-medium instances.

3 - Exact Methods for Discrete Gamma-Robust Min-Max Problems
Yasmine Beck, Ivana Ljubic, Martin Schmidt

Developing solution methods for mixed-integer bilevel problems is known to be a challenging task - even if all parameters of the problem are exactly known. Many real-world applications of bilevel optimization, however, involve data uncertainty due to some kind of bounded rationality. We study mixed-integer min-max problems with a follower who faces uncertainties regarding the parameters of the lower-level problem. We adopt a flexible robust approach such that the follower only hedges against a subset of deviations in the uncertain parameters. Two approaches are presented to model this type of problem: an extended formulation and a multi-scenario formulation. For both settings, a generic branch-and-cut framework is provided. Moreover, we focus on interdiction problems with a monotone and flexible robust follower to derive problem-tailored cuts, which extend existing techniques that have been proposed for the deterministic case. Extensive computational results are presented for the flexibly robust knapsack interdiction problem to evaluate and compare the performance of the proposed algorithms, which clearly justify both modeling approaches.

4 - The Cent-Dian Network Design Problem
Juan A. Mesa, Victor Bucarey, Martine Labbé, Natividad González-Blanco

Center and Median problems are two classical branches of Location Science. Evolved criteria aim at different features of the facility to be located. This was the main reason for considering a convex combination of the corresponding objective functions, thus leading to balanced solutions. Network design problems consist in choosing vertices and edges from an underlying network to form a subnetwork that will be optimum from a certain point of view. In this work, we extend cent-dian problems to network design. Several variants of cent-dian network design problems are introduced, formulated, and their properties studied. Since this problem is NP-hard, we have studied both, exact methods based on Benders decomposition and GRASP metaheuristics to solve problems at scale.

■ WC-07

Wednesday, 12:30-14:00 - U3

Multi-objective combinatorial optimization #1

Stream: Multiobjective Combinatorial Optimization
Invited session
Chair: *Matthias Ehrgott*

1 - A minimax regret based interactive approach for inverse multiple criteria sorting problem
Ozgur Ozpeynirci, Selin Özpeynirci, Vincent Mousseau

Multiple criteria sorting problem is to assign objects that are evaluated on multiple criteria to ordered classes. In inverse multiple criteria sorting problem, the assignment of objects to classes is known. The decision maker can implement actions to improve the scores of objects on criteria, thus enabling the assignment of objects to better classes. In inverse multiple criteria sorting problems, two types of questions arise: 1) What is the set of actions that will result in the desired classification with minimum cost? and, 2) What is the set of actions to obtain the best classification without exceeding a predetermined budget? In this study, we focus on the case where the decision maker does not provide any budget limitation or desired classifications a priori. By implementing more actions, i.e. by spending more money, better classifications may be obtained. We aim to analyze the trade-off between cost and classification, and determine the set of actions that will result in the most preferred cost-classification compromise by the decision maker. We decompose the problem into two phases; (i) a preprocessing phase that computes the minimum costs of all possible object-class assignments and (ii) an interaction phase that utilizes a minimax regret approach. We present the details of the developed approach and the computational test results.

2 - New Dynamic Programming Algorithm for the Multiobjective Minimum Spanning Tree Problem
Pedro Maristany de las Casas

We discuss a new dynamic programming algorithm for the Multiobjective Minimum Spanning Tree (MO-MST) problem. The new algorithm manages explored subtrees in the same way as the recently introduced Multiobjective Dijkstra Algorithm. This means that it avoids the costly 'merge' operations that are needed to delete dominated subtrees from the algorithm's priority queue, achieving state of the art complexity bounds and improved practical running times. The latter are further improved by pruning techniques that detect irrelevant subtrees early during the search. State of the art dynamic programming MO-MST algorithms do not search for solutions in the input graph. Instead, an implicit search graph (called Built Graph in the literature) is built during the search. The number of nodes in this graph is exponential in the input size. However, its influence on the algorithm's complexity bound is logarithmic. The number of implicit arcs has a bigger impact: the arcs' cardinality can be exponential and it appears unaltered in the algorithm's complexity bound. This means that the new algorithm is not output sensitive, since it does not depend polynomially in the size of the input and the output. We discuss which properties of the input graphs can lead to a polynomial (at least parametrized) number of arcs in the implicit search graph. For MO-MST instances with such input graphs an FPTAS can be directly described using our new algorithm and classical outcome space partitioning techniques.

3 - Approximated anytime method to solve multiobjective combinatorial optimization problems
Miguel Ángel Domínguez Ríos, Francisco Chicano, Manuel López-Ibáñez

Combinatorial multiobjective optimization problems (MOCO) have been widely used and have a variety of applications in several fields. An algorithm that solve MOCO problems is said to be anytime when we can obtain a well-spread subset of solutions (approximated or not) over the objective space at any time during the execution. Most of the techniques to solve them use metaheuristics, although we can also find exact methods to this purpose, as in TPA algorithm. Based on the idea of Dächert and Klamroth, we propose a new anytime algorithm to solve MOCO problems, called HBOXES. The method is selecting regions (or boxes) to explore in the objective space. At each iteration we solve one ILP subproblem using CPLEX. If a new solution is found, we reduce the search region by eliminating those solutions that are dominated by the last solution found. Due to the fact that the ILP solver may require a great computational time at each call, we introduce some input parameters that control a trade-off between time and quality of the solutions. Thus, we force the ILP solver not to waste too much time during the exploration. The selection of these input parameters may well have an impact of the quality of solutions. We analyze the computational results using 911 instances for different benchmarks of datasets. We compare HBOXES with two other methods, one exact and one approximated. With the appropriate configuration of the input parameters, HBOXES could perform as an exact method.

4 - An evaluation of the fairness of railway timetable rescheduling
Matthias Ehrgott, Edwin Reynolds, Judith Y. T. Wang

Making changes to the timetable in response to an initial delay can help to reduce the amount of additional delay caused to other trains as a result of the initial incident. This Train Timetable Rescheduling Problem (TTRP) can be solved in order to determine the optimal way to reschedule the imetable. A large number of different TTRP problem variants, models, objective unctions and solution methods have been studied. However, the implications for TTRP models of economic competition between railway operators has not been considered. Where trains are operated by more than one different company over the same tracks, timetable rescheduling has the potential to impact these operators unequally. In order to be perceived as fair, a TTRP model must not systematically favour some operators over others. A perception of unfairness would be a serious barrier to the practical deployment of TTRP models in competitive railway systems. Therefore, it is essential that the fairness characteristics of such models are understood. This study investigates the fairness of solutions obtained from solving the TTRP. The talk is organised as follows. We first describe our methodology by defining our notions of fairness and efficiency and how to evaluate them. In our results section, we present an analysis of the fairness of efficiency-maximising TTRP solutions. This is supplemented by an analysis of the interactions between pairs of operators, where we also consider the fairness-efficiency trade-of.

■ WC-08
Wednesday, 12:30-14:00 - U4

Nonlinear topics in mixed-integer optimization

Stream: Combinatorial Optimization
Invited session
Chair: Sandra Ulrich Ngueveu

1 - Solving a bilevel energy market problem to optimality by price discretization
Stephan Marnach, Arie Koster

In this talk we study a simple approach to demand side management in a regional energy market: The goal of a distribution network operator (DNO) is to cover the energy demand of consumers in his subnetwork cost-efficiently with a mix of supply from local renewable energy sources and (non-)renewable energy purchased on the energy market. Since the supply of renewable energy cannot be increased or decreased at will, the DNO has to dynamically adjust the energy prices in each period to stimulate a shift in energy consumption in his favor. Each consumer, on the other hand, tries to minimize his energy bill. The emerging mathematical problem is a bilevel problem with bilinear objective functions. Each of the bilinear terms is a product of price and consumption. Applying the strong-duality reformulation results in a single level quadratically constrained quadratic problem. Alternatively, we show by the theory on min-cost-flow how to linearize all quadratic terms in the formulation via exact big-M contraints without loss of global optimality. To strengthen the resulting MIP formulation we introduce valid inequalities. Computational experiments show that all formulations, the quadratically constrained quadratic strong duality reformulation, the MIP reformulation and the strengthened MIP reformulation are decent at finding strong feasible solutions. However, the MIP formulations, especially the strengthened one, are much better at closing the duality gap and proving optimality.

2 - A Decomposition Method for MINLPs with Multivariate Lipschitz Continuous Nonlinearities
Julia Grübel, Richard Krug, Martin Schmidt, Winnifried Wollner

We continue the work of Schmidt et al. (2019) in which a decomposition method for mixed-integer optimization problems with Lipschitz continuous nonlinearities is presented. We extend this method by considering multivariate Lipschitz functions. Due to this, the number of problems that fit in our framework is increased significantly including, e.g., problems where some constraints cannot be evaluated exactly, which is the case for many control problems governed by partial differential equations, or bilevel problems with non-convex lower level. We develop an algorithm that solves these mixed-integer optimization problems with multivariate Lipschitz continuous nonlinearities by iteratively approximating the nonlinear functions using their Lipschitz constant. We prove convergence to an approximate global solution and give a worst-case estimate for the number of iterations. Moreover, in two case studies, we derive the necessary Lipschitz constants and apply the method to bilevel problems and gas transport problems.

3 - Optimality Certificates for Convex Mixed-Integer Nonlinear Problems: Computation and Size Analysis
Katrin Halbig, Lukas Hümbs, Florian Rösel, Lars Schewe, Dieter Weninger

Every optimization problem has a corresponding verification problem that checks whether a given optimal solution is in fact optimal. In the literature there are a lot of such ways to verify optimality for a given solution, e.g., the branch-and-bound tree. We introduce an optimality certificate for convex mixed-integer nonlinear programs and present an algorithm to compute these certificates. Subsequently, we analyze the size of a certificate for different problem classes. Theoretical upper and lower bounds on the size are proven and computational experiments are presented.

4 - LinA: A faster approach to piecewise linear approximations of univariate functions
Sandra Ulrich Ngueveu, Julien Codsi, Bernard Gendron

We address the problem of approximating and over/under-estimating univariate functions with piecewise linear (PWL) functions with the minimum number of linear segments given a bound on the pointwise approximation error allowed. Through a new geometric approach and building on the work of Ngueveu[2019] we develop new algorithms that can solve the problem in quasi-logarithmic time on a very broad class of error types including absolute and relative ones. Such algorithms find many applications, mostly related to solving certain classes of (mixed-integer) nonlinear and nonconvex programming (MINLP) problems by mixed-integer linear programming (MILP) techniques. An efficient implementation of our algorithms is available as a Julia package named LinA (http://homepages.laas.fr/sungueve/LinA.html). Benchmarks are also provided to showcase how our method outperforms outperforms what already exists to compute PWL approximations with predefined pointwise maximal error. Finally, we illustrate how our algorithms can be used to efficiently solve certain classes of MINLP problems by a case study on multicommodity network design problems with congestion.

■ WC-09
Wednesday, 12:30-14:00 - U5

Applications of Mixed integer Linear Programming

Stream: Mixed Integer Linear Programming
Invited session
Chair: Selin Ahipasaoglu

1 - A branch-and-bound algorithm for the exact optimal experimental design problem
Selin Ahipasaoglu

We discuss a generalisation of the approximate optimal experimental design problem, in which the weight of each regression point needs to stay in a closed interval. We work with Kiefer's optimality criteria which include the well-known D- and A-optimality as special cases. We propose a first-order algorithm for the generalised problem that redistributes the weights of two regression points in each iteration. We develop a branch-and-bound algorithm for exact optimal experimental design problems under Kiefer's criteria where the subproblems in the search tree are equivalent to the generalized approximate design problem, and therefore, can be solved efficiently by the first-order method. We observe that our branch-and-bound algorithm is favourable to a popular exchange heuristic for certain problem instances.

2 - A Polyhedral Approach to the Total Matching Problem
Luca Ferrarini, Stefano Gualandi

Given a graph G= (V, E) a total matching is a subset T⊆V∪E such that every pair of elements is not incident to each other. The Total Matching Problem asks for a total matching of maximum size. This problem generalizes both the Stable Set Problem, where we look for a stable set of maximum size, and the Matching Problem, where instead we look for a matching of maximum size. Motivated by this, in this talk, we will introduce the Total Matching Polytope, defined as the convex hull of characteristic vectors of all total matchings of G. In particular, we will present families of non trivial valid inequalities which are facet-defining for the Total Matching Polytope. Finally, we show computational results to compare the cuts generated and we will address new open questions.

3 - A Risk averse MILP Formulation for the Antibiotic Time Machine Problem
Deniz Tuncer, Burak Kocuk

Antibiotic resistance is the phenomenon of a bacterium developing ability to not being affected by a certain type of drug. This ability is gained by mutations after repeated drug applications. After some mutations, the treatment plans may become inefficient due to mutated genotype of the bacterium. Given a set of drugs and a treatment length, the antibiotics time machine problem aims to find the optimal treatment plan of the drugs that maximizes the expected probability of reversing the possible mutations. In biology community, the main method utilized to solve the problem is complete enumeration. However, optimization-based solutions will be a better approach to solve the problem. Due to the nature of the problem and the seriousness of the danger of drug resistance, risk averse formulations would be a better approach than maximizing the expectation. Therefore, we develop a risk averse Mixed-Integer Linear Program (MILP) formulations for the antibiotics time machine problem, that are efficiently solvable compared to the complete enumeration. We carry out extensive computational experiments with real data to highlight the efficacy of our approach.

4 - Identifying disease-causing genetic characteristics using MILP
Marleen Balvert

Many diseases that cannot be cured today are caused by genetic factors. Knowing these genetic variants would improve our understanding of the disease and advance development of medication. To identify disease-causing variants large databases are collected containing the genetic information of patients of a specific disease and healthy controls. The data analysis methods available for analyzing genome data can find individual genetic features that cause disease in isolation. These variants explain only part of disease prevalence, as many diseases are caused by non-additive combinations of genetic variants. Currently the tools needed for identifying these combinations are unavailable. There are several challenges: genome data contains millions of variants; the combinatorial explosion arises from the many subsets of genetic variants one can draw from millions of variants; and interpretability of a classification model is crucial. This work proposes an MILP-based heuristic called IRELAND that identifies Boolean phrases in disjunctive normal form (DNF) to predict disease from binary data, the format of genome data. Boolean phrases in DNF are inherently interpretable and correspond to how biologists view genotype-disease relationships. While current methods can identify Boolean phrases in DNF from datasets with up to 1000 variants and samples, IRELAND can handle synthetic data with up to ten thousand variants and samples. We present initial experiments on real genomics data.

■ WC-10
Wednesday, 12:30-14:00 - U6

Sustainable Investing

Stream: Financial Risk Measurement and Management
Invited session
Chair: *Roy Cerqueti*

1 - Is Green ETF the winning investment strategy?
Rita D'Ecclesia, Kevyn Stefanelli, Giacomo Morelli

The environmental, social, and governance (ESG) exchange-traded funds (ETFs) have become quite popular in the last few years. An important question to ask is whether they are really green or simply the result of marketing initiatives (greenwashing). The way environmental performances of the green funds are evaluated remains unclear. The large set of the currently available metrics often present large contradictions, generating confusion in investors, especially among those retailers. In this paper, we analyze a sample of ten most capitalized global green ETFs quoted on International Exchanges. We create a unique dataset of 246 firms and classify the most popular metrics, namely the Environmental (E) pillar of the ESG Score and the carbon intensity, which is a factor proportional to the total net CO2 emissions. We screen the sample through a stock picking process based on the two metrics to build equally weighted and global minimum variance synthetic funds considering: (i) only the best-in-class green companies, (ii) exclusively the best half of the sample, and (iii) all the firms except the most polluting ones, that belong to the last quantile of the environmental metrics (EMs) distributions. The resulting synthetic funds are statistically compared with each other and the sample of the ten listed green ETFs, both evaluating their environmental and financial performances.

2 - ESG investing: A chance to reduce systemic risk
Marco Nicolosi, Roy Cerqueti, Rocco Ciciretti, Ambrogio Dalò

We consider a network of equity mutual funds characterized by different levels of compliance with Environmental, Social, and Governance (ESG) aspects. We measure the impact of portfolio liquidation in a stress scenario on funds with different ESG ratings. Fire-sales spillover from portfolio liquidation propagates from one fund to another through indirect contagion mediated by common asset holdings. The analysis is conducted quarterly from March 2016 through June 2018 using daily data from different sources at the fund and firm levels. Our estimation strategy relies on a network analysis where funds are not taken as stand-alone entities but are interconnected components of a unified system. We find evidence that the relative market value loss of the High ESG ranked funds is lower than the loss experienced by the Low ESG ranked counterparts in the time span with lower volatility. In the higher-volatility period there is not always a clear dominance of one class over another. Results are robust when controlling for size and for feedback effects, and for different model specifications. Our analysis offers new insights to both asset managers and policymakers to exploit the aggregate effect of portfolio diversification related to the system as a whole.

3 - Value Creation and sustainable business model
Rosella Castellano

In recent years, sustainable finance has undergone a very consistent expansion, motivated by both regulatory and cultural changes deriving from the greater awareness of the positive role of sustainable finance in mitigating the negative externalities on the environment generated by economic activities. At the same time, it should not be forgotten that structural changes have occurred in the market in which non-financial information sets and sustainability ratings are systematically and increasingly available, and regulatory pressure has intensified interest on sustainability issues by institutional investors. This rapid expansion of sustainable finance, however, leaves some issues open to which it is important to pay attention and which need further investigation. Companies that integrate ESG factors in their business model manage their resources respecting environmental sustainability criteria, invest in innovation for growth, believe in corporate social responsibility, attract and cultivate young talents and seek new strategies to reduce business risks by involving in their actions all stakeholders. The basic idea is that the adoption of good ESG practices is the source of long-term competitive advantages (Bailey, 2014).We will address this issue from the investor's point of viewin order to understand whether sustainable financial products satisfying ESG criteria have a better risk/return profile compared to traditional investments.

4 - Firms' profitability and ESG score: a machine learning approach
Susanna Levantesi, Rita D'Ecclesia, Valeria D Amato

Existing literature pointed out that corporate social responsibility (CSR) has a potential impact on the performance of firms. However, the literature provides only limited evidence of the relationship between non-financial indicators, such as the ESG score and the firm's profitability, often measured by the earnings before interest and taxes (EBIT). We investigate this issue by analyzing a sample of about 400 companies in the EuroStoxx-600 from 2011 to 2020 using different machine learning techniques. The novelty of our contribution lies in assessing whether the ESG score, in both its aggregate specification and each component, has a significant impact on the firms' profitability. The relationship between ESG score and EBIT is deepened using interpretability dedicated toolboxes such as partial dependence plots and individual conditional expectation, which help to visualize the functional relationship between the predicted response and one or more features, and the Shapley value allowing to examine the contribution of the feature to the prediction. Our findings show that the model can reach high levels of accuracy in detecting EBIT. In particular, we find that the ESG score has a promising predictive ability, higher than other traditional accounting variables

■ WC-11

Wednesday, 12:30-14:00 - U7

MCDA applications in health and healthcare

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Monica Oliveira*
Chair: *Ana Vieira*
Chair: *Vladislav Rajkovič*

1 - Multicriteria model for assessing the suitability of remote patient care
Vladislav Rajkovič, Adriana Kozina, Valentina Rok, Uroš Rajkovič

With technological development in the fields of diagnostic devices and ICT, the possibility for remote patient care is increasing. This opens up the possibility of reducing patient treatments in healthcare institutions, which in turn makes life easier for patients and, with proper work organization, also better quality treatment. In doing so, it is important to assess the suitability of the patient for remote care by taking into account various factors such as: the patient's health problem, his/her wishes and abilities, the necessary knowledge and technology, and the possibilities of a health institution for such treatment. This paper presents a multi-criteria model for assessing the suitability of a patient for remote care. The model contains 16 basic criteria for assessing necessary data about a patient and his/her ecosystem. These criteria can be adapted to specific situations. The criteria are hierarchically arranged in the tree of criteria. The root of the tree is the final assessment of suitability. The model was developed according to the DEX methodology. Value domains are qualitative. Although it is possible to use weights to indicate the importance of individual criteria, the aggregation functions are defined by logical rules. This allows for expressing importance of criteria depending on their values. This way, we contribute to the greater expressive power of the model and increase its comprehensibility, which allows the model to be adapted to specific situations.

2 - A socio-technical approach for multicriteria evaluation of emerging biomarkers in hospital settings
Liliana Freitas, Beatriz Coelho, Teresa Cipriano Rodrigues, Hugo Quintino, Monica Oliveira

Breast cancer is the most common cancer in the world, and a large number of innovative biomarkers with a potential to improve diagnosis, care and patients' outcomes contexts have been emerging. However, due to the relatively recent discovery and non-widespread use of emerging biomarkers in clinical practice, there is often little evidence of their effectiveness and safety and a stringing need for hospitals assessing their overall value so as to inform adoption decisions. To address this challenge, a socio-technical approach - combining the MACBETH multicriteria method, a rapid review for evidence synthesis, and fit for purpose participatory processes enabled by distinct decision support systems - was designed to help hospitals building novel health technology assessment (HTA) models. The approach was applied to build a multicriteria model to evaluate emerging biomarkers for HER2-positive breast cancer cases at Hospital do Espírito Santo de Évora (HESE), in Portugal. The resulting model enables a continuous evaluation of emerging biomarkers by HESE, was structured with six evaluation criteria and allowed to inspect the value of 11 emerging biomarkers, providing important insights to HESE stakeholders about which biomarkers should be adopted. This study contributes to literature by proposing a novel socio-technical approach, and discussing, based on a real case study, how HTA combined with innovative multicriteria modelling can change hospital decision processes.

3 - Towards understanding vaccine hesitancy with multicriteria decision analysis
Yu-Wang Chen

Vaccination is widely accepted as the most effective way to protect people against infection by viruses, including Covid-19, but vaccine hesitancy has always existed among a proportion of people and it was listed by the World Health Organization as one of the ten threats to global health. Thus, it is crucial to understand the determinants, which are likely to influence people's vaccine hesitancy and acceptance in order to support vaccine deployment and vaccination policy-making.

Theoretical and experimental studies have suggested that a variety of decision criteria, such as safety of vaccines, severity of diseases, socioeconomic status, information and advice from healthcare professionals, influence an individual's intention to vaccinate. In this research, multi-criteria decision analysis is applied to characterise the vaccination decision-making process, in which each individual's beliefs and subjective judgements on the decision criteria can be formulated as belief distributions. Furthermore, social influence, which exists in a social network environment is incorporated into the dynamic information aggregation process for analysing vaccination decision making. Simulation on a small social network is conducted to illustrate how the vaccination coverage is affected by individuals' beliefs on the decision criteria as well as the characteristics of social influence spreading in the network.

4 - Decision tools and adaptive designs for health policies
Christine C Huttin

This project continues a research stream on choice sets at individual or subgroup levels (Huttin, Ispor 2021) for policy design. Recent statistical tests on heterogeneity of demand are used for impact assessment on health policy (Huttin and Hausman, 2021; Hahn, Hausman and Lustig, 2020). A first choice model was tested on drug choice sets (IFORS 2021), with mixed logit model and random prices. This research developps other choices sets: referrals, biopsies, combined drug and tests, with or without medical devices (with different stages of ICT diffusion (Huttin, 2020). Other discrete choice models are appropriate to explore providers or patients' decision shifts under different economic conditions and to capture large heterogeneity of demand from diversity of value judgements and preferences among providers of care, populations and minorities. This milestone discusses how and which choices sets are selected for policy choices, another empirical application of the new test (Hahn et al.) is also explored on a second choice model: the BLP model for oligopolistic markets. Findings with these new tests are compared with results using other models (latent class models). Value-based pricing may benefit from such an approach, especially with an implementation in adaptive designs. Comprehensive selection of choice sets may be necessary for user tools to health policy makers.

■ WC-12

Wednesday, 12:30-14:00 - U9

OR in Energy I

Stream: OR in Energy
Invited session
Chair: *Saeed Mohammadi*

1 - A bi-level probabilistic security constrained optimal power flow for short-term adequacy
Manuel Ruiz

The energy transition is driving the integration of renewable energies and increasing the complexity of the processes that guarantee the balance between supply and demand on the electricity grid at all times. This work focuses on the resolution of a PSCOPF where the actions decided by the TSO are balanced by a market with a minimal (or no) view of the network. The TSO can curtail renewable energies or limit the production of thermal units as long as it is compatible with the operational constraints of the system actors. The flows on the network are calculated using the DC approximation and the uncertainties are discretised by scenario. A bi-level formulation is presented, where the TSO is the leader and the balancing market is the follower. The bi-level problem is solved using the KKT reformulation of the follower. Business cases demonstrating the need for a bi-level formulation and numerical results will be presented.

2 - LTI plant design for regulating potential provision in Nordic FCR markets with second-order cone programming
Istvan Selek, Joni Vasara

Fueled by the eager adaptation of fossil-free technologies, the (electric) power production pool has been under „siege" by the emerging alternatives. With their fingerprints on the stability of the power transmission system, grid-balancing duties are emphasized heavier than ever before by the transmission system operators. As a well-recognized consequence, competitive power production is unavoidably forced to participation in the so-called FCR markets requiring the fulfillment of tight regulations against the production entity.

In Finland, the rules defining the FCR regulations are developed and released by FINGRID and shall come into force in 2023. The development simultaneously triggered the response of the industrial control–engineering community to align the control solutions with the outlined regulations. Despite all efforts and success, in practice, it is still unclear whether a feasible solution exists to FCR constraints on a prescribed class of Linear Time-Invariant (LTI) systems.

To resolve the outlined problem, this paper proposes a solution approach to the FCR feasibility problem on the domain of asymptotically stable, continuous-time, SISO LTI systems with proper transfer functions. Using mathematical machinery, the FCR feasibility problem is posed and relaxed to a SOCP based on engineering arguments. The authors show that the FCR feasibility problem satisfies Slater's condition and has infinitely many solutions on the prescribed domain of LTI systems.

3 - Distribution Locational Marginal Pricing (DLMP) for Unbalanced Three Phase Networks
Saeed Mohammadi, Mohammad Reza Hesamzadeh, Derek Bunn

Distribution networks are unbalanced three-phase networks due to one/two phase loads, distribution feeders, and distributed energy resources. Operating such DNs is challenging with constant network expansion/changes as a result of faults, maintenance, uncertain resources, etc. Distribution network operators (DSOs) may follow the spot pricing theory with distribution locational marginal pricing (DLMP) to maintain their commitment to flexible operation of DNs with higher social welfare. With critical response-time in DN operation, linear programming (LP) is the most practical model which must include the network losses. In this work, an LP model is proposed to calculate DLMPs in fully three-phase unbalanced DNs. Uncertainties in solar energy, wind power, energy storage systems, cables, overhead lines, shunt capacitors, voltage regulators, and transformers are addressed by scenarios in a detailed model by exploiting stochastic optimization. Through a proposed No U-Turn sampler (NUTS) based algorithm, probability density functions (PDFs) of DLMPs are calculated. These PDFs provide statistical information about the locational and temporal price risks. The numerical results showed promising performance of the proposed LP model and the NUTS-based algorithm in creating PDFs of DLMPs in a timely manner. DLMP price densities will be increasingly useful as DSOs seek flexible, low risk solutions from embedded generators and aggregators resources.

4 - Multi-objective optimization for investments in hybrid power generation with battery energy storage systems
Paulo Rotella Junior, Jonas Silva, Arthur Leandro Guerra Pires, Luiz Celio Souza Rocha, Rogerio Peruchi, Karel Janda

Combination of wind and photovoltaic (PV) energy sources with the use of a battery storage system may mitigate one of the main characteristics of renewable energy, intermittency. Thus, the present study proposes a financial optimization routine to identify the optimal configuration of residential hybrid distributed generation systems using battery energy storage, maximizing prosumer profitability. For this, the Design of Experiments (DOE) approach was used, specifically the Response Surface Methodology (RSM), to verify which are the input parameters that optimize the financial indicators Net Present Value (NPV) and Levelized Cost of Energy (LCOE). To perform the optimization, the Desirability multi-objective optimization method was selected. Empirical verification was done on Brazilian data. As input variables were adopted: (X1) wind energy share in the project (in %), (X2) Level of demand (in kWh), (X3) Battery type (Lead-acid or Lithium-ion), and (X4) Scenario type (Peak/intermediary or Total). The optimization results showed that the values that optimize the two response simultaneously are: X1 = 7.60%, X2 = 407.14 kWh, X3 = Lead-acid, and X4 = Total. Finally, the results obtained showed the need for incentives for residential wind power generation, which is currently not as cost-competitive as PV energy. In addition to higher cost of wind energy, batteries also have a high cost, which in certain situations can make residential power generation projects unfeasible.

■ WC-13

Wednesday, 12:30-14:00 - U119

Parallel solvers instantiated by UG

Stream: Mixed Integer Linear Programming
Invited session
Chair: Stephen Maher

1 - A parallel branch-and-bound heuristic for the integrated long-haul and local vehicle routing problem on an adaptive transportation network
Stephen Maher, Junko Hosoda, Yuji Shinano, Jonas Christoffer Villumsen

Consolidation of commodities and coordination of vehicle routes are fundamental features of supply chain management problems. While consolidation locations—thus, coordination points—are typically known a priori, in adaptive transportation networks this is not the case and the identification of such locations forms part of the decision making process. Supply chain management problems integrating the designation of consolidation locations with the coordination of long haul and local vehicle routing is not only challenging to solve, but also very difficult to formulate mathematically. A mathematical model integrating location clustering with long haul and local vehicle routing is proposed and used to develop algorithms to find high quality solutions. The UG framework is used to combine exact and heuristic methods in a parallel algorithm to improve the search for high quality solutions and provide valid bounds. The results demonstrate that using exact methods to guide heuristic search is capable of significantly reducing the transportation costs for difficult supply chain management problems.

2 - Faster exact solution of sparse maximum-cut and quadratic unconstrained binary optimization problems
Daniel Rehfeldt, Thorsten Koch, Yuji Shinano

The maximum-cut problem is one of the fundamental problems in combinatorial optimization. With the advent of quantum computers, both the maximum-cut and the equivalent quadratic unconstrained binary optimization problem have experienced much interest in recent years.

This talk introduces a new solver for the exact solution of both problems. The main focus lies on sparse problem instances, although also dense ones can be solved. We enhance several algorithmic components such as reduction techniques and cutting-plane separation algorithms, and combine them in an exact branch-and-cut solver. Furthermore, we describe a parallel implementation. The new solver is shown to significantly outperform existing state-of-the-art software for sparse maximum-cut and quadratic unconstrained binary optimization problems. Furthermore, we improve the best-known bounds for several instances from the 7th DIMACS Challenge and the QPLIB, and solve some of them (for the first time) to optimality.

3 - Solve Large Scale QAPs by Massively Parallel DNN-based Branch-and-bound Method
Koichi Fujii, Naoki Ito, Sunyoung Kim, Masakazu Kojima, Hans Mittelmann, Yuji Shinano, Kim-Chuan Toh

We report our progress on the project for solving large scale quadratic assignment problems (QAPs).

Our main approach to solve QAPs is a parallel branch-and-bound method efficiently implemented on a powerful computer system, using the Ubiquity Generator Framework (UG) which can utilize more than 100,000 cores.

Though the Lagrangian doubly nonnegative (DNN) relaxation of QAPs generate less nodes than other lower bound procedures, it requires much more computational time to solve one node. Since solving QAPs is different from solving MIP by LP-based branch-and-bound at this point, we added some new features to UG.

The checkpointing mechanism is implemented in UG to save nodes in branch-and-bound tree for the calculation of the supercomputers with limited available time. Usually UG avoid to collect all the open nodes in branch-and-bound tree at generating checkpoint file. The new feature Enhanced Checkpoint is added to UG to collect all the open nodes at the end of the execution. This helps a lot to avoid calculating redundant nodes in multiple execution. The new feature Huge Checkpoint File Split is also added to UG to deal with huge number of nodes in checkpoint files by split nodes into two groups.

In this talk, we describe the details of new features of UG for solving QAPs and present some preliminary numerical results of solving large QAPs on supercomputers.

■ WC-14

Wednesday, 12:30-14:00 - U261

Metaheuristics for routing

Stream: Metaheuristics, Matheuristics
Invited session
Chair: Luana Almeida

1 - A new heuristic for the Driver and Vehicle Routing Problem
Inmaculada Rodríguez Martín, Bencomo Domínguez-Martín, Juan José Salazar González

In this work we address the Driver and Vehicle Routing Problem, a complex routing problem with two depots in which the vehicles go from one depot to the other, while the drivers leaving from a depot must return to it within a given time limit. With these assumptions, it is mandatory for drivers to change vehicles in order to be able to go back to their base depots. The exchange of vehicles can only take place at some point. The objective is to design feasible routes for the vehicles and the drivers, so that the total cost is minimized. Only small instances of this problem can be solved to optimality. We present a multistart heuristic to tackle the problem in an efficient way. The computational experiments show that the proposed heuristic usually manages to find the optimal solution for the benchmark instances in the literature, being competitive when compared with previous heuristic results, and it is able to cope with instances with up to 1000 nodes.

2 - Multi-depots concrete delivery problem with a heterogeneous fleet
Nassoma Wattara Ousmane Ali, Jean-François Côté, Leandro Coelho

We study the daily scheduling of concrete delivery. Truck drivers are dispatched based on assignment priority, and remaining working time over the horizon planning. A customer may be served from several available production plants. Due to the heterogeneity of the fleet, the number of visits at a customer location is not known ahead of time. The objective is to schedule drivers while minimizing travel times, waiting duration, idle time, and overtime. We solve this problem using a greedy randomized adaptive search procedure, and a genetic algorithm, both enhanced with a local search. Computational experiments with real data show the performance of our methods over the approach used by a local company.

3 - A multi-objective evolutionary algorithm applied to Tourist Trip Design Problem
Alessio Salvatore, Daniela Ambrosino, Veronica Asta, Pasquale Carotenuto, Luca Peraccini

In the last decades, the operational research studies applied to tourism are becoming increasingly important. One of the most studied topics concerns the definition of a personalized plan for tourists to visit different points of interest (POI) based on their preferences without exceeding a preassigned budget. This problem, named Tourist Trip Design Problem (TTDP), has been modeled as an Orienteering Problem (OP). In this work, we want to investigate the use of a Multi-objective Evolutionary Algorithm based on Decompositions (MOEA/D) to solve the Multi-Objective Orienteering Problem with Time Windows.

We consider that the distances and times matrix among POIs and the opening, closing, and visit times of each POI are known. Finally, two scores are assigned for each POI. The objective is to maximize the sum of the two scores of the tour. By considering these parameters and the available time budget for the tourist we implemented a web-based algorithm. We process the individual request and provide a set of non-dominated tours.

The tests have been performed on a set of benchmark instances; the early results have been very promising; indeed, we outperform the benchmark results on several instances.

Acknowledgements: This work has been supported by the Italian Ministry of Instruction, University and Research (MIUR) within the Program "Smart cities and communities and Social Innovation - Project "SMARTOUR: Intelligent Platform for Tourism" - Grant n. SCN_00166.

4 - A Greedy Randomized Adaptive Search Procedure to the multi-depot prize collecting arc routing for connectivity problem
Luana Almeida, Floris Goerlandt, Ronald Pelot

In the aftermath of a disaster, emergency response activities such as the distribution of relief supplies can be jeopardized because of roads being blocked with debris. In the multi-depot prize collecting arc routing for connectivity problem (MPC-ARCP), multiple depots have a number of road clearing teams available whose goal is to unblock the roads and reconnect isolated communities to critical supply infrastructures such as ports and airports. In this presentation, we introduce a Greedy Randomized Adaptive Search Procedure (GRASP) approach to MPC-ARCP.

■ WC-15

Wednesday, 12:30-14:00 - U262

Business Intelligence and Data-Centric DSS

Stream: Decision Support Systems
Invited session
Chair: *Isabelle Linden*
Chair: *Pavlos Delias*

1 - Clustering of cycling race profiles
Bram Janssens, Jelle De Bock, Steven Verstockt, Matthias Bogaert

Current cycling analytics solutions are too heavily scoped as they do not consider the unique characteristics of each race. Race profiles are extremely diverse with courses ranging from flat 260 km cobblestone races to 100 km mountain stages. By performing a clustering analysis of web-scraped gpx elevation profiles, we identify the unique race types. This analysis allows for race type-specific analyses, such as talent identification, race performance estimation, and rider selection, thereby solving one of two major current issues in the field of cycling analytics.

2 - Designing a functional dashboard for pandemic diseases in hospitals
Kacem Addaoud, Sabri Erdem

The main contribution of this study is creating a functional pandemic and a real-time dashboard in the context of healthcare. The pandemic dashboard contains quality measures that help managers, doctors, nurses, and support staff, from different levels (Administration Unit, Intensive Care, General Care, Emergency, Pandemic unit) answer high value questions based on the analyses provided. Through a theoretical background research, the paper analyzed the relevant theories that are engaged in creating a functional dashboard for pandemic disease in a hospital; the Feedback intervention theory (FIT), Incremental model of the Decision-making theories, Crisis management model, Stakeholder theory, and the Cognitive fit theory. The data collection mode was through questionnaires, which included 40 different questions. The 40 questions were representation of the 40 different KPIs to be included on the dashboard. The participants for the research were employees 7 different hospitals across the Algerian cities, whom are categorized into various pandemic levels; including administration unit, intensive care, general care, emergency, and pandemic services. Under each pandemic level, there various categories of employees positions; including managers, doctors, nurses, and support employees. The functional pandemic dashboard created contains some basic functional features; Real-time notifications and alerts, scenario analyses, and drill-down capabilities. The dashboard was presented to 16

3 - A Hybrid Approach for Learning Performance Evaluation Criteria of Logistics Service Providers
Sinem Tokcaer, Bülent Cem Sertel

Shippers attach high importance to the performance of Logistics Service Providers (LSP) under several categories since it largely affects the overall performance of all supply chain. Hence, there is an extensive literature on performance evaluation criteria of logistics services including both qualitative and quantitative methods. In this research, we applied a hybrid approach including the qualitative research and Aspect Based Sentiment Analysis to explain the performance evaluation criteria applied by the shippers to LSPs. As the preliminary research, we investigated the LSP performance criteria by interviewing a small sample of manufacturing companies. On the gathered data, we applied open-axial-selective coding to reveal the main criteria categories and sub-categories. Consecutively, we applied Aspect Based Sentiment Analysis (ABSA) on the same gathered data to find the main aspects and sentiment related to each aspect. We compared the findings ABSA with the categories of open-axial-selective coding procedures used in qualitative research.

■ WC-16

Wednesday, 12:30-14:00 - U264

Modeling credit and systemic risk

Stream: Risk Management in Finance
Invited session
Chair: *Davide Radi*

1 - A hazard rate model for pricing CDS spreads
Davide Radi

In this paper we propose a hybrid credit risk model, in closed form, to price risky debt. The likelihood of default is captured by the firm's non-interest sensitive assets, default-free interest rates and stochastic volatility. In this four-factor hazard rate model, default-free interest rates can be negative as experienced in the past decade in the euro area. A closed-form solution is obtained for pricing bonds and the spreads of credit-default swaps (CDSs). An empirical investigation that involves European companies shows that stochastic volatility and stochastic (negative) default-free interest rate increase the goodness-of-fit of the model.

2 - Catastrophic and systemic risk in the non-life insurance sector: A micro-structural contagion approach
Hana Dvorackova

Borrowing from the interbank contagion literature, we propose a model to study the stability of the non-life insurance sector in the presence of catastrophic events. These events are increasingly common, and cause a large amount of damage in short periods. To account for this risk we introduce random and correlated reinsurance claims. We show in a simulation study that the sector is particularly sensitive to random correlated insurance claims, and the threat of systemic risk emerges. The risk persists even with highly diversified network structures. The work is relevant for regulators to define macro-prudential policies, and for practitioners to measure credit risk.

3 - Financial contagion and systemic risk in multilayer networks
Gabriele Torri, Davide Radi, Giovanni Covi

banking networks are complex system, where shocks can transmit and build up fast, due to interconnection among institution across different levels. Micro-structural contagion model can provide relevant information to regulators by allowing to study the spread of shocks and the buildup of risk in a system, using granular information available to regulators. To provide a comprehensive assessment of the risk, multiple contagion channels and their complex interaction need to be considered, such as solvency contagion, liquidity contagion, and fire sales. In this work we analyze systemic risk using a state-of-art multilayer interbank contagion model in a simulation framework, studying the effect of different network configurations. We focus in particular on the role of the similarity among different layers of the network, and on the presence of correlated exernal shocks applied to the system.

4 - A sequential analysis of the role of clean energies and european union allowances in investment portfolios
Pilar Gargallo, Luis Lample, Jesús Miguel, Manuel Salvador

We examine the capability of clean energy stocks and European Union Allowances (EUA) to reduce a portfolio risk when combining them with dirty energy assets. The weights allocation proposed in this work is enclosed in a volatility-timing context, which responds to changing market environments by taking different portfolios at different points in time. To achieve the objective we use the ADCC-GARCH models family, which allows us to obtain good estimations of the conditional covariance matrices of the daily asset returns. In order to determine the weights of the optimum minimum-risk portfolio, we provide a very flexible and adaptive framework of estimation and selection of model based in a sequential strategy with different size of estimation and validation windows, as well as update frequency. We compared the observed portfolios volatility using a procedure based on Engle and Colacito (2006). The analysed period goes from January 2010 to February 2022, which, on the one hand, includes half of phase II, full phase III and what goes of phase IV of the EU ETS; and, on the other hand, it considers some crisis episodes (Sovereign debt crisis, Brexit, COVID-19). Our findings show that investing in clean energy companies is now valuable for not only its contribution to a sustainable energy transition to renewable sources, but also for its attractiveness from a financial point of view.

■ WC-17

Wednesday, 12:30-14:00 - U356

EWG-ORD Workshop

Stream: OR for Development and Developing Countries
Invited session
Chair: Nina Kajiji
Chair: Gordon Dash

1 - Schools performance and the role of principals' managerial practices.
Anna Mergoni, Ana Camanho, Kristof De Witte, Tommaso Agasisti, Mara Soncin

In this paper, we investigate the effect of school principals' managerial practices on the schools' ability to deliver knowledge. To do so we develop a measure to assess the impact of the external variables in the context of conditional efficiency estimation. Firstly, we evaluate schools' performance through a robust order-m and conditional order-m data envelopment analysis (DEA). This allows to account for the endogeneity of principal practice and for the heterogeneity in the school environment they might have to face. Secondly, we investigate how the managerial practices affect the performance of the school, in terms of students' achievements and school climate, focusing in particular on the interaction effects between the managerial practices. Data refers to a nationally representative sample of Italian schools in 2019 and students in the 8th grade. Findings support the hypothesis that principals' managerial attitudes are a key element to establish a positive learning environment.

2 - A decision-making framework for prioritizing school infrastructure investment
Rafael Fernández, Andrés Calvo, Dina DAyala, Juan Francisco Correal, Andres Medaglia

School infrastructure affects the quality of learning and performance of children and youth. Particularly, in the Latin-American and Caribbean context, natural hazards such as earthquakes, floods, and landslides, threaten school facilities. Additionally, problems related to the functionality of these facilities are common in the region, such as an inadequate number of classrooms, lack of recreation and leisure spaces, poor lighting and ventilation, old furniture, and deficient connectivity. At a national level, the decision-making process to prioritize schools' interventions becomes even more challenging due to limited resources and lack of information. We propose a decision-making framework that prioritizes school infrastructure investment with limited budgets. This framework allows better public policy decisions and benefits students in terms of infrastructure quality with a multicriteria perspective, improving both safety and functional conditions. We illustrate the framework with a case study applied to the school infrastructure in Cali (Colombia), a part of the Global Program for Safer Schools of the World Bank.

■ WC-18

Wednesday, 12:30-14:00 - U358

Cutting and packing session 3

Stream: Cutting and Packing
Invited session
Chair: Antonio Martinez Sykora

1 - Procedural bilevel programming: applications to the bin packing problem
Antonio Martinez Sykora, Stefano Coniglio, Tony Wauters

The assumption of a follower solving their optimization problem to optimality is key to bilevel optimization. In practical applications, though, where the follower's problem is typically solved by a human, it is arguably very rare that the follower would always find an optimal solution. Motivated by this observation, we introduce a new bilevel optimization paradigm, which we refer to as "procedural bilevel programming", where the follower, rather than seeking an optimal solution to their problem, applies a well-defined procedure (such as a constant-factor approximation algorithm) for its solution. Assuming the bin packing problem as the motivating example, we propose (and experiment with) exact single-level formulations for the problem where the leader affects the problem instance (modifying, e.g., the item weights and/or the bin capacity) in such a way that, by anticipating the procedure the follower would use to solve the resulting instance, the leader's objective function is maximized.

2 - A matheuristic for the two-dimensional cutting stock problem with usable leftovers and uncertainty in demand
Douglas Nogueira do Nascimento, Adriana Cherri, José Fernando Oliveira, Beatriz Brito Oliveira

In this work, we deal with the two-dimensional cutting stock problem with usable leftovers (2D-CSPUL) and demand uncertainty, which has great practical importance due to its economic and environmental impact reducing the waste of raw materials. This waste reduction is leveraged by using leftovers from previous cutting processes. The main difficulty of the 2D-CSPUL is planning the production of both demanded items and leftovers in a multiperiod perspective without knowing the future demand. To solve this problem, we propose a matheuristic that consists in creating a set of cutting patterns, evolving scenarios for items demand and solving a stochastic model using both cutting patterns and scenarios. The scenario evolution method is based on a BRKGA (Biased Random-Key Genetic Algorithms) framework proposed in the literature. The stochastic model is solved through a new solution method adapted from the L-shaped method. This research was funded by FAPESP - Fundação de Amparo à Pesquisa do Estado de São Paulo (2016/01860-1, 2018/16600-0, 2019/25041-8) and by Conselho Nacional de Desenvolvimento Científico e Tecnológico - CNPq (421130/2018-0, 306558/2018-1). This work is partially financed by the ERDF - European Regional Development Fund through the Operational Programme for Competitiveness and Internationalisation - COMPETE 2020 Programme and by National Funds through the FCT - Fundação para a Ciência e a Tecnologia, I.P., within project POCI-01-0145-FEDER-029609.

3 - The Multi-Class Constrained Bin Packing Problem
Baptiste Coutton, Dario Pacino, Martin Kidd, Stefan Guericke

Global freight transportation relies heavily on the use of standardised containers. To reduce the costs and the environmental footprint of their operations, logistics companies seek to improve container utilisation. But this objective is sometimes challenged by freight owners who impose rules on how the cargo items can be mixed together inside the containers. In this work, we study such a container loading problem under a specific formulation of cargo mixing constraints encountered by a major international logistics company, referred to as the Multi-Class Constrained Bin Packing Problem. Each cargo item has a volume and a fixed number of classes, with one value per class. Bins are of variable sizes and each can contain at most a fixed number of different values per class, while its volume capacity has to be respected. Previous work about this problem is scarce and deals with instances much smaller than those the logistics company faces. Based on a set of existing and newly generated benchmark instances, we argue that exact methods struggle to scale up as the numbers of items and classes increase. As the logistics company requests a solution running for less than 30 minutes, we develop a number of greedy heuristics and an Adaptative Large Neighbourhood Search. We show that those algorithms have the ability to yield much better solutions than a mathematical solver in up to a few hundred seconds.

■ WC-19

Wednesday, 12:30-14:00 - Y228a

Queueing Systems with Heterogeneous Customers

Stream: Performance Evaluation of Queues
Invited session
Chair: *Céline Comte*
Chair: *Elene Anton*
Chair: *Ellen Cardinaels*

1 - Stochastic Service Systems with Heterogeneous Boundedly Rational Customers
Shayan Sharifi, Pelin Canbolat

In this talk, we explore the effects of heterogeneity in the degree of bounded rationality of customers visiting a service system. We model bounded rationality of customers through logistic quantal response functions and heterogeneity with respect to bounded rationality through randomness in the parameter of these functions. We focus mainly on service systems represented by M/M/1 queues. We provide several analytical and numerical results on the effects of heterogeneity in bounded rationality for a given system with a fixed service rate and fee. We then consider the pricing and the capacity decisions under revenue and social-welfare maximization objectives. We conclude with insights about potential losses due to ignoring heterogeneity in bounded rationality.

2 - Load-balancing for multi-skilled servers with Bernoulli routing
Josu Doncel

We study the optimal Bernoulli routing in a multiclass queueing system with a dedicated server for each class as well as a common (or multi-skilled) server that can serve jobs of all classes. Jobs of each class arrive according to a Poisson process. Each server has a holding cost per customer and use the processor sharing discipline for service. The objective is to minimize the weighted mean holding cost. First, we provide conditions under which classes send their traffic only to their dedicated server, only to the common server, or to both. A fixed point algorithm is given for the computation of the optimal solution. We then specialize to two classes and give explicit expressions for the optimal loads. Finally, we compare the cost of multi-skilled server with that of only dedicated or all common servers. The theoretical results are complemented by numerical examples that illustrate the various structural results as well as the convergence of the fixed point algorithm.

3 - Stochastic dynamic matching: A mixed graph-theory and linear-algebra approach
Céline Comte

Stochastic dynamic matching problems have recently drawn attention in the stochastic-modeling community due to their numerous applications, ranging from supply-chain management to kidney exchange programs. In this paper, we consider a matching problem in which items of different classes arrive according to independent Poisson processes. Unmatched items are stored in a queue, and compatibility constraints are described by a simple graph on the classes, so that two items can be matched if their classes are neighbors in the graph. We analyze the efficiency of matching policies, not only in terms of system stability, but also in terms of matching rates between different classes. Our results rely on the observation that, under any stable policy, the matching rates satisfy a conservation equation that equates the arrival and departure rates of each item class.

This presentation is based on a joint work with Fabien Mathieu (LINCS) and Ana Bušić (Inria and PSL University).

4 - On stochastic matching systems with reneging
Pascal Moyal

We consider a stochastic matching model, viewed as an interface to match heterogeneous incoming items. Items are of different classes, enter the system at random times, and possible matches are given by a compatibility graph that is fixed beforehand. This is a relevant model for peer-to-peer networks, dating websites, kidney transplants, housing allocations or assemble-to-order systems, among others.

In this talk, we focus on the case where items renege from the system. This is a natural assumption in contexts in which the element have a finite lifetime in the system, such as for kidney transplants. We first study the stability region in models in which some, but not all classes of items renege, and provide moments bounds at equilibrium. Then, we give tools to perfectly sample the steady state of models with finite patience times, and present several directions for future research.

■ WC-20

Wednesday, 12:30-14:00 - Y228b

Dynamical Systems and Mathematical Modeling in OR 2

Stream: Dynamical Systems and Mathematical Modeling in OR
Invited session
Chair: *Benedikt Meylahn*

1 - Trusting alone and together
Benedikt Meylahn, Arnoud den Boer, Michel Mandjes

We study the problem of an agent continuously faced with the decision of placing or not placing trust in an institution. The agent makes use of Bayesian learning in order to estimate the institution's true trustworthiness and makes the decision to place trust based on myopic rationality. For special cases, we derive the probability that such an agent ceases placing trust at some point in the relationship as well as the expected time spent placing trust conditioned on their discontinuation thereof. Subsequently, we consider the complexity of the transition from one to two truster agents both in separate relationships with the institution as well as some relationship with one another. Here we still consider the rational learning case in the context of some limited communication. As opposed to other models of social influence we do not impose an effect of the neighboring agents on one another but rather describe the resulting model when considering the specifics of the available communication. The two kinds of communication considered are information sharing in which agents disclose their experience with the institution with one another and observational communication in which agents merely witness the actions of their neighbor (placing or not placing trust) and not the resulting response of the institution. The interest here is in the resulting effect of social connections in relation to trusting and learning relationships between individuals and institutions.

2 - The Use of Volatility Modeling in Monetary Policy Evaluation
Dominik Kavřík

Given a specific functional form of the loss function, which is minimized by the central bank while conducting the monetary policy, there is a trade-off in the second moments of inflation and output gap. This trade-off, first proposed by John B. Taylor in 1979, is also known as the Taylor curve. In theory, this negatively sloped curve is an efficiency frontier, and any deviation from it indicates suboptimality of the monetary policy. The second moments of said variables are not directly observable, which means it is necessary to estimate them for further analysis. One possible approach is to generate the volatilities from macroeconomic DSGE models. The second, empirical approach, is to estimate them from the data. The multivariate GARCH model is used to estimate the volatility of output gap and inflation on the latest US data. Multivariate GARCH is well-suited for this task since it is reasonable to assume that there are spillovers between inflation and output volatilities. The empirical results are consistent with the literature studying the monetary policy before the financial crisis. The empirical results imply that the variability trade-off does not hold in the period from 2009 Q1 to 2018 Q3.

■ WC-21

Wednesday, 12:30-14:00 - Y229a

General papers in Behavioural OR

Stream: Behavioural OR
Invited session
Chair: Hugo Herrera

1 - Problem structuring behavioral effects in revenue-sharing contracts
Jafar Rezaei, Rozhin Sharifi, Hamideh Razavi

Recent studies have shown that, in a newsvendor setting, order quantities placed by the buyers significantly differ from the expected profit-maximizing quantities. The differences could be related to different cognitive biases. Mitigating the effects of such biases in placing orders is essential. So far, research has focused on reducing the biases by mitigation strategies such as repeating and providing feedback, training, and decision support. Nonetheless, the effect of problem structuring on decisions has been overlooked. This study investigates the impact of provided order options and contract parameters (wholesale price and revenue share) on the retailer's inventory decisions in a revenue-sharing contract between a supplier and a retailer. To investigate such potential effects, we designed experiments consisting of ten treatments. We used the within-between subjects design and treatments differ in provided options and contract parameters. 240 students participated in our study, taking the role of a retailer placing an order to a computerized supplier. The between-subject factor is the options provided in five levels, and the within-subject factor is two revenue-sharing contracts with different wholesale prices and revenue shares. We found that limiting the options, placing the optimal order quantity in the middle of the provided options, and increasing the revenue shares and wholesale prices reduce the deviation of subjects' order quantity from the optimal quantity.

2 - Negotiator confidence in a dynamic bargaining model
Rudolf Vetschera, Luis C. Dias

We empirically study a bargaining model of boundedly rational negotiators, who in each step have to decide whether to accept their opponent's offer, terminate the negotiation, or continue with a counteroffer of their own. In each step, negotiators have a subjective expectation of the final outcome if negotiation is continued, which depends on their level of confidence in achieving a good outcome. The model, which is similar to the classical Zeuthen-Hicks bargaining model, predicts both the concessions made in each step, and the negotiation outcome, which corresponds to the asymmetric Nash bargaining solution. By comparing the model's predictions to bargaining processes and outcomes observed in online negotiation experiments, we find that the model is largely compatible with the observed process, but that actual agreements deviate from the predicted solution by being more concentrated at a moderate level of imbalance. We also find a close relationship between the negotiator confidence in the model and negotiator's (independently ascertained) aspiration levels, thus providing additional evidence for the model's external validity

3 - Biases and debiasing in analytically supported resource allocation and portfolio selection
Jyri Mustajoki, Juuso Liesiö, Mika Marttunen, Gilberto Montibeller

We study the biases related to the use of three approaches - decision analysis (DA), portfolio decision analysis (PDA) and cost-benefit analysis (CBA) - to support resource allocation in environmental planning. We identify different types of biases and discuss the possibility of them in these approaches. The identification of biases builds on the earlier work of Montibeller and von Winterfeldt on cognitive and motivational biases in decision and risk analysis (Risk Analysis 35(7), 2015), and it is widened to also cover PDA and CBA in resource allocation by a literature review on related review articles. We discuss how the characteristics of different approaches (such as interactions between actions, monetization of costs and benefits, a priori vs. a posteriori composition of portfolios) affect the possibility of biases, and techniques/protocols for debiasing. According to the results, each method is prone to numerous biases and errors, but there are also ways to reduce the risk of biases. However, the approaches have paid attention to debiasing differently. For the application of valuation techniques (e.g., contingent valuation) in CBA, there are certain protocols for debiasing, but in DA/PDA the identification of biases is more on the responsibility of the analyst because of the lack of clear guidance. Practitioners of different approaches can learn from each other's practices and therefore closer co-operation between CBA and DA/PDA practitioners would be welcome.

4 - Together, we think differently: Using group model building to frame resilience analysis in policymaking settings
Hugo Herrera

This study proposes to use Facilitated Modelling (FM) methods in an analysis of resilience in socio-ecological systems (SES). While resilience is a compelling framework for analysing adaptation mechanisms, our limited understanding of how SES works limits the extent to which resilience can be applied to real-world problems. Broad participation has been extensively discussed in the literature as a strategy for enhancing understanding regarding complex systems. However, the same literature still lacks practical details regarding how and when participation should occur. This study explores how FM serve as a framework to operationalise the participatory process in the analysis of resilience. Namely, it uses Group Model Building (GMB), a popular FM approach based in system dynamics methodology, to develop a common and robust understanding of small-scale farming systems in a rural community in Guatemala. The analysis found at least two indications of a learning process occurring during the GMB process. First, the CLD produced integrated all the main loops described during the interviews. Second, new feedback loops resulted from integrating these different structures. We hypothesise structure elicitation was a key contributor to these outcomes as we saw how participants linked variables suggested by different stakeholders' groups into a single explanation that was larger than the sum of the parts.

■ WC-22

Wednesday, 12:30-14:00 - Y229c

Logistics I

Stream: Supply Chain Management
Invited session
Chair: Alastair Main

1 - Analysis of supernetwork and hypernetwork applications in logistics and supply chain

Mohammad Kaviyani Charati, Hanno Friedrich, Sandra Transchel

Over the last decade, logistics and supply chain structures and characteristics have become more and more complex due to digitalization and globalization. Accordingly, different networks (financial, logistical, and informational) have been interconnected where the complex network importance has been more identified and highlighted in logistics and supply chains. Therefore, modeling and optimizing these complex networks is challenging especially since they are not independent and homogenous. Moreover, decision-makers have different criteria and objectives like environmental impacts where their individual decisions not only affect themselves but also others. This complexity of relationships among decision-makers has fueled the importance of complex networks applications. Despite the facts and significance, it seems that few attempts have been made to examine the development of complex networks including supernetwork and hypernetwork approaches in logistics and supply chain. To verify this, we use a systematic literature review to define complex networks and identify their importance and main applications in logistics and supply chains. Furthermore, the existing research in the areas is surveyed and analyzed. Finally, future research directions and new dimensions of the complex network applications in logistics and supply chains will be outlined.

Key Words: Logistics and supply chain, Complex network, Supernetwork, Hypernetwork, Optimization

2 - A constraint programming approach for the premarshalling problem with an auxiliary bay

Celia Jiménez-Piqueras, Kevin Tierney, Rubén Ruiz

The premarshalling problem aims to find the minimum number of crane movements necessary for reordering a set of containers placed in adjacent stacks in a port terminal so that each container is readily accessible at its retrieval time without performing any additional relocation. The classical formulation of the premarshalling problem assumes that every crane movement is performed inside the bay that needs to be reordered. However, in practice, it is possible to use an adjacent bay as a storage buffer if it facilitates the reorganization procedure. In this work, we propose a more realistic version of premarshalling where the use of an auxiliary bay is allowed and solve this using a constraint programming model. Furthermore, we investigate several different constraint programming formulations. We conduct experiments on realistic premarshalling instances and show that the new formulation provides solutions with less movements and crane operations than the classical one.

3 - The Dynamic RORO Stowage Planning Problem

Alastair Main, Dario Pacino, Filipe Rodrigues

The shipping industry's greenhouse gas emission reduction has received significant focus over the past years. One of the research areas is that of stowage planning for RORO vessels. Efficient stowage plans are necessary to reduce the turnaround time for vessels in port. Reducing turnaround time results in prolonged sailing time, allowing vessels to reduce fuel consumption through slow steaming. When RORO vessels have calls at several ports, they handle cargo as an approximately FILO queue. Therefore, cargo can potentially become blocked when stowing cargo for later ports, behind cargo with an earlier discharge port.

Planning the cargo assignment onboard the vessels also requires considering the arrival time of cargo at the port. Recent research assumes that all freight is available for stowage when the RORO vessels arrive at the port. However, this is not always the case. The unique elements of scheduling and generation of loading/discharge paths are therefore of academic interest.

We propose a novel mathematical model with a weighted objective function that minimizes the relationship between the fuel consumption cost and the revenue gained from shipping cargo. The model schedules the cargo loading sequence to reduce time spent handling and rehandling cargo at each port. The problem is studied for a single deck layout for a vessel calling multiple ports. Results of the mathematical model and accompanying metaheuristic will be presented.

4 - Inventory Routing Problem with Multiple Time Windows and Time-based Cost Structure

Nooshin Heidari, Ahmad Hemmati

We propose a mathematical model and a math-heuristic algorithm to solve an Inventory Routing Problem with multiple time windows and time-based cost structure. The problem is to manage distribution of products that are produced and consumed with different rates within a many-to-many distribution structure. A heterogeneous fleet is used to transport products. Vehicles are allowed to visit each node during its multiple predefined time windows. The total number of visits for each node is limited to a given number during time horizon. The min/maximum stock level for each product at each node is predefined. The quantity of product to be handled at each node is limited. We defined different shifts during time horizon in which economical and environmental costs of transportation and driver wage cost are varied. The other operational costs are fixed and variable handling costs. Given the complexity of the problem, we develop an Adaptive Heuristic to determine routing variables which combines with a mixed integer programming formulation to specify the rest of variables. The algorithm starts with applying a number of heuristics to decrease penalty function. Once the algorithm reaches to the original feasible region, other heuristics defined for finding the best solution of the original problem. The performance of the algorithm is assessed through several small and large-sized problems. The quality and running time provide us with promising results compared to the one reported by Gurobi.

■ WC-23

Wednesday, 12:30-14:00 - Y307

CBBM 2

Stream: EWG CBBM, EURO working group on Computational Biology, Bioinformatics and Medicine
Invited session
Chair: Marta Szachniuk
Chair: Maciej Antczak

1 - Resolving the reference genome in the Genomic Map of Poland

Aleksandra Swiercz

The first draft of the human reference genome was published more than two decades ago. Due to the technological limitations, it was full of gaps, especially in highly repetitive regions of centromeres and telomeres. Since that time, the reference genome was updated and corrected several times; until now, the newest version is GRCh38. DNA sequencing has become much cheaper in the last few years, and large sequencing projects are more popular. Many countries are sequencing large populations of individuals from their countries, which results in population genetic maps, with the most common variants that appear in the population. However, people noticed that the reference genome GRCh38, although well-annotated, is not sufficient to represent a given population. Several attempts were made in this area, and a few reference genomes were already published (e.g. Korea, China, Japan).

We present the results of the sequencing project called Genomic Map of Poland. The first polish reference genome is created de novo based on the trio: mother, father and child. In the pipeline, we used several technologies: short read, long high-quality reads (PacBio HIFI), artificial long reads (stLFR), long-distance contact reads (HiC), and ultralong reads (Nanopore). The result scaffolds, spanning the whole chromosome, were compared with the GRCH38 reference genome, showing the differences between the references.

2 - Processing and validation of population scale genomic data

Pawel Wojciechowski

Implementing a project where thousands of samples are sequenced is a demanding task. It requires high throughput sequencers, high-performance computing infrastructure and large data storage, as well as human resources and money. From the computer science point of view, especially when taking into account the whole genome sequencing it is also a challenge. Collecting and sequencing samples involve analysis of huge volumes of data. Processing a single human sample of standard size from raw data into germline variant calling takes around 30 hours on a CPU cluster node. In the case of the project Genomic Map of Poland, where genomes of around 5000 inhabitants will be sequenced, part of the work was outsourced, which caused new problems, e.g. with data transfer. Additionally, we had to introduce an additional stage of checking the consistency of the obtained results. Despite high expected overall quality of the data, some inaccuracies can be present, for example, samples may be swapped or files associated with a sample may have a wrong content. The data analysis we propose is for verification of correctness of such sequencing results provided on a massive scale.

3 - Improving the matching of genomic data with the crowd knowledge

Artur Laskowski

Understanding the human genome is a task that scientists have devoted much attention to over the last few decades. The enormous development of technology has reduced the total cost of reading the genome of a single human from a billion to a thousand dollars. The technology is not perfect yet; machines provide the genome divided into many overlapping sequences. We use ALGA, the fastest and the most reliable de novo assembly method. Despite the extraordinary speed of ALGA, it would take months to complete the task of assembling the genomes of thousands of people on a dedicated server. Given the problem with the amount of time and computational power required, we decided to propose a moderately faster approach. We want to perform the differential assembly (DA). The method uses the fact that human genomes are 99% alike. We assemble the next genome using common parts of a previously constructed assembly graph. The problematic fragments (structural variants) would be resolved separately. One of the challenging steps of DA is deciding which sequences of a new genome are connected to which parts of the previously assembled graph. We created the heuristic method using digraph matching, which performs decently. However, we decided to create an open contest on the optil.io platform for resolving this troublesome step. The problem is available on the optil.io platform, known for hosting optimization problems. We hope to use the knowledge of a crowd to improve our algorithm.

■ WC-24

Wednesday, 12:30-14:00 - Y307a

OR in Military and Defense Systems

Stream: OR in Military, Defense, and International Security

Invited session

Chair: *Tobias Andersson Granberg*

Chair: *Michael Bendersky*

1 - Artillery Firing Shift with Two Registration Targets

Michael Bendersky, David Raz

Firing Shift is the shifting of artillery fire from one target (registration) to another by the application of corrections determined from the adjustment of the initial firing data for the first target to the second (application). In this paper a shift method based on simultaneous firing at two different registration targets rather than a single one is introduced. A method is presented for using the observed data to solve explicitly for four major environmental parameters which affect ballistic trajectories and subsequently update them for the application mission. The distribution of the remaining errors is determined and compared with that of other correcting algorithms. Numerical examples show the potential of the proposed method.

2 - Capabilities Design for a Modular Block-Based Organization via Robust Optimization

Luis San Martin, Jorge Vera

A capability is defined as an ability that an organization exhibits to pursue an operational task. Although the concept is abstract, we can associate capabilities with minimal organizational modules called building blocks (BBs) which means that a BB delivers a particular capability. The design problem for an organization is to combine BBs to achieve a total desired capability. The problem exhibits a combinatorial nature but also various uncertainties, for example, in the capabilities as well as the required tasks to fulfill. In this work we propose a novel and tractable binary optimization model to allocate those modules under an additive rule i.e., all modules contribute with a specific capability that is aggregated to build the global desired capability balance. We use robust optimization to address uncertainties and we reformulate some nonlinear elements of the model to make it tractable. The results show that the effects of uncertainty can be effectively controlled by the robust solution at optimality. Finally, the relevance of this work is that we obtained a significant formulation that allows decision-makers to plan the organizational design not only from a qualitative perspective but also by estimating quantitative behaviors. This is especially crucial for emergency and first-response organizations all of which are service providers that cannot exhibit a lack of capabilities because of their relevance to society.

3 - Determining needs and functionalities of artificial intelligence control systems for military unmanned ground vehicles using virtual simulation

Christian Andersson, Ville Vatanen, Kai Virtanen

We discuss artificial intelligence (AI) concepts that are required for controlling unmanned ground vehicles (UGVs) during military operations. First, we classify requirements of AI into categories based on capability requirements in different military operations. Second, we describe a simulation experiment where the use of a multi-purpose UGV called Laykka is explored in a virtual battlespace simulator (VBS). VBS provides a virtual training environment for different kinds of battlefield situations. Laykka is an autonomous multi-modular military UGV. In the experiment, the mine module, recon module and anti-tank module of Laykka are tested. It is controlled by human operators consisting of commissioned officers, and armored reserve officer students act as opponents. Based on the results of the experiment, we determine needs and functionalities of AI for control systems of autonomous UGVs conducting mine, recon and anti-tank operations.

■ WC-25

Wednesday, 12:30-14:00 - Y308

Scheduling order picking operations in warehouses 2

Stream: Warehouse Design, Planning, and Control
Invited session
Chair: Shine-Der Lee

1 - A human-centric order assignment mechanism for warehouse operations
Thomas De Lombaert, Kris Braekers, René de Koster, Katrien Ramaekers

Warehouses play an important role in a company's supply chain and contribute to the failure or success of modern-day companies. Although many activities are performed within a warehouse environment, it has been established that order picking (OP) is by far the costliest. In order to control these costs, managers aim to organise the OP process in the most efficient way. However, this often comes at the expense of worker autonomy, resulting in boredom and motivation decrements. This particular research focuses on how and under which conditions work efficiency and worker autonomy can coincide in warehouse operations. In particular, we focus on the job assignment planning problem, a decision problem that regulates the sequence according to which orders should be retrieved, as well as the assignment of these orders to a cohort of pickers.

This work presents the design and first results of an experiment where pickers get the opportunity to participate in the assignment of orders. The experiment employs a within-subject design and 'order allocation mode' acts as independent variable. Rather than in an artificial lab context, this study is conducted in a real-life environment and evaluates both objective and subjective measures, such as economic KPIs and psychosocial constructs. The study's contributions and relevance for OR researchers are discussed in the context of human-centric order picking systems.

2 - A heuristic approach to replenish the forward area of a B2C warehouse while minimizing product stockouts
Babiche Aerts, Trijntje Cornelissens, Kenneth Sörensen

In a warehouse with a separate reserve and forward area, internal replenishments from the reserve to the forward area are crucial to avoid stockouts and support an efficient order picking process. We present a model for the internal replenishment problem assuming an out-of-rack forward reserve system, where (advanced) replenishment and picking occur in alternating waves. The aim of the model is to determine for the upcoming replenishment wave(s), which products to replenish, in which quantity, and by which replenisher, such that the number of products experiencing a stockout is minimized, and the limitations of replenishment capacity and time are respected. To solve this replenishment problem, we propose a heuristic solution approach inspired by the capacitated team orienteering problem, that aims to determine the most profitable selection of products to store while meeting time and capacity constraints. A various set of warehouse replenishment-instances is solved, characterized by different demand and initial inventory characteristics. We analyze the performance of our heuristic by comparing it to the results obtained by a mixed-integer linear solver. In addition, we study the importance of the different storage and replenishment policies for our objective, and we discuss the advantage of looking further than one pick wave.

3 - Scattered storage assignment: mathematical model and VNS meta-heuristic to optimize the intra-order item distances
Harol Mauricio Gamez Alban, Trijntje Cornelissens, Kenneth Sörensen

In scattered storage, individual items are intentionally distributed across multiple positions in the picking area. Especially in e-commerce environments, where orders typically consist of a few items in small quantities, such a storage policy can reduce picking travel times by increasing the likelihood that items belonging to the same order can be found in nearby positions. In this paper, we propose a scattered storage policy that, when determining the position where each replenished item should be stored, attempts to minimize the sum of pairwise distances (SPD) between all items belonging to the same order, including a drop-off point. Moreover, we propose a variable neighborhood search (VNS) metaheuristic to obtain for large instances near-optimal solutions in reasonable computation time. Computational results show that VNS improves the objective function by 6% on average, compared to the best results obtained using a truncated exact method. Finally, by implementing a picking routing algorithm, we prove that minimizing the SPD between items belonging to the same order helps to reduce the picking distances compared to a traditional storage allocation policy (volume-based) and a random scattered storage policy.

4 - A Cut-based Heuristic for Solving the Bi-directional Single-Row machine Layout Problem
Shine-Der Lee

The optimal assignment of workstations in a bi-directional linear flow layout with fixed input/output stations at opposite ends is to be determined to minimize the total material flow cost. Equivalence of this layout problem and the corresponding network optimization problem has been demonstrated. We also show that the minimization of total flow cost is equivalent to the minimization of total backtracking flow cost in this layout problem. An efficient polynomial time O(n4) algorithm that is based on the cut approach in the location model is developed and tested to find the optimum or near optimum sequence for equidistant linear layout problem, where n is the number of machines in the layout. The computational study has demonstrated that the proposed heuristic is efficient and effective. The average cost deviation is less than 0.6%, when the approximate solution is compared with that in the optimization model.

■ WC-27

Wednesday, 12:30-14:00 - Y313

Distributed and large-scale learning

Stream: BIGMATH - Mathematics for Big Data
Invited session
Chair: *Claudia Soares*
Chair: Stevo Rackovic

1 - Accurate and Interpretable Animation: An Iterative, Sparse and Nonconvex Approach
Stevo Rackovic

Digital human animation relies on high-quality 3D models of the human face - rigs. A face rig must be accurate and, at the same time, fast to compute. One of the most common rigging models is the blendshape model. We propose a novel algorithm for solving the nonconvex inverse rig problem in facial animation. Our approach is model-based, but in contrast with previous model-based approaches, we use a quadratic instead of a linear approximation to the higher-order rig model. As confirmed by the empirical results, this increases the accuracy of the solution and increases the sparsity of the resulting parameter vector - an important feature for interpretability by animation artists. The proposed solution is based on increment optimization, applied to a nonconvex constrained problem with sparsity regularization. In order to reduce the complexity of the iterates, a paradigm of Majorization Minimization (MM) is further invoked, which leads to an easy-to-solve problem that is separable in the parameters at each algorithm iteration. The algorithm is evaluated on a number of animation datasets, proprietary and open-source, and the results indicate the superiority of our method compared to the standard approaches based on the linear rig approximation. Although our algorithm targets the specific problem, it might have additional signal processing applications.

2 - Employing a consensus nonlinearity in distributed estimation under heavy-tail noise
Manojlo Vukovic, Dusan Jakovetic, Dragana Bajovic, Anit Kumar Sahu, Soummya Kar

There has been increased interest in distributed multi-agent algorithms for inference and learning over networks, motivated, e.g., by emerging Internet of Things (IoT) applications. A relevant aspect in the design of such methods is robustness with respect to imperfect inter-agent communications. Indeed, communications therein may be subject to noise that is often impulsive or exhibits heavy tails, or to various adversarial attacks. We present an algorithm for distributed estimation over networks that exhibits robustness to heavy-tail communication noise. To combat this noise, for which we allow to have infinite variance, the presented algorithm introduces a general nonlinearity in the so-called consensus update through which the neighboring agents combine their estimators. We present comprehensive results on strong theoretical guarantees for the distributed estimator, including almost sure convergence, asymptotic normality, and explicit evaluation of the asymptotic covariance. Several analytical and numerical examples further corroborate our findings and illustrate the effects of heavy-tail noise on the distributed estimation performance.

Acknowledgement. The work of M. Vukovic and D. Jakovetic is supported by the Ministry of Education, Science and Technological Development, Republic of Serbia, and in part by the European Union's Horizon 2020 Research and Innovation program under grant agreement No 871518.

3 - Permutation Compressors for Provably Faster Distributed Nonconvex Optimization
Alexander Tyurin

We study the MARINA method of Gorbunov et al (ICML, 2021) – the current state-of-the-art distributed non-convex optimization method in terms of theoretical communication complexity. Theoretical superiority of this method can be largely attributed to two sources: the use of a carefully engineered biased stochastic gradient estimator, which leads to a reduction in the number of communication rounds, and the reliance on independent stochastic communication compression operators, which leads to a reduction in the number of transmitted bits within each communication round. In this paper we i) extend the theory of MARINA to support a much wider class of potentially correlated compressors, extending the reach of the method beyond the classical independent compressors setting, ii) show that a new quantity, for which we coin the name Hessian variance, allows us to significantly refine the original analysis of MARINA without any additional assumptions, and iii) identify a special class of correlated compressors based on the idea of random permutations, for which we coin the term PermK, the use of which leads to significant improvement in the theoretical communication complexity of MARINA in the low Hessian variance regime. We corroborate our theoretical results with carefully engineered synthetic experiments with minimizing the average of nonconvex quadratics, and on autoencoder training with the MNIST dataset.

4 - Knowledge-based Initialization for Deep Neural Network Training
Argon Chen, Ann Shyu, Cheng-Hsi Chung

The Deep Neural Network (DNN) has been extensively applied to various areas. The DNN, however, is known to be a black box with limited explainability. A great deal of studies has now focused on developing explainable DNN and hopes to obtain knowledges from the networks. In contrast, our research takes a different direction by planting, but not being confined to, the prior knowledges into the DNN such that the deep learning can be fast and effective. All DNN learning requires initializing the network first. To ensure the information flowing through deep layers, Glorot (2010) studies the gradient changes between consecutive layers of neural network through the training process and found that following the principles of Glorot uniform based on Xavier's randomized initialization method is essential. The initial weights in a neural network are actually the initial solution to optimize the objective (loss) function and are crucial to the convergence and the effectiveness of the subsequent back-propagation updating process. In this research, network initialization will be used to implant prior knowledges into learning of the network based on the Glorot uniform for various types of DNNs. Initialization methods embedded with knowledge-based preferences are developed to help transfer learning. Datasets from internet open databases and delinked medical images will be then used to validate the proposed methods.

■ WC-28
Wednesday, 12:30-14:00 - Y405

Data Mining, Statistics and Uncertainty Management

Stream: Data Mining and Statistics
Invited session
Chair: *Gerhard-Wilhelm Weber*
Chair: *Mario Jadric*

1 - Exploring the potential of discrete-event simulation modelling to develop urban mobility scenarios
Mario Jadric, Maja Cukusic, Tea Mijac

The importance of smart cities and urban mobility issues and researches that derives from them are all supported by the projections of the growing urban population. Also, the increasing usage of IoT technologies in smart vehicles, smart infrastructure, and smartphones allows the development of new urban mobility models, scenarios, and services. Among all the simulation approaches, discrete-event simulation (DES), system dynamics and agent-based simulation were the most widely used in operational research to model business problems. This paper focuses on discrete-event simulation (DES) to highlight the importance of the process approach and promote it in the smart city context. DES can provide solutions to problems in cities by optimizing the transport of people, freight, and waste in more innovative ways. We present a systematic review with relevant studies where discrete-event simulation has been used to support the design of the enabling infrastructure for urban mobility development. For each stage of development of a specific discrete event simulation model, such as process mapping, input data modelling, model building, experimentation, and output analysis, specific examples applied in the urban mobility scenario were mapped. Finally, two scenarios were presented to show the potential of DES modelling in acquiring new knowledge of the simulated system in the urban mobility domain.

2 - Interpretable Cost-Sensitive Regression through One-Step Boosting
Thomas Decorte, Tim Verdonck, Jakob Raymaekers

Regression problems have, unlike classification problems, few effective methods to deal with cost-sensitivity, whilst there are many real-world cost-sensitive regression problems. These regression problems are often characterized by an asymmetric cost structure, where over- and underpredictions of a similar magnitude face vastly different costs. Several advances have been proposed for the post-hoc introduction of cost-sensitivity into a trained regression model. In this paper, we introduce a more general strategy for this post-hoc approach. We propose a one-step boosting method for cost-sensitive regression minimizing the average misprediction cost. Our method leverages a secondary learner to incorporate cost-sensitivity into an already trained cost-insensitive regression model. The secondary learner is defined as a linear function of variables deemed interesting for cost-sensitivity. These variables do not need to be the same as in the already trained model. Optimization is achieved through iteratively reweighted least squares using the asymmetric cost function. Empirical validation of our method on several public datasets, different cost functions and various initial cost-insensitive learning methods indicates a significant reduction in the average misprediction costs. The obtained results become interpretable through bootstrapping of our method, enabling decision makers to distinguish important variables for cost-sensitivity as well as facilitating statistical inference.

3 - Multi-objective Regression Modeling for Natural Gas Prediction with Ridge Regression and CMARS
Ayse Ozmen

Residential customers are the main users that generally need a great quantity of natural gas in distribution systems, especially, in the wintry weather season since it is particularly consumed for cooking and space heating. Hence, it ought to be non-interruptible. Since distribution systems have a restricted ability for supply, reasonable planning and prediction through the whole year, especially in winter seasons, have emerged as vital. In this study, two multi-objective regression models are developed for one day, and one week ahead natural gas demand prediction using Ridge Regression (RR) and Conic multivariate adaptive regression splines ((C)MARS) model. RR is formulated mainly to decrease collinearity results through shrinking the regression coefficients and reducing the impact in the model of variables. CMARS model is constructed as an effective choice for MARS by using inverse problems, statistical learning, and multi-objective optimization theories. In this approach, the model complexity is penalized in the structure of RR and it is constructed a relaxation by utilizing continuous optimization, called Conic Quadratic Programming (CQP). Here, CMARS and RR are applied to obtain forecasts of residential natural gas demand for local distribution companies that require short-term forecasts, and the model performances are compared by using some criteria as well as the mean absolute percentage error (MAPE) which is the main performance indicator for energy modeling.

4 - The effect of demand amplification into supply chain network designing
Pablo A. Miranda, Francisco J. Tapia-Ubeda, Luis Olivares-Álvarez, Salvatore Cannella, Roberto Dominguez

In the last decades, Inventory Location models are widely studied for Supply Chain Network designing, where inventories at warehouses are optimized jointly with traditional decision variables (i.e., warehouse location and customer assignments). In these models, customer demand's variability is a significant driver that may condition the optimal Supply Chain Network configuration. Besides, a well-known phenomenon that consists of demand amplification along the Supply Chain (i.e., the Bullwhip Effect) may also affect the inventory levels and the underlying Supply Chain Network configuration. However, this issue has not been studied in related literature. Accordingly, a novel Inventory Location Problem is proposed that explicitly integrates Bullwhip Effect as a fixed parameter for each potential warehouse. In the proposed formulation inventory control is modeled at each located warehouse and at a single plant that serve all the warehouses. A Generalized Benders Decomposition-based solution approach is developed, which efficiently and effectively solved the studied model. Well-known bounds for Bullwhip Effect at each warehouse are used in the numerical implementation, where the results significantly differ from a Supply Chain Network design solution without considering demand amplification, denoting the advantages of using the proposed novel formulation.

■ WC-29

Wednesday, 12:30-14:00 - M1

Integrated Problems

Stream: Industrial Production, Planning and Inventory Management
Invited session
Chair: Alexander Baumeister

1 - Integrated consideration of assembly line scheduling and line feeding
Pirmin Fontaine, Daniel Müllerklein, Frederik Ostermeier

Even though scheduling models for assembly lines determine the usage rates and the point of use of parts at the assembly line, no line feeding model till date integrates the operational production schedule decision into the tactical line feeding decision. Therefore, we introduce an integrated model and develop a new mixed-integer linear programming formulation that considers the interactions between both planning problems explicitly.

We apply the developed model in a real-life case study of a mixed-model assembly line from a first-tier automotive supplier. The numerical results show that both the cost-optimal line feeding policy decision as well as the resulting costs depend on the production schedule with the inherent degree of grouping of equal jobs and the product mix. Considering a leveled schedule, which is mostly done in currently line feeding models, can increase line feeding costs by up to 18 percent compared to optimal joint decisions where equal jobs are grouped. Further analysis shows that there also in the integrated model, there is no clear choice of schedules but it depends on the production mix. Thus, the scheduling decision has to become a crucial element of future line feeding models for mixed-model lines.

2 - Integrated Production Planning and Scheduling of the Steel-Production Processes Continuous Casting and Hot Rolling using Relax-and-Fix in a Rolling Horizon Procedure
Alexander Lohr, Hubert Missbauer

Production planning and scheduling in the steel industry is one of the most difficult industrial scheduling problems. Two major production steps of the energy-intensive steel production process are continuous casting (CC) and hot rolling (HR), which are often the bottleneck in integrated steel plants and often scheduled separately in practice. During CC, hot steel is cast through a mold as a strand which is cut into slabs. During HR, hot slabs are rolled flat to steel sheets. Between CC and HR, intermediate stages might be passed. Many publications on the separate scheduling of CC resp. HR exist. Compared to the few existing integrated scheduling approaches, our solution approach is the first to consider intermediate stages and allow an m:n relationship between the scheduling unit of CC (cast) and HR (rolling turn). Based on a novel model formulation for the integrated scheduling of CC and HR, a solution algorithm is developed that applies a rolling horizon procedure with two steps. In step 1 a specific two-stage lot sizing problem for technically similar slabs is solved that yields setup patterns for casts and rolling turns using relax-and-fix. Based on these setup patterns, in step 2 specific slabs are assigned. Numerical experiments using random variants of real data sets provided by a major Austrian steel plant show the functionality of the solution approach and indicate its applicability in large integrated steel plants with high product variety.

3 - Tabu search method using disjunctive graph modeling for flexible job shop with transport resources
Lucas Berterottiere, Claude Yugma, Stéphane Dauzere-Peres

The production of microelectronic devices is a complex process where many processing steps are required. The scheduling of these steps is core in the production process. A lot of work has been done on scheduling problems to optimize the production, especially on the Job-Shop Scheduling Problem and its extensions. The introduction of schedulers in modern factories has made it possible to better anticipate production operations and therefore to plan transport operations. The integration of transport operation into the production planning can help to improve the production schedule and avoid idle time on the machines. Our work focuses on the Flexible Job Shop with transport resources (FJSPT), which is a combination of two extensions of the Job-Shop problem: the Flexible Job-Shop, where several machines can perform the same task, and the Job-Shop with transport resources, where transport task between machines are considered.

In this conference, we will present our method to solve the FJSPT, including a disjunctive graph modeling and an extension of a Tabu search method used for the Flexible Job-Shop. We will present some results on instances from the literature and compare them with state-of-the-art algorithms and resolution methods.

4 - Capacity-driven performance optimization of hybrid product configurations
Alexander Baumeister

Bundling and hybrid value creation complicate operational performance management considerably. For example, product or service bundles may predetermine capacity requirements in subsequent periods by guaranteed follow-up services. Oftentimes, these capacity requirements may be largely beyond the company's own control and depending on the customer's call-off behaviour. Hence, traditional capacity, price and cost management approaches could be misleading, since the resulting stochastic (opportunity) costs have to be taken into account when configuring bundles. However, approaches that deal with the optimization of the bundle configuration considering lifecycle performance effects under capacity constraints for downstream partial services and operational design options such as overtime production, outsourcing or working time account management are scarce. Therefore, this paper deals with performance optimization of hybrid products considering joint stochastic utilization of capacity over time. For that, a planning model is developed and solved by simulation for a reference case.

■ WC-30

Wednesday, 12:30-14:00 - M237

Vector and Set Optimization IV

Stream: Vector and Set Optimization
Invited session
Chair: *Domenico Scopelliti*

1 - A solution method for rank-two programs involving linear fractional functions
Riccardo Cambini

Linear fractional functions are widely used in applications, for example in DEA models and efficiency models. In this light, bicriteria programs are assuming an important role in generalizing the applicative models. Efficient optimal solutions can be obtained by scalarizing the bricriteria objective function, thus obtaining a rank-two program involving linear fractional functions.

The aim of this talk is to present some preliminary results concerning a solution method for these very programs, that is to say rank-two programs involving linear fractional functions.

The approach is aimed to extend the one already presented in: - Cambini R. (2020), "Underestimation functions for a rank-two partitioning method", Decisions in Economics and Finance, vol.43, n.2, pp.465-489. ISSN 1593-8883. DOI: 10.1007/s10203-020-00288-6. - Cambini R. and I. Venturi (2021), "A new solution method for a class of large dimension rank-two nonconvex programs", IMA Journal of Management Mathematics, vol.32, n.2, pp.115-137. ISSN 1471-678X. DOI: 10.1093/imaman/dpaa001.

2 - Some remarks on scalarization in games with vector pay-offs
Elena Molho, Elisa Caprari, Lorenzo Cerboni Baiardi

Games with vector pay-offs play a relevant role to describe situations where the players evaluate the outcome in terms of conflicting objectives. Moreover, more recently, vector-valued utility functions have been proposed as a tool to represent incomplete preferences of the decision maker. Linear scalarization techniques, introduced by L. Shapley in 1959, are considered a standard tool for multicriteria game theory. We point out some drawbacks in the non convex case, related to the fact that not all the pure Nash equilibria are equilibria for the mixed extension of the game.

3 - Non linear scalarizations in non-cooperative multi-objective games: an axiomatic approach
Lorenzo Cerboni Baiardi, Elena Molho, Elisa Caprari

Along the line marked by L. Shapley in his seminal work "Equilibrium points in games with vector payoffs" (1959), we consider an axiomatic approach to scalarization that allows us to identify (pure and mixed) Nash equilibria in non cooperative games with vector payoffs. Properties of the scalarizing functions that are necessary and sufficient to find all Nash points through scalarization are identified. We show that the scalarization process we consider reduces to several other scalarization methods as special cases.

4 - Maximization of Preferences Without Numerical Representation: a Variational Approach
Domenico Scopelliti, Monica Milasi

In Decision Theory, a preference characterizes an individual's attitudes, perceptions, tastes, and inclinations with respect to the alternatives that are the object of choice. Once this is defined, the behavior of the individual considers the preference relation together with any other factor and/or constraint in order to make the best possible decision. This preference is described by means of a binary relation, and the individual does make the best according to it and the constraints in place. Debreu proved that, under certain assumptions on the set of alternatives and/or the binary relation, a preference can be represented by means of a real-valued function. In many real-world situations, the alternatives are vectors; this leads us to work with assumptions that are not sufficient to guarantee the existence of a real-valued function representing the preference relation. We present a variational approach to study a maximization problem of preferences that cannot be represented by a real-valued function. In particular, we opportunely characterize the preference maximization problem and we prove some regularity properties on the map of solutions of the relative parametric variational problem. The strength of our approach is that it relies only on the study of the strict upper counter set and the associated normal cone. We apply the theoretical results to an economic equilibrium problem under time and uncertainty.

■ WC-31

Wednesday, 12:30-14:00 - M240

(Semi-) infinite optimization

Stream: Variational analysis and optimization
Invited session
Chair: *Maria Dolores Fajardo*

1 - Duality and limiting formulas for convex infinite optimization problems
Miguel Goberna

We present a limiting formula for the conic Lagrangian dual of a convex infinite optimization problema which corrects the classical one of Karney [Math. Programming 27 (1983) 75-82] for convex semi-infinite programs. A reformulation of the convex infinite optimization problem with a single constraint leads to a limiting formula for the corresponding Lagrangian dual, called sup-dual, and also for the primal problem in the case when strong Slater condition holds, which also entails strong sup-duality.

2 - Fenchel duality for convex optimization on Riemannian manifolds
Jose Vidal-Nunez, Roland Herzog, Ronny Bergmann, Mauricio Louzeiro

This talk introduces a new duality theory that generalizes the classical Fenchel-Legendre conjugation to functions defined on Riemannian manifolds. We present that results from convex analysis also hold for this novel duality theory on manifolds. Especially the Fenchel–Moreau theorem and properties involving the Riemannian subdifferential can be stated in this setting. A main application of this theory is that a specific class of optimization problems can be rewritten into a primal-dual saddle-point formulation. This is a first step towards efficient algorithms.

3 - On subdifferentials via a generalized conjugation scheme: an application to DC problems and optimality conditions
Maria Dolores Fajardo, Jose Vidal

We present properties of a subdifferential defined using a generalized conjugation scheme. We relate this subdifferential together with the domain of an appropriate conjugate function and the ϵ-directional derivative. In addition, we also present necessary conditions for ϵ-optimality and global optimality in optimization problems involving the difference of two convex functions. These conditions will be written via this generalized notion of subdifferential set.

■ WC-32

Wednesday, 12:30-14:00 - F101

Logistics

Stream: YoungWomen4OR
Invited session
Chair: Dilek Gunnec

1 - Operations Research Application for Solving Transportation Problems
Lorena Reyes-Rubiano

Transportation is the backbone of the global economy. This abstract focuses on applying operation research methodologies to transport logistics problems. The primary methodology base is mixed-integer programming and heuristics. These methodologies allow addressing logistics problems in the private and public sectors. This abstract focuses on four research lines: 1. Logistics in the health sector: optimization of patients and medical staff transport. 2. Management of emergency situations, decision-making problems in the deployment of humanitarian aid. 3. Public transport operations: design an optimal tariff zone system. 4. Urban logistics include sustainability indicators studies of urban cartridges to evaluate mobility policies to reduce the negative impact of transport activities on society.

2 - Stochastic Nash Equilibrium Problems during emergency situations
Georgia Fargetta, Laura Rosa Maria Scrimali

We develop two different two-stage procurement planning model in a random environment. Firstly, we focus on evacuation planning which is a complex and challenging process able to predict or evaluate different disaster scenarios. In particular, we present an evacuation model where a population has to be evacuated from crisis areas to shelters, and propose an optimization formulation for minimizing a combination of the transportation cost and the transportation time. Secondly, we study the competition of healthcare institutions for medical supplies in emergencies caused by natural disasters. In particular, we consider a pre-event policy, in which each healthcare institution seeks to minimize the purchasing cost of medical items and the transportation time from the first stage, and a recourse decision process to optimize the expected overall costs and the penalty for the prior plan, in response to each disaster scenario. In these models the competitors simultaneously solve their own stochastic optimization problems and reach a stable state governed by the stochastic Nash equilibrium concept. Moreover, we formulate the problems as a variational inequality. In order to illustrate the modeling framework, we present a numerical example.

3 - Time is Money: Scheduling in Production and Logistics
Julia Lange

Decisions on sequences of activities must be made in various fields of production and logistics on a daily basis. Since an efficient use of resources, like manufacturing equipment, energy or road networks, is as important as customer satisfaction and smooth operation flows, fitting schedules are a key to economic success. At the same time, most scheduling problems belong to the hardest issues in combinatorial optimization. Throughout my carrier, I had the opportunity to work on several of these fascinating problems from theoretical and practical perspectives. This talk will give a short overview of my experiences, findings and future directions in this field. Considering production on the one hand, the blocking job shop scheduling problem with a lack of intermediate storage and the parallel machine scheduling problem with conflicts appearing in metal-working industries are two examples for classical scheduling issues with complex real-world constraints. For both, general mixed-integer programming techniques struggle in finding near-optimal solutions in reasonable time, while metaheuristic methods show promising results. However, the restrictions involved cause significant feasibility issues, and rugged solution spaces complicate the search for globally optimal schedules. Considering logistics on the other hand, scheduling tasks are of increasing importance when it comes to multi-tier city logistics systems. Transportation demands shall be fulfilled by heterogeneous fleets of vehicles with limited spatial resources at handover points in urban areas. Following the goal of minimal traffic and storage requirements, exact synchronization of all operated transportation services constitutes a challenging scheduling task to tackle.

4 - Using real-time information to plan a Smart Waste Collection Operation
Carolina Soares de Morais, Tania Ramos, Ana Paula Barbosa-Póvoa

Due to a high uncertainty associated with waste accumulation, waste collection is usually performed in an inaccurate, inefficient, and expensive way. To reduce the associated uncertainty, volumetric sensors can be installed inside waste bins to transmit real-time information about the amount of waste inside them. The sensor information may be used to feed computer systems based on operational research techniques so that smart waste collection routes are designed, resulting in a more efficient operation with higher service levels. To optimize waste collection, we develop optimization-based tools that define smart waste collection routes taking into account the fill levels of the bins and their locations in order to maximize profit (defined as the difference between the revenues obtained from selling the collected waste and the transportation costs of collecting that waste), considering different planning horizons (short and medium term). Furthermore, we develop a solution methodology to address the decision on which bins, from the whole set of waste bins, should receive a sensor, considering both the expensive investment value of the sensor and the economic gain provided by the early knowledge of information about the bin fill levels. We solve real large-scale smart waste collection routing problems and validate the proposed approaches using real case studies.

■ WC-33

Wednesday, 12:30-14:00 - F102

Game Theory, Solutions and Structures V

Stream: Game Theory, Solutions and Structures
Invited session
Chair: Marco Dall'Aglio

1 - A note on necessary and nullifying players
Margarita Domènech, José Miguel Giménez, María Albina Puente

We focus on multinomial probabilistic values,previously introduced by one of the authors in reliability and extended later to all cooperative games. The main characteristics of these values are:(1)each one of them is defined by n parameters(n being the number of players) and (2)the weighting coefficients of the value are generated in terms of these parameters. We attach to each parameter the meaning of tendency of each player to form coalitions. In the simple game case, each parameter can also be attached the meaning of tendency of each player to support a given proposal when this proposal is submitted to the approval of the collectivity. In this context, each parameter may be understood as the probability of each player to vote for the proposal. Here, we consider two special classes of players: necessary and nullifying players. Alonso-Meijide et al. proposed two new properties related to these players in order to characterize the Shapley and the Banzhaf values. The aim of this work is to introduce new properties that propose reasonable payoffs for this kind of players and to consider some classical properties as linearity, null player and null player exclusion property, in order to provide new axiomatic characterizations of each multinomial probabilistic value. In all cases, a set of independent properties that univocally determine them is given. As a particular case of one of these characterizations, we provide a new axiomatic characterization of the Banzhaf value.

2 - On the structure of anonymous voting games with abstention

Dani Samaniego, Josep Freixas

The structure of simple games has been studied in depth in various areas of study such as Boolean functions, reliability, code theory or game theory. In this work we extend the context of simple games to three alternatives and on the other hand we specialize to the context of anonymous games. An important link between these games and complete simple games allows us to find structural results concerning: the dimension, minimum integer representations of weighted games, trade robustness, etc.

3 - How to Share a Budget Based on Jointly Created Performance Scores

Frank Huettner

How should we split a given budget or burden based on performance scores of individual entities? How to do so if performance comes from joint efforts? We characterize rules for splitting a fixed budget that satisfy a simple monotonicity criterion, which requires that an individual entity shall not be punished whenever its contribution increases while at the same time the average performance of all entities is reduced. We show that ACE-rules (in advance, agree on a conversion rate for reward-to-performance; center and convert the measured performance to obtain transfers; equally split the budget) are the only anonymous and budget balanced rules that satisfy monotonicity. We provide a second characterization that relies on reallocation-proofness, which requires that a coalition of enities cannot achieve a higher payoff by transferring its performance scores. Our characterizations generalize to a setup where performance scores are the result of joint initiatives and reflect gains from cooperation, captured by a transferable utility game. We use analogous axioms to charactertize ACES-rules, which apply an ACE-rule to the Shapley value of the joint performances.

4 - Comparing notions of group decisiveness: differential vs. minimal essential orders of criticality

Marco Dall'Aglio, Michele Aleandri

The classical notion of criticality of a player in simple games, i.e. the ability of that player to change the outcome of a coalition, has been recently extended to include the cases where a player is effective only in conjunction with other players, the cardinality of the group determining the order (or rank) of criticality. We compare the definitions given in Beisbart (2009) and, more recently in Dall'Aglio M, Fragnelli V and Moretti S (2016). We show that power indices based on the differing notions can be decomposed in several parts, with one part shared by both: that of the critical players that belong to minimal essential critical coalition with respect to any given coalition of players.

■ WC-34

Wednesday, 12:30-14:00 - T003

Societal complexity and Governance

Stream: Ethics and OR
Invited session
Chair: *Dorien DeTombe*
Chair: *Cathal MacSwiney Brugha*

1 - Societal Governance: Atlantic Wind and Wave Protecting Europe from Energy Deficiency

Cathal MacSwiney Brugha

Two opposite approaches to governance power are societal and the individual, with the latter corporate or dictatorial. Both use political and institutional systems as mediators. The individual-driven approach takes resources, uses political means to bring resources to the people, then institutional means to make things of value, intending to give benefits to society. The alternative society-driven governance starts with communities, such as the people of Europe, and our energy deficit, our reliance on imported energy. It next makes European institutional systems source and distribute energy adequately to satisfy European societal needs. It then uses political means to bring energy from sources to institutions, and onwards to people. And finally it uses individual points of sourcing energy, to get the process of energy supply started. The current project is to distribute energy from the Atlantic across Europe. Its elements: First is 'bobbing energy': where Atlantic waves cause ships to bob up and down. Second: Atlantic wind is used to power jet engine wind turbines. Third: both are incorporated on redundant cruise passenger ships. Fourth: both wave and wind energy are converted into Green Hydrogen. Fifth: the Green Hydrogen is converted into electricity and brought into the grids. Institutions and politicians have vested interests in the old ways, and don't understand the opportunities. The EURO OR community should drive this, and also resolve its technical challenges.

2 - Better policy for pandemics

Dorien DeTombe

In the years 2020-2022 the SARS-CoV-2 pandemic created a disastrous situation in the whole world. Many governments panicked; what to do? Most governments were not prepared to handle a pandemic despite the long-time warnings from epidemiologists. In trying to diminish the deaths and mitigating the infection the governments tried to isolate people from each other by several lock-downs. This had negative consequences not seen by the governments for the well-being of people and special for the education of children. The governments should have been prepared for pandemics. Pandemics come and go. In order to do prepare themselves for the next pandemic the governments can get support of the Field of Societal Complexity based on the Compram methodology (DeTombe, 2015). The government policy can be guided to prepare for and mitigate the damages of a pandemic focusing not only on healthcare aspects but all aspects of the society.

Government, Policy Compram, Pandemic, Corona SARS-CoV-2

3 - How alarmism and generalizations impede diplomacy

Ulrike Reisach

Negative propaganda and nasty words are components of war. They are the opposite of mindfulness and caring for all individuals which shaped European discussions in recent years. It is time to learn how a rational, well-balanced discourse may foster mutual understanding as well as decisions for a fair compromise, collaboration and mutual or global benefit. This research will use historical and current examples to (1) explain how negative and generalizing comments and campaigns on both sides create anger and hate, (2) why and how the negative narrative will go viral globally, and (3) why a smart diplomacy by both sides is an art that is difficult to practice in the digital world. Generalizing, distancing, and cutting off contacts causes more problems than keeping in touch and trying to see the issues and goals from multiple perspectives. Even if there are few Ethics in war, mutual respect, humanitarian care and two-sided proposals during in-person meetings can and shall be applied to avoid further harm for all sides.

■ WC-35

Wednesday, 12:30-14:00 - T004

Railway Timetabling

Stream: Transportation
Invited session
Chair: Dennis Huisman

1 - An Exact Integer Linear Programming Formulation for the Passenger Oriented Timetabling Problem
Pedro José Correia Duarte, Marie Schmidt, Dennis Huisman

We present a new mathematical formulation for tactical railway timetabling that aims at minimizing total passenger perceived travel time. This new formulation for the POT problem of Polinder et al. (2022), uses as input a railway network, an existing line plan, and a demand matrix, and outputs a timetable. Contrary to general tactical timetabling models, we relax the assumption that line frequency is given as input in the mathematical model. Instead, we consider a maximum frequency, such that some lines' frequencies can be decreased. We come up with solution methods to solve the problem formulation and expect experimental results to improve on timetables created using current state-of-the-art methods that take line frequency as input. We will test the instances using the most utilised parts of the Dutch railway network as input and compare methods for the perceived travel time (including waiting time). In particular, we expect to see better results in specific cases where the trade-off between a lower average travel time and fewer trains running is possible.

2 - Modelling the Railway Network Design Problem with Capacity Expansion under Timetable constraints
Nadine Friesen, Tim Sander, Nils Nießen, Karl Nachtigall

Due to long planning and construction times, railway infrastructure is planned while only rough information about the intended operation is known. Hence, the timetable is adjusted to the infrastructure. Since space, time and budget for extension measures of railway infrastructure are limited, each modification should be planned with respect to the future demand.

Here, we determine the required expansion measures for future timetables. We model this railway network design problem as a minimum cost flow under capacity constraints with expansion costs. The objective of this problem is to minimize the expansion costs such that a given timetable can be executed. The timetable comprises a set of trains, each of which is defined by an origin and a destination node and a train type while being restricted by an earliest departure time and a latest arrival time. The capacity of some arcs can be expanded if the capacity constraints cannot be met for all trains within their respective temporal constraints. The capacity of railway lines is evaluated through the use of train-type- and train-sequence-dependent minimal headway times.

To incorporate the temporal aspect, we take two approaches: On the one hand, we model the arrival and departures times in each node as variables and on the other hand, we use a time expanded network. Both approaches are implemented using Python and solved by Gurobi. We present and compare these two approaches and give some computational results.

3 - Adjustment of the Dutch railway timetable under infrastructure maintenance possessions
Maaike Vollebergh

Railway timetables are designed to provide the best possible service on the entirely available infrastructure. However, preventive maintenance works are necessary in order to ensure safe and smooth traffic. Infrastructure maintenance is scheduled several months before actually carrying it out, and renders the nominal timetable infeasible. This research considers large-scale maintenance works that affect an entire day. We are looking for an adjusted timetable that minimises the deviation from the nominal timetable. As the Dutch railway timetable is cyclic, we compute a 1-hour timetable. Our macroscopic approach extends the work of Van Aken et al (2017). The proposed model is part of a prototype developed by the Dutch rail infrastructure manager ProRail and the Dutch passenger rail operator Netherlands Railways. Our aim is to support the planning process by finding good solutions for all practically relevant problem instances. Heuristics are used to find these solutions in reasonable time. Currently, the prototype excels at estimating the coherence between several maintenance possessions and giving out-of-the-box ideas. In this talk we demonstrate our approach with examples from practice, and we discuss the methodological and practical challenges we faced during the development process.

4 - Real-time train retiming of a CBTC suburban railway line
Hugo Meunier, Valeria Borodin, Stéphane Dauzere-Peres, Juliette Pochet, Sylvain Baro

Automated control systems deployed on suburban lines increase their performances. Compared to traditional lines, automatically controlled lines are more sensitive to disturbances. It may have a huge impact due to a higher traffic density. An efficient automated regulation policy is thus needed to tackle the impact induced by disturbances. This work aims to take advantage of the accuracy of the control systems, such as the Communication Based Train Control system (CBTC), to provide real-time instructions to trains. Dwell time and travelling time decisions are given to optimise both punctuality in sparse areas and frequency in dense areas. The real-time train timetable rescheduling problem for a CBTC suburban railway line is modelled as a multi-resource job shop scheduling problem. Each station is modelled as a conjunctive graph based on the planned timetable. Graphs are then linked by speed constraints to describe the whole system. Resource, signalling and headway constraints model industrial rules at a microscopic scale. As the CBTC system uses a moving block headway system, travelling times between stations are observed to depend non-linearly on the headways between trains. Travelling times are approximated by piecewise linear functions of headways between trains. These considerations help to provide feasible solutions in a real-time context. Tests are conducted on the simulated infrastructure of the E line in Paris, France, using simulation-optimisation approach.

■ WC-36

Wednesday, 12:30-14:00 - U006

Healthcare Applications

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: Alec Morton

1 - MILP model for designing menus for controlled feeding trials
J.c. Gerdessen, Karin Borgonjen-van den Berg

Controlled feeding trials (CFTs) are an important method to determine cause-effect relationships between dietary intake and health outcomes. Participants of a CFT receive full-day menus during a prespecified period of time. The menus have to comply with the nutritional and operational standards of the trial. Levels of the nutrients under investigation should differ sufficiently between intervention groups, and be as similar as possible within intervention groups. Levels of other key nutrients should be as similar as possible for all participants. All menus have to be nutritious and varied. Designing these menus is both a nutritional and a computational challenge that relies largely on the expertise of the nutritionist. The process is very time consuming, untransparent, nonreproducible, and last-minute disruptions are very hard to cope with. We present a MILP model to support the design of menus for CFTs. Use in a real-life case shows that the model helps to design menus in a fast, objective, transparent and reproducible way. The generated menus comply better with the standards of the trial than menus designed without the model. The model helps to propose several alternative menus and to handle last-minute disruptions. It can easily be adapted to suit trials with other components or different nutritional requirements. The model helps to lower the development cost of controlled feeding trials, and to improve their quality.

2 - New insight into the CATIE study by constrained confidence partitioning
Andreas Brieden

The CATIE schizophrenia trial was a very influential randomized controlled trial in patients with chronic schizophrenia. Patients were followed for up to 18 months under treatment with a randomly assigned antipsychotic. The primary endpoint, time to discontinuation of treatment for any reason, is influenced by individual patient characteristics, external factors as well as effects of drug treatment. New insight concerning time to discontinuation and the efficacy of different second-generation antipsychotics is obtained by applying an innovative survival analysis based on constrained confidence partitioning (ccp). Our findings suggest that ccp may assist in identifying relevant responder subgroups, probably missed by conventional statistical methods, making it a potential tool for personalized medicine.

3 - Managing drug prices in a complex competitive and regulatory environment using a multimethod scenario simulator
R Kazakov, Susan Howick, Alec Morton

Pharmaceutical markets are complex adaptive systems consisting of competing (on and off patent) drug firms, drug regulation authorities, parallel traders, doctors, patients and pharmacies. Managing drug prices requires taking account of the behaviors of competing actors and the effects of resource flow dynamics. This includes taking account of conflicting perspectives such as drug firm strategies and drug price regulation, both of which should be subject to achieving the key healthcare goals of providing and maintaining availability and affordability of on patent and off patent drugs on local and global markets. This work takes account of the above two conflicting perspectives through simulation experimentation using a multimethod scenario simulator. The work demonstrates that this decision support tool can be used to find a strategy that satisfies these seemingly contradicting perspectives. Achieving this can help to maintain key healthcare objectives of providing equitable and affordable drug therapies to patients with minimum or no drug market entry delays, drug market exits or excessive drug pricing. The scenario simulator used in this work applies a hybrid agent based and system dynamics simulation model to explore the above-mentioned behaviors and their effects on the pharmaceutical market systems (both local and global). This includes its impact on agents' decision making and resource feedback dynamics. The development of the hybrid simulation model was supp

4 - What is the value of explicit priority setting for health interventions? A simulation study
Alec Morton, Euan Barlow, Saudamini Dabak, Sven Engels, Wanrudee Isaranuwatchai, Yot Teerawattananon, Kalipso Chalkidou

Many countries seek to secure efficiency in health spending through establishing explicit priority setting institutions (PSIs). Since such institutions divert resources from frontline services which benefit patients directly, it is legitimate and reasonable to ask whether they are worth the money. We address this question by comparing, through simulation, the health benefits and costs from implementing two alternative funding approaches - one scenario in which an active PSI enables a cost-effectiveness-threshold based funding decisions, and a counterfactual scenario where there is no PSI. rule compared to a number of baseline comparator funding rules. We present indicative results for two one datasets from the United Kingdom (published in 2015) and one from Malawi (published in 2018), which show that the threshold rule reliably resulted in decreased health system costs, improved health benefits, or both. Our model is implemented in Microsoft Excel and designed to be user-friendly, and both the model and a user guide are made publicly available, in order to enable others to parameterise the model based on the local setting. Although inevitably stylised, we believe that our modelling and results offer a valid perspective on the added value of explicit PSIs.

■ WC-37

Wednesday, 12:30-14:00 - V001

Routing Problems Under Uncertainty

Stream: Vehicle Routing and Logistics
Invited session
Chair: *Fabien Lehuédé*
Chair: *Maria I. Restrepo*

1 - Stochastic modeling and algorithms for the Dynamic Vehicle Routing Problem with Urgent Tasks
Jasper Bos, Richard Boucherie, Dylan Huizing, Diego Pecin, Remy Spliet

We consider the problem of routing a fleet of vehicles over regular, plannable tasks and dynamic, urgent tasks that arise following a random process. Our objective is to minimize response time to urgent tasks while maintaining efficient operation for the regular tasks. We develop a Markov Decision Process that may be solved to optimality for small instances. For larger instances, we develop an approximate solution using Approximate Dynamic Programming and Reinforcement Learning. Our approach fully exploits the available information on the random nature of urgent tasks, which allows us to further reduce response time compared to models available in literature, among others, due to an improved spatial and temporal spread of vehicles over the service area. The routing problems arise, for example, in cleaning, maintenance and security applications.

2 - Capacitated Vehicle Routing with Stochastic Loading Constraints
David Winkelmann, Jakob Schulte, André Hottung

The optimisation of operational processes related to the transportation of products is of crucial importance for many companies. Using homogenous vehicles for the shipping process of packages requires the allocation of customers to tours with respect to constraints caused by the characteristics of the vehicle, e.g. volume and maximum loading weight. However, if the shape of packages is highly heterogeneous, the achievable fill rates vary and, e.g. in case of a manual packing process, are unknown when the tours are determined. This leads to an optimisation problem under uncertainty addressing the trade-off between routing costs and additional (penalty) costs if not all packages can be loaded into the trucks as planned. We propose to model the problem as a capacitated vehicle routing problem that integrates a binary regression model to estimate the probability that the packages do not fit into a truck. Using Taylor series expansion of the exponential function allows to reduce the transformation of the linear predictor to a polynomial term, which can be directly incorporated into the Gurobi optimiser.

3 - The Hazardous Orienteering Problem
Alberto Santini, Claudia Archetti

The Hazardous Orienteering Problem (HOP) is a stochastic generalisation of the classical Orienteering Problem. In the HOP, some customers load hazardous items on the vehicle. Each item has a probability to explode which depends on its travel time onboard. If any item explodes, the entire content of the vehicle is lost. Besides routing hazardous material, the HOP has applications in law enforcement and cash-in-transit problems. We present a non-linear formulation, several bounds, and both exact and heuristic algorithms.

4 - Tour Scheduling in Attended Home Delivery
Maria I. Restrepo, Fabien Lehuédé, Tom Perroux

We study a tour-scheduling problem for an attended home delivery problem with uncertain order requests. The problem is modelled as a two-stage stochastic programming problem and solved using the multi-cut L-shaped method. Weekly working patterns are generated by means of a pricing heuristic. Numerical results on randomly generated instances show that including weekly working rules increases the total cost by only a small amount (up to 2.54%) when compared to an approach that only considers daily working rules for the generation of driver schedules. These results also show that increasing flexibility in the definition of working patterns could lead to important cost savings.

■ WC-38

Wednesday, 12:30-14:00 - V002

Public Transportation

Stream: Transportation
Invited session
Chair: *Oskar Eikenbroek*

1 - A welfare optimal model for intermediate public transportation services
Atanu Bhuyan

Improving the efficiency and service quality of intermediate public transportation (IPT) modes can enable the personal-to-public transportation modal shift, which is a desired step toward sustainable urban mobility. The mobility market that IPT modes operate in can be segmented based on the mode preferences and accompanying hassle cost. Considering the dearth of research on the commuters' perception of the service quality of IPT modes, we examine how the different user segments perceive the same against other competing modal options of ride-hailing and personal car modes in providing first/last mile connectivity. We use a game-theoretic approach to study government policy interventions to enhance the social welfare of the concerned stakeholders. An analytical model embodying the research problem is developed and solved to help capture the tactical interactions among the various stakeholders. Our findings offer policy tools to help boost IPT ridership and curb the traffic congestion problem on account of growing private car ownership.

2 - An adaptive modular evolutionary scheme for solving the integrated timetabling and vehicle scheduling problem
Lucas Mertens, Bastian Amberg, Natalia Kliewer

Public transport planning is historically a hierarchical process and can be divided into multiple sequential planning problems. Our study focuses on solving the Timetabling Problem (TT) and the Vehicle Scheduling Problem (VSP), building the connection between tactical and operational public transport planning. Given a network and line design, the TT aims at achieving a high range of passenger service while keeping the total anticipated costs for serving the timetable reasonable. The VSP is concerned with allocating service trips to specific vehicles at minimal costs. In contrast to solving the TT first and the VSP second, we utilize an integrated solution approach to achieve further improvements. Since solving real-world instances for either planning step is considered NP-Hard, an integrated solution approach increases the solution space, hence the complexity. We apply an adaptive modular evolutionary scheme to weight and manage heterogeneous recursing solving heuristics. Neither heuristic is capable of optimally solving the decision problem solely. However, by executing promising once repeatedly and by locating patterns for multiple ordered executions of heterogeneous heuristics, we are able to integratedly solve the TT and VSP. By utilizing this approach, the overall costs of the VSP can be reduced while keeping the TT quality equally good compared to sequential planning.

3 - Social rerouting in public transport networks
Oskar Eikenbroek, Xiaojie Luan, Francesco Corman, Eric van Berkum

The services of many public transportation systems are regulated by pre-defined timetables. In order to satisfy the demand at best, researchers and practitioners have been seeking robust demand-oriented scheduling approaches while keeping a low operation cost. Tactical decisions are limited to supply-side measures, typically made in the long term based on historical data. Such measures fail to quickly react to short-term changes in passenger demand and disturbances. Where the realized level of service (LOS) might be substantially different from what was expected, demand management measures, such as advising travelers to use specific routes in the interest of congestion and travel time of the entire population (social rerouting), can be implemented alongside supply-side measures to improve the LOS over different timescales. In this study, we introduce multimodal social rerouting strategies to improve the LOS of public transport networks by asking a portion of the demand to change departure time, line or service. In fact, we balance network load by rerouting passengers using a centrally-coordinated information strategy. Such a strategy anticipates feedback effects in (over)crowding by incorporating behavioral responses to advice over different timescales. We explore theoretical and practical challenges by evaluating effectiveness and performance of strategies using real-world data from the Zürich public transport network.

4 - Empirical Analysis of the Depreciation of Electric Vehicles compared to Gasoline Vehicles
Lukas Schloter

The depreciation pattern of passenger vehicles is an important input parameter for economic considerations of buyers and other stakeholders such as financial institutions. Due to their technical specifications and uncertainties in respect of their degradation and life expectancy, it seems plausible that electric vehicles depreciate differently to conventional vehicles. In my research, I gathered over 24,000 data records on used vehicles to empirically analyze the depreciation of electric vehicles. The results show that vehicles have a degressive depreciation relationship over the age of the vehicle, but that electric vehicles have a substantially higher depreciation of 1.16% per month (13.9% per annum) compared to gasoline vehicles with 0.87% per month (10.4% per annum). Consequently, research into the economics of vehicles and budgeting considerations should apply a different depreciation rate for electric vehicles than for conventional vehicles.

■ WC-39

Wednesday, 12:30-14:00 - U8

MAI: OR in action

Stream: Making an Impact
Invited session
Chair: *Michele Quattrone*
Chair: *Waldemar Kocjan*

1 - Ever-decreasing circles: how iterative modelling led to better performance at Seagate Technologies
Robert Moss

Real world wafer fabricators have multiple manufacturing Key Performance Indicators such as throughput, cycle time, load balancing between tools, reticle moves and batch size. Some of these KPIs might be conflicting, for example maximising the throughput of a photolithography toolset while reducing the number of reticle movements between tools. This talk describes the iterative development with Seagate Technologies of Flexciton's novel solution strategy that combines MILP optimisation with heuristic techniques to schedule thousands of wafers and a large variety of tool types. This has been deployed in Seagate fabs and using Seagate's production data I'll show how we discovered constraints, improved the workflow and tuned the objective weights to achieve significant KPI improvements in low/high WIP and slow/fast moving toolsets.

2 - Reducing flood impact on healthcare accessibility in developing countries
Britt van Veggel

The UN Sustainable Development Goal 3.8 aims to achieve universal access to essential healthcare services. To achieve these goals, the Analytics for a Better World Institute has developed a toolbox that////optimizes locations of healthcare facilities. In many developing countries, access to healthcare is hindered by floods, as they can cause roads to become inaccessible for a long period of time. The newest addition to our toolbox is////an optimization methodology that minimizes the impact floods have on healthcare accessibility through road interventions. In this talk we show how our toolbox has been applied to Timor-Leste to improve healthcare accessibility by finding optimal locations of hospitals and optimizing investments for road upgrades. We extensively discuss the challenges of data availability and the huge scale of the optimization problems.

3 - Implementing deep learning in digital railway control rooms
Marijn Verschelde, Léon Sobrie

While all predictive models rely on data, only some firms conduct predictive analytics in a full data-driven fashion via machine learning. In many business settings, predictive analytics pivot on inflexible rule-based models. However, business systems are becoming increasingly integrated, complex and heterogeneous, resulting in an exponential increase in the number of required rules. In this */presentation/*, we show the usefulness of deep learning for data-driven decision support in the context of digital railway traffic control rooms and general punctuality management; and discuss the tool we developed for the Belgian railway infrastructure company Infrabel. This tool provides visuals tailored for the traffic controller, traffic supervisor and punctuality manager at the digital control rooms. The application and near real-time implementation of our advocated DL-based predictive model are made possible by the data structure uniquely created for this project, entailing railway traffic and infrastructure data for the entire railway network.

4 - Putting the action into OR
Ruth Kaufman

This closing talk in the 'Making an Impact' stream will review some of the issues raised by the previous talks and the earlier sessions in the stream, not least the fact that for OR to have impact on the rest of the world, it needs a customer - moreover, an active customer, who is the crucial link in the chain converting the insights or modelling outputs from OR to real-world systems, processes or decisions. We will invite discussion and contributions from the audience.

Wednesday, 14:30-16:00

■ WD-01

Wednesday, 14:30-16:00 - A

Jacek Gondzio

Stream: Keynotes
Keynote session
Chair: Antonio Frangioni

1 - New Optimization Techniques for Sparse Approximations
Jacek Gondzio

A variety of problems in modern applications of optimization require a selection of a 'sparse' solution, a vector with preferably few nonzero entries. Such problems may originate from very different applications in computational statistics, signal or image processing or compressed sensing, finance and machine learning, to mention just a few. Sparse approximation problems are often solved with dedicated and highly specialised first-order methods of optimization.

In this talk I will argue that these problems may be very efficiently solved by the more reliable optimization techniques which involve some use of the (inexact) second-order information as long as this is combined with appropriately chosen iterative techniques of linear algebra, such as for example methods from the Krylov-subspace family. Two particular classes of methods, the Newton Conjugate Gradient and the Interior Point Method will be interpreted as suitable homotopy type approaches and will be applied to solve problems arising from: compressed sensing, multi-period portfolio optimization, classification of data coming from functional Magnetic Resonance Imaging, restoration of images corrupted by Poisson noise, and classification via regularized logistic regression. In all these cases, the performance of the proposed methods will be compared against competitive first-order methods. Computational evidence will be provided to demonstrate that specialized second-order methods compare favourably and often outperform the cutting-edge first-order methods.

■ WD-03

Wednesday, 14:30-16:00 - C

Mathematical Optimization, Machine Learning and Supply Chain

Stream: Machine Learning and Mathematical Optimization
Invited session
Chair: Emilio Carrizosa

1 - Cost patterns learning trough logistic and sorting models integration in Waste Management
Diego Maria Pinto, Giuseppe Stecca, Marco Boresta

New advanced information systems, digital technologies and mathematical models are required to achieve the targets of sustainability and circular economy paradigms. Circular economy includes products, but also infrastructure, equipment and services offered by waste recycling centers where materials are collected and then sorted to be converted in secondary raw materials. This scenario imposes a new view of operations with the aim of zero waste, in order to obtain this result it is critical to adopt an holistic approach and to optimize every step of production and logistics processes. These targets are addressed in this work by the development of an integrated models framework that is fueled by data and supported by two OR models. In the presented framework, the output of each model becomes an input of the following one. A mixed integer programming model is used to optimize the sorting operations while a pick-up and delivery routing model supports the logistic operations. Once both logistic and sorting processes have been optimized, a machine learning model performs process cost analysis. Decision makers can use these outcomes to support and verify management decisions, such as updating contracts of loss making customers or increasing service level in profitable locations. Validation of the approach is done with data of a real test case with promising preliminary results.

2 - The role of big data on bullwhip effect under rationing game: A control-theoretic approach
Christos Papanagnou

Recent examples are drawn from supply chain disruption events (e.g., Covid-19, Brexit) showed that retailers often compete by inflating their order quantities in order to tackle inventory shortages. This phenomenon is known as the rationing game and makes up a contributing factor to the bullwhip effect in supply chains. This presentation investigates the impact of using big data to mitigate the bullwhip effect when a rationing game is present. A novel two-node supply chain model is presented, where base-stock replenishment policies are modelled by a proportional controller. Customer demand is represented by a stochastic sequence, while the model is analysed under stationarity conditions with the aid of a covariant matrix. This allows expressing the bullwhip effect as a function of replenishment policies and big data attributes. Sharing information policies are also examined to explore the impact of big data on minimising inventory levels, leading to bullwhip effect alleviation.

3 - A Bilevel Optimization Approach for Feature Selection in the Data-Driven Newsvendor
Breno Serrano, Stefan Minner, Maximilian Schiffer, Thibaut Vidal

We study the feature-based newsvendor problem, in which a decision-maker has access to historical data consisting of demand observations and related features. Existing approaches integrate demand estimation and inventory optimization by learning a decision function that predicts order quantities directly from features. In this setting, we investigate the task of feature selection, aiming to derive sparser, more explainable models with improved out-of-sample performance. State-of-the-art methods for feature selection utilize regularization, for which the user must specify a regularization parameter heuristically. To remedy this drawback, we introduce a bilevel programming formulation that avoids explicit regularization. Our upper-level problem selects a subset of features that minimizes an estimate of the out-of-sample cost of ordering decisions based on a held-out validation set. In turn, our lower-level problem learns the optimal coefficients of the decision function on a training set, using the selected features. We present a mixed integer linear program (MILP) reformulation for our bilevel program and solve it to optimality with branch-and-bound algorithms. Our computational experiments show that our method accurately recovers ground-truth features already for instances with a sample size of a few hundred observations. In contrast, previous techniques often fail at feature recovery or require thousands of observations for similar accuracy.

4 - Derivative-free optimization in value chain optimization
Damien van de Berg, Antonio del Rio Chanona, Nilay Shah

Enterprise-wide optimization aims to coordinate all geographically distributed and hierarchical layers of decision-making within enterprises. A centralized solution requires integration of all decision-making units into a single model and is thus in practice often hindered by game-theoretical and numerical considerations: The conflicting objectives of coordinating decision-makers are realistically represented by large-scale multilevel and multiobjective problems; this makes their solution not only numerically intractable, but also mathematically difficult.

However, these formulations present mathematical structures that lend themselves well to data-driven techniques. We present variations on a multi-agent case study, where geographically distributed plants (the agents) along the same value chain coordinate on connecting material streams to optimize their inventory management subject to optimal scheduling. We show different ways that derivative-free optimization (DFO) can be leveraged to make an otherwise intractable problem solvable with little optimality gap. DFO can be used on the agent level to find the optimal set of upper-level planning variables; additionally, DFO presents a competitive alternative to distributed optimization: It can find the complicating, ‘coordinated’ material stream variables when the subproblems are ill-behaved and optimization software cannot be used in a centralized formulation due to agent, organizational, or privacy considerations.

■ WD-04

Wednesday, 14:30-16:00 - D

The role of Statistics in Machine Learning algorithms

Stream: Machine Learning and Mathematical Optimization
Invited session
Chair: *M. Remedios Sillero-Denamiel*
Chair: *Sandra Benítez-Peña*

1 - Clustering in FDA applying machine learning and statistical techniques
Belén Pulido Bravo, Alba M. Franco-Pereira, Rosa Elvira Lillo Rodríguez

Clustering is considered as one of the most used techniques in Data Science. Clustering functional data is a challenging problem since it involves working in an infinite dimensional space. To tackle this problem, the functional dataset is converted into a multivariate one by applying different functional indexes: the epigraph and the hypograph. Once the multivariate dataset is available, statistical and machine learning procedures typically used for clustering multivariate data can be applied to solve our problem. This process is followed considering simulated and real datasets, outperforming different methodologies available in the literature for clustering functional data.

2 - Estimating Class Probabilities in SVM
Sandra Benítez-Peña, Rafael Blanquero, Emilio Carrizosa, Pepa Ramírez-Cobo

Support Vector Machines (SVMs) are one of the best examined and used machine learning models for two-class classification. Here, classification is based on a score procedure, which provides a deterministic classification rule, but does not provides probabilistic outcomes in a natural way. In this work, we propose a novel approach to generate probabilistic outputs for the SVM. The highlights of the paper are: First, a SVM method is designed to be cost-sensitive, and thus the different importance of sensitivity and specificity is readily accommodated in the model. Second, SVM is embedded in an ensemble method to improve its performance, making use of the valuable information generated in the parameters tuning process. Finally, the probabilities estimation is done via bootstrap estimates, avoiding the use of parametric models as competing probabilities estimation in SVM. Numerical tests show the advantages of our approach.

3 - Evaluation of the treatment alternatives for spinal cord tumor using fuzzy-promethee
Berna Uzun, Efe Precious Onakpojeruo, Ilker Ozsahin, Dılber Uzun Ozsahin

Spinal cord tumors are the abnormal mass of cells that grow, divide and multiply uncontrollably in the spinal cord. About 2500 new cases of spinal cord tumors are diagnosed annually in the United States, and it occurs most often in people between the age group of 20 and 60 years (American cancer society report 2022). Spinal cord tumors can either be benign or malignant tumors. Treatment of spinal cord tumors is dependent on the type, the affected site, the level of complications, and the levels of spread. The treatment of spinal cord tumors is not limited to conventional methods of chemotherapy, radiotherapy, and surgery, but also other techniques which include immunotherapy, targeted therapy, proton therapy, interventional radiology, radiofrequency ablation, and cryoablation. This study compares the treatment alternatives of spinal cord tumors using a Multi-criteria Decision-making technique called fuzzy preference ranking organization method for enrichment evaluations. The criteria for each alternative are includes reliability, use in isolation, cost of treatment, complications during use, side effects after use, pain relief rate, recovery period, session duration, necrotic tumor rate, and survival rate. Results show that Radiofrequency ablation with the highest net outranking flow (0.2717) was the best treatment alternative for the spinal cord tumor. Cryoablation therapy counted as the second (with 0.1167 net flow), and the surgery follows (with -0.0346 net flow).

4 - Bayesian Regression for Selection Bias
M. Remedios Sillero-Denamiel, Simon Wilson, Hieu Cao

In the regression setting, it is typically assumed that training and test sets follow similar distributions, but that is not always true, as is the case with the sky surveys of galaxies where faint ones are not observed in favour of brighter ones. In addition, when data follow complicated non-Gaussian distributions, the full conditional density has to be estimated to properly quantify the uncertainty in the predictions. We present a Bayesian approach to estimate the conditional density under selection bias.

■ WD-05

Wednesday, 14:30-16:00 - E

Data Driven Decision Making

Stream: Data Driven Decision Making
Invited session
Chair: *Wouter Verbeke*
Chair: *Kristof Coussement*

1 - Modeling with Hybrid Segmentation Methods: A Statistical Library for R and Python
Trung Hoai Minh Phan, Kristof Coussement, Koen W. De Bock, Arno De Caigny

In business analytics, segments or homogeneous groups exist naturally everywhere. Among a group of customers or companies, there are always segments with distinct characteristics, preferences, needs, and reactions. Individuals in those segments, therefore, could be studied and treated differently to maximize the efficiency of business activities. Most of the machine learning prediction algorithms treat such individuals as the same group, however, recent studies have proven that categorizing them into different segments for modeling may significantly increase the predictive performance and comprehensibility of the model. In this study, we introduce a statistical library for R and Python that contains two hybrid segmentation methods for binary classification and uplift modeling. Each of the two implemented methods is benchmarked with other standard models on 5 sets of data from marketing, finance, and education topics. Final, we create cases studies to demonstrate their applications.

2 - An optimal effectiveness-driven target segment selection modeling approach for marketing campaign management
César Salazar Santander, Alejandro Mac Cawley, Carolina Martínez

Defining a target group for a mass marketing campaign is a non-trivial goal, which depends on the correct definition of a commercial stimuli and the selection of a customer segment that will maximize the effectiveness of the campaign, demanding the analysis of multiple variables and interactions. The problem becomes more complex when we consider, for a particular commercial action, a limited budget. We propose a methodology based on a mixed multi-objective optimization formulation that allows to determine which continuous segments customers to target in massive campaigns in order to maximize its effectiveness with a maximum budget constraint. The model multi-objective function maximizes the effectiveness of the campaign while minimizing the "broadness" of the segments targeted, allowing to detect the most effective and homogeneous target group possible for a commercial action within a set of n continuous variables. The methodology performance was benchmarked against traditional customer segmentation algorithms (K Means and Spectral Decomposition) together with Greedy selection methodologies. The experiments were performed in 1. simulated data environments and 2. based on real campaign information. The compared scenarios show that 1. the proposed methodology outperforms the baseline models by locating the optimal possible campaign target and 2. the complexity of the problem scales non-linearly by reducing the budget and increasing the number of variables under study.

3 - Interpretation in models for crime prediction
Joaquín Roa, Kristof Coussement, Sebastian Maldonado, Richard Weber

Delinquency is a major concern in many countries worldwide. Several approaches from social sciences, among others, have been proposed to address this challenge for public policymakers adequately. Lately, advanced technologies, such as, e.g., artificial intelligence, big data, and data science have contributed to developing more sophisticated solutions to this problem. Machine learning-based crime prediction models are a fundamental part of public policy implementation and public decision-making supported by artificial intelligence. Therefore, their development and deployment must always consider interpretability and avoid inherent biases relating to the data sources, data collection, and city crime distribution overall. Even further, the results from the machine learning predictions must be readily available for public policymakers, who might rely on interpretable data science for decision-making techniques and support systems for their proper territorial development. In this presentation, we focus on data collection, processing, and model implementation when developing crime prediction machine learning models, and we present a use case developed using a dataset from a mobile application collecting user reports regarding public security (FONDEF ID20I10230ANID).

4 - A Learning Analytics application for data-driven improvement implementation in Higher Education
Nidia Guadalupe Lopez Flores, María Óskarsdóttir, Anna Sigríður Islind

Data analysis and data-driven decision making have been the cornerstone of improvements in several fields, including economics, healthcare, and logistics. Learning analytics (LA), defined by the Society of Learning Analytics Research as: "the measurement, collection, analysis and reporting of data about learners and their contexts, for purposes of understanding and optimising learning and the environments in which it occurs" has grown since the last decade as a leveraging field for educational research. In this paper, we present an application of LA and data-driven decision making in higher education. Data of five courses were gathered through the learning management system (LMS), cleaned, and analysed to identify and evaluate changes in the students' interaction activity between (1) 2019 and 2020, under pandemic restrictions; and between (2) 2020 and 2021, after a data-driven modification in the structure of teaching was implemented. Qualitative information from interviews with the teachers was helpful to get insights about teaching methods, assessment structure, and classroom technology used in the courses, whereas interviews with students were conducted to evaluate their opinion about the change. Results from (1) provide insights on how the interaction with the LMS relates to the year of study, and (2) demonstrate how data analysis can lead to changes that positively impact the learning experience of students in higher education institutions.

■ WD-06

Wednesday, 14:30-16:00 - U1

Topics in Combinatorial Optimization

Stream: Combinatorial Optimization
Invited session
Chair: Marius Roland

1 - Scenario-Based Algorithms for Same-Day Delivery Problems
Francesco Gallesi, Jean-François Côté, Thiago Alves de Queiroz, Manuel Iori

We study a dynamic vehicle routing problem where customer requests arrive dynamically during the day and must be served within a strict time window. The aim is to use a fleet of vehicles to maximize the number of served requests and minimize the traveled distance. This problem is known in the literature as the same-day delivery problem. It is of high importance because it models a number of real-world applications, including the delivery of online purchases. We solve the same-day delivery problem by proposing efficient solution algorithms, ranging from a simple reoptimization heuristic to a sophisticated branch-and-regret heuristic in which sampled scenarios are used to anticipate future events. All algorithms adopt a tailored adaptive large neighborhood search to optimize the routing plans. We also present two new consensus functions to select routing plans for implementation, and propose strategies for determining the number and size of the sampled scenarios. The algorithms are also adapted to solve the problem variant where vehicles are allowed to perform preemptive returns to the depot. Extensive computational experiments on a large variety of instances prove the outstanding performance of the proposed algorithms, also in comparison with recent literature, in terms of served requests, traveled distance, and computing time.

2 - The Hybrid Flexible Flowshop with Transportation Times: Models, Metaheuristics, and Hybrid Heuristics
Michele Garraffa, Eddie Armstrong, Barry OSullivan, Helmut Simonis

The Hybrid Flexible Flowshop with Transportation Times (HFFTT) is a novel extension of the well-studied Hybrid Flowshop (HFS) problem. It arises in the context of a medical device corporation. In contrast to the HFS, the HFFTT considers non-negligible, machine-dependent transportation times. This talk presents the problem and proposes three classes of solution approach: exact methods based on Mixed Integer Linear Programming (MILP) and Constraint Programming (CP), metaheuristics, and hybrid heuristics. The MILP models are obtained by extending the state-of-the-art MILP formulations of the HFS to include transportation times, while the proposed CP models are based on two different modelling choices. The proposed metaheuristics for the HFFTT are reference-based approaches relying on forward scheduling. Finally, the proposed hybrid heuristics can be further categorized into two subclasses. The first class consists of fixing a part of the solution provided by a metaheuristic and running a CP model to solve the remaining problem. The second class is based on decomposing the problem into smaller subproblems and iteratively solving them by relying on a metaheuristic approach. These approaches are assessed by considering a synthetic dataset generated by following the guidelines of our industrial partner. The computational results show that the hybrid heuristics strongly outperform all other approaches in terms of solution quality.

3 - Logic-Based Benders' Decomposition - evaluation of cut-strengthening techniques
Aigerim Saken, Emil Karlsson, Stephen Maher, Elina Rönnberg

This talk presents a computational study of cut-strengthening techniques in Logic-Based Benders' decompositon (LBBD). Formulating strong Benders' cuts is crucial in reducing the solution time of LBBD. Various techniques have been proposed to strengthen feasibility and optimality cuts by identifying a subset of variables or constraints that prove optimality (or infeasibility) of the inference dual subproblem, thus reducing the size of the cuts. The following techniques were evaluated: greedy, deletion filter, additive/deletion filter, and depth-first binary search. The techniques differ in their computational effort and in the guarantees in the strength of the cut. In order to have a systematic study, three general types of problems were considered: assignment and cumulative scheduling, assignment and disjunctive scheduling, and vehicle routing problems. We evaluate the techniques by comparing the trade-off between the computational effort to strengthen the cuts and the impact the cuts have on the algorithm.

4 - Exact and Heuristic Solution Techniques for Mixed-Integer Quantile Minimization Problems
Marius Roland, Diego Cattaruzza, Martine Labbé, Matteo Petris, Martin Schmidt

We consider mixed-integer linear optimization problems whose objective involve the quantile (VaR) of random costs. They constitute large-scale problems that are very hard to solve for real-world instances. We motivate the study of this problem class by two important real-world examples: a maintenance planning problem for electricity networks and a variant of the classic portfolio optimization problem. For these problems, we develop valid inequalities and present an overlapping alternating direction method. Moreover, we discuss an adaptive scenario clustering method for which we prove that it terminates after a finite number of iterations with a global optimal solution. We study the computational impact of all presented techniques on both the maintenance planning problem and the portfolio optimization problem.

■ WD-07

Wednesday, 14:30-16:00 - U3

Multiobjective combinatorial optimization #2

Stream: Multiobjective Combinatorial Optimization
Invited session
Chair: Manuel López-Ibáñez

1 - How to design mitigation strategies for COVID-19 considering both the prevention effects and the economic consequences in Korea: an optimization
Chansoo Kim, Haneol Cho, Kyu-Hwan Lee

It is of importance to consider impacts on the national economy when designing mitigation strategies to fight pandemic diseases. As an example in a field of multiobjective optimization, we suggest an optimal policies. As we have witnessed over the years, the COVID-19 pandemic has extensively influenced our lives both in the health and the economy. One of the most important non-pharmaceutical interventions, 'social distancing', which seriously asks people to reduce their mobility, has shown its effectiveness in alleviating the spread, but it cannot last for a long time due to the (negative) economic consequences. Increasing infections inevitably induces the social distancing to be tightened, then the decreasing community mobility weakens the national economy. Thus, we have set up a model to find optimal strategies to mitigate the COVID-19 pandemic in Korea with the consideration of their economic impacts. One objective is to reduce the number of new infections, while the other objective focuses on minimizing the economic impacts. Using heuristic methods including AI and machine learnings as well as the Korean dataset such as the reported COVID-19 cases and economic indicators, we construct a model incorporating the disease propagation and the economy. It mainly deals behavioral factors, and the computed results manifests heavy-tailed phenomena. We show a series of suggested historical instances, which have been discussed with the authorities in Korea during recent years.

2 - An analysis of the facility location problems in personalised biopharmaceuticals
Andreea Avramescu, Richard Allmendinger, Manuel López-Ibáñez

The manufacturing and delivery of pharmaceutical products is usually done in large batches to accommodate a large population. This supply chain, however, is sub-optimal for the treatments developed under personalised medicine in the past years. The new medical therapies are individualised and start with the cells of a patient before being re-engineered and administered back to the same person. The delivery model is thus changed to a patient-specific batch and on-demand model. From an operations research perspective, this leads to the need for new mathematical models and decision-making frameworks able to account for a new set of constraints, low global demand, and a complex manufacturing process.

The research work presented here aims to understand the discrepancies between the supply chain requirements of personalised medicines and the requirements of similar supply chains in blood and vaccine distribution. We characterize the main practical challenges of strategic configuration of the supply chain of personalised medicines for the biopharmaceutical companies and the patients, and address them as a multi-objective combinatorial optimisation problem. Initial results following the main configurations will be discussed using current personalised therapies with market authorisation.

3 - Metaheuristics for the Support Vector Machine: evaluating the performance through ROC analysis
Daniel Valero Carreras, Javier Alcaraz, Mercedes Landete

Support Vector Machines are an efficient alternative for supervised classification. In the classical model, two different objectives are optimized and the set of alternative solutions represent a Pareto-front of points, each one of them representing a different classifier. Moreover, when the SVM includes feature selection, the model becomes hard to solve and exact techniques require an excessive computational effort. The performance of the classifiers that form the Pareto-front can be evaluated and compared through a Receiver Operating Characteristics (ROC) graph. In this work we present an alternative SVM model with feature selection and the performance of the new classifiers is compared to those of the classical model through ROC analysis. Given that the models are hard to solve and exact techniques fail when solving medium or large sized instances, both, the classical SVM model with feature selection and our proposal have been implemented by multi-objective metaheuristics. The computational experiment shows that the classifiers derived from the new proposal are better than those obtained from the standard model.

4 - Interdicting dense clusters in network systems
Foad Mahdavi Pajouh, Haonan Zhong, Sergiy Butenko, Alkiviadis Vazacopoulos

This paper introduces and investigates the weighted quasi-clique interdiction problem. In this problem, given a vertex-weighted undirected graph with blocking costs of its vertices and edges, we seek a minimum cost subset of vertices and edges to block such that the weight of any quasi-clique in the remaining graph is bounded above by some user-defined threshold. We address the computational complexity of the weighted $gamma$-quasi-clique interdiction problem, and characterize the set of feasible solutions to this problem by exploring its fundamental problem-specific theoretical properties. We then propose a linear 0-1 programming formulation for this problem, and develop a lazy-fashioned branch-and-cut algorithm for its solution. We also propose new combinatorial bounding schemes and employ them to develop the first combinatorial branch-and-bound algorithm for this problem. The computational performance of these exact algorithms is then studied on a test bed of randomly-generated and real-life networks.

■ WD-08
Wednesday, 14:30-16:00 - U4

Timetabling

Stream: Combinatorial Optimization
Invited session
Chair: *Greet Vanden Berghe*
Chair: *Sanja Petrovic*

1 - EURO-2022 conference scheduling: Related session secheduling
Thomas Stidsen

Scheduling the sessions of the EURO-2022 conference is a complex planning problem, where more than 300 sessions have to be placed in rooms and timeslots. In this talk we will describe how EURO-2022 was planned, utilizing an approach, based the sequential solution of Mixed Integer Programming (MIP) models. The focus in this talk will be on planning the sessions such that sessions with related topics are not scheduled at the same time.

The work on the models behind the EURO-202 conference, is based on the previous scheduling of the conferences, EURO-2015, EURO-2016, IFORS-2017, EURO-2018, EURO-2019, IFORS-2021 and EURO-2021. The details for the approach for EURO-2016 is documented in our previous article "Scheduling EURO-k conferences", Stidsen et al, EJOR, 2017.

2 - A metaheuristic approach to the shift minimization personnel task scheduling problem
Nico Kyngäs, Kimmo Nurmi

The Shift Minimization Personnel Task Scheduling Problem (SMPTSP) involves assigning a given set of tasks with predetermined starting and ending times to as few employees, or shifts, as possible. Each task can only be carried out by a subset of the employees, and must be carried out by exactly one employee in one go. The problem is NP-hard, but several practical solution methods exist. Practically, the problem can be used for e.g. short-term scheduling of fixed tasks to a combined set of scheduled shifts and a minimum number of on-demand employees.

The subproblem of maximizing the contribution of a single employee with respect to a given metric is called pack. In the pack problem, an employee is selected, each task is given a weight, and the objective is to maximize the total weight of the tasks carried out by the employee. This subproblem can be efficiently solved using dynamic programming.

We propose a simple metaheuristic based on a local search operator using pack with dynamic weighting of the tasks. Any task that does not fit into the solution has its weight dynamically grown until it becomes profitable to insert it back into the solution, thereby ejecting some other task(s) from the solution. We also use a small elitist pool of solutions in which the worst current solution is replaced by the best current solution each generation. The heuristic produces results of high quality in well-known benchmark instances reasonably fast.

■ WD-09
Wednesday, 14:30-16:00 - U5

Mixed Integer Linear Programming and routing problems

Stream: Mixed Integer Linear Programming
Invited session
Chair: *Cebrina Lindstrøm*

1 - A Hyper-heuristic Algorithm for the Multiple Roaming Salesman Problem
Masoud Shahmanzari

In this paper, we study multiple Roaming Salesman Problem (m-RSP), a new variant of the recently introduced Roaming Salesman Problem, the goal of which is to determine daily tours for traveling salesmen who collect time-dependent rewards from various cities during a planning horizon. m-RSP is a generalization of the traditional traveling salesman problem (TSP) and has a wide range of real-world applications including touristic trip planning, election logistics, nurse routing, multi-period vehicle routing, and marketing campaigns. We propose a MILP model to tackle the m-RSP that includes relevant real-life assumptions, some of which are widely used in the business context. Rewards are increased linearly in time as we get closer to the end of the planning horizon rather than the other way around. The objective function consists of maximizing collected rewards, including rewards corresponding to first and repeat meetings, and minimizing traveling costs. To tackle large-size instances, we develop a new hyper-heuristic algorithm that consists of a Skewed Granular Tabu Search which is embedded in a Variable Neighborhood Search algorithm. The proposed method is experimentally validated on 50 real-life instances with actual travel times and distances. The computational results indicate that our method can produce near-optimal solutions effectively.

2 - An Exact Algorithm for the Two-Echelon Inventory-Routing Problem
Sara Charaf, Duygu Tas, Simme Douwe Flapper, Tom van Woensel

The two-echelon inventory-routing problem (2E-IRP) addresses the coordination of vehicle routing and inventory management throughout a two-echelon supply network. The latter consists of intermediate facilities that are located in the city outskirt, supplied from distant depots, and serve a set of geographically widespread customers. The customers' demand is met from either their local inventory or intermediate facilities' inventory. The 2E-IRP aims to minimize the transportation and inventory costs while meeting customers' demands over a finite discrete planning horizon. We propose a route-based formulation and develop a branch-and-price algorithm to solve the 2E-IRP. For each period and intermediate facility, a pricing subproblem is defined and solved using an adapted labeling algorithm in a multithreaded fashion. We generate 400 instances derived from the well-known benchmark instances for the inventory-routing problem and obtain optimal solutions for 116 instances and an average gap of 11.29% for the feasible solutions. We obtain good upper bounds for 60 instances with a gap of less than 5% (with an average of 2.8%), and variations of the algorithm could solve seven more instances to optimality. We provide comprehensive analyses to evaluate the performance of our solution approach.

3 - Time Window Vehicle Assignment Vehicle Routing Problem with Stochastic Travel Time and Delay Propagation
Sifanur Celik, Layla Martin, Albert Schrotenboer, Tom van Woensel

The joint optimization of vehicle routing and time window assignment to customers is a fundamental problem arising in many distribution networks. At the start of the day, vehicle routes are constructed and time windows are communicated towards the customers. However, the uncertainty of travel and service times is only observed while executing the route, making the joint optimization of time window assignment and vehicle routing a difficult optimization problem. In this paper, we present the first exact method for the so-called Time Windows Assignment Vehicle Routing Problem with Stochastic Travel Times. Its objective is to minimize the sum of i) the expected time window exceedances, ii) the expected shift overtime, iii) the penalty for time windows width, and iv) the vehicle routing cost. Hereby, smaller time windows imply lower penalties but are more difficult to be met in route execution. We formulate the problem as a two-stage stochastic programming model that captures delay propagation throughout the execution of the vehicle routes. The first stage decisions are the time window assignment and the vehicle routing, and in the second stage we evaluate the costs after realization of the travel times. Our exact approach is based on Benders Dual Decomposition (BDD) method, together with valid inequalities to tackle large-size problem instances. Our preliminary results suggest that the algorithm can solve instances with up to 18 customers and 45 scenarios to optimality.

4 - Group Consistent Dial-A-Ride using Adaptive Large Neighborhood Search
Cebrina Lindstrøm, Stefan Ropke, Morten Revsbæk, Kent Andersen

The dial-a-ride problem (DARP) consists of scheduling and routing vehicles such that all users will be picked up and delivered within their specified time windows. Each user or customer has a pick-up location and a delivery location and has a time window that specifies the earliest pickup time as well as the latest delivery. Furthermore, the problem must consider the capacity constraints of the vehicles. A real-life example of the DARP is the transportation of school children to and from school, which is a service offered through the municipality to selected children. Varying the driver, driving time, and other passengers can be stressful - especially for children. This work considers the Group Consistent DARP (GC-DARP) which seeks to ensure that each user drives with a limited amount of different users. In this formulation of the GC-DARP, all users have some schedules. A schedule is one or more travel requests (with a defined pickup, delivery, and time window) that have a known set of repetition - i.e. weekly, every other week, once every 4 weeks, etc. The schedule can at maximum consist of an outbound and inbound travel request each day, depending on whether or not a return trip is desired. The problem must then not only consider trips with proximity in both time and location, but also the consistency and frequency with which the trips will be driven. We use the Adaptive Large Neighborhood Search (ALNS) to solve this problem for instances with up to 200 different schedules.

■ WD-11

Wednesday, 14:30-16:00 - U7

Multi-Actor Multi-Criteria Analysis

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Cathy Macharis*
Chair: *He Huang*

1 - A stakeholder-involved criteria pre-processing framework in the multi-actor multi-criteria analysis
He Huang, Cathy Macharis

Stakeholder involvement is a crucial step in the multi-actor multi-criteria analysis (MAMCA). By involving the related interest groups in the MAMCA evaluation process, a solution can be sought by having a more comprehensive understanding of the consensus and conflict among the stakeholder groups. It is a methodology that can reveal the points of view in different stakeholder groups. The weighing of criteria for stakeholder groups represents their priorities ranking. Therefore, identifying the priorities and interests of the stakeholder groups is one of the keys for a successful MAMCA evaluation. When there are massive stakeholders involved, the identification of the criteria set becomes more important. Missing one important criterion can lead to the change of the final ranking of alternatives from stakeholders. Hence, the concept of co-creation is integrated into MAMCA by not only asking stakeholders to evaluate but also identifying the criteria set for evaluation beforehand. In this work, we propose a framework that helps the decision-maker in the criteria pre-processing step: from pre-defining criteria list, filtering related criteria, to deciding the final criteria set by gathering the stakeholders' information.

2 - A framework to reach sustainable consensus in the multi-actor multi-criteria analysis
Shary Heuninckx, He Huang

Sustainability is a key factor in the decision-making process in the field of transportation, mobility, energy, etc. The engagement of stakeholders plays an increasing role in sustainable decision-making as it can express different perspectives and interests to achieve a balance between the three pillars of sustainability. The multi-actor multi-criteria analysis (MAMCA) is a decision-making methodology that allows the involvement of multiple stakeholder groups. In MAMCA, these groups can have different criteria sets for the evaluation, and therefore can better express their preferences and understand each other's interests.

The MAMCA process however doesn't necessarily lead to what is considered the most sustainable solution. Therefore, we propose a novel framework that uses stakeholder rankings to help decision-makers find a sustainable consensus, by taking into account the potential impact of each stakeholder on sustainability. The framework consists of two steps of evaluation. The alternative scores of the stakeholder groups that result from the MAMCA process are aggregated into a final ranking by combining them with the respective stakeholder group weights. Several scenarios are built based on different weight allocations for the stakeholders to test the robustness of the alternative rankings. In this study, the proposed framework is tested out on a real-life case in which a decision on a suitable form of energy community is to be made.

3 - Multi-criteria multi-actor analysis of emission abatement and energy efficiency measures in container terminals
Erik Pohl, Sebastian Schär, Jutta Geldermann

Container terminals are crucial for international trade and supply chains. Decision making in European container terminals involves different stakeholders and actors from governments, communities, and operators. A container terminal is usually run by a terminal operator who is in the end responsible for every decision concerning the terminal. Nevertheless, the terminal operator acts in a surrounding of port authorities, politicians, city representatives, ship operators, ship owners and population that should be considered. In recent years, terminal operators strive to improve the environmental footprint of terminals by implementing several distinct measures for emission abatement and energy efficiency that should preferably selected in accordance with every stakeholder group.

In this talk we present a decision problem to rank measures for emission abatement and energy efficiency in the container terminal Tollerort in Hamburg, Germany, while considering multiple actors, i.e., the corresponding terminal operator, terminal staff, and port terminal consulting experts. The measures are assessed based on sustainability assessment criteria within the ecological, economic, social, and technical categories using the multi-actor multi-criteria decision-making method and PROMETHEE. The results indicate that a consensus between all actors can be achieved by one preferred measure.

■ WD-12
Wednesday, 14:30-16:00 - U9

OR in Energy II

Stream: OR in Energy
Invited session
Chair: Jose Arellano

1 - Potentials of sector coupling to improve the resilience of electricity and gas networks
Christina Leinauer, Lisa Hanny, Rajon Bhuiyan, Martin Dr. Weibelzahl

Global warming leads to an increase in extreme weather events that considerably threaten critical infrastructures (e.g., electricity or gas networks). The failure of one critical infrastructure may have far-reaching consequences triggering a "cascade of failures" that affects other critical infrastructures. As extreme weather events usually hit affected regions unexpectedly, flexibility in energy systems is key to sustain resilience and rapidly respond to changing conditions, e.g., failed network lines. Hence, we analyze sector coupling (SC) as one option to increase flexibility and exploit synergies between electricity and gas networks. We investigate SC investments that allow for a bi-directional conversion of gas and electricity in the form of gas-fired power plants or power-to-X technologies and their effect on resilience. We propose a two-level market model where, in the upper-level problem, long-term investments in SC technologies are made in anticipation of short-term market clearing as well as uncertain failures and, in the lower-level problem, SC technologies may be activated. We model extreme weather events as a set of discrete scenarios that pose an external risk to the energy system. In our paper we derive optimal SC investments representing a trade-off between enhancing system resilience and increasing investments. Moreover, we derive optimal SC responses for selected weather events to guide the operation of SC plants under extreme conditions.

2 - Multi-objective energy system model to defossilise the commercial existing building stock of a municipality
Christine Nowak, Jonas Finke, Valentin Bertsch

Defossilising the heating sector, especially existing buildings, is one of the major challenges on the path to climate neutrality. On top, the heating supply with low-temperature heating networks within the public sector has been little addressed. This study presents an energy system investment model for three public buildings in a small municipality in Germany. Based on an existing feasibility study and on direct interaction with municipality stakeholders, data such as simulated heating demands using U-values and building structure information is implemented in the energy system model. Possible heat supply generators are water-to-water heat pumps combined with a low-temperature heating network and geothermal probes, air-to-water heat pumps as well as biomass boilers. Electricity can be obtained either from photovoltaic systems in combination with battery storages or from the electric grid. Scenarios are outlined which consider different renovation stages of the buildings and variable future emission factors of the electric grid. A multi-objective optimisation using the augmented epsilon-constraint method is performed with the objectives of minimising system costs, carbon emissions and particle emissions. Pareto fronts quantify trade-offs between the objectives and present different Pareto-optimal alternatives. Thereby, the stakeholder's decision making for the investment in heating supply generators for the municipality's commercial existing building stock is supported.

3 - Minimization of the energy procurement cost of large consumers considering self-consumption facilities and power-purchase agreements
Jose Arellano, Miguel Carrión

We consider the electricity procurement problem of a large consumer that desires to acquire its energy consumption at minimum cost. It is considered that the consumer can obtain its energy demand from a retailer, power purchase agreements with renewable generation units, bilateral contracts with power generators or through the installation of a solar PV self-consumption facility. This problem is formulated using a stochastic programming formulation. Results from a realistic case study are discussed.

4 - A Methodology to Improve the Predictability of Solar Energy Generation with Confirmatory Evidence from Great Britain
Kevin Forbes

This paper observes that the current intraday solar energy forecasts in Great Britain are not accurate. Specifically, the forecast's weighted mean absolute percentage error (WMAPE) equals 19 % over the daylight periods of the 14 Jan 2019 through 31 Dec 2020 time interval.

One reason for this result is that the forecasts do not fully reflect expected metrological conditions. In addition, there is a significant diurnal pattern in the solar energy generation levels over the 48 operating periods for each day that is not fully reflected in the existing forecast model. An Autoregressive Moving Average with Exogenous Inputs (ARMAX) model is formulated based on these insights. This modeling approach predicts solar energy generation based on the outputs of the intraday forecasting model, modeled meteorological conditions, and time-series terms that reflect the autoregressive nature of solar energy generation.

The model is estimated using 30-minute data from 14 Jan 2019 through 31 Dec 2020. There are 19,069 daylight periods in the sample. The preliminary model has an explanatory power equivalent to an R-Square of about 0.99, an encouraging value. The model is evaluated using out-of-sample half-hour data from 1 Jan 2021 - 31 Dec 2021. The preliminary out-of-sample predictions have a WMAPE of about 5 %, substantially less than the WMAPE associated with the intraday solar energy forecasts reported by the system operator over the same period.

5 - Application of the Level Method for Computing Locational Convex Hull Prices
Nicolas Stevens, Anthony Papavasiliou

Convex hull pricing is a well-documented method for coping with the non-existence of uniform clearing prices in electricity markets with non-convex costs and constraints. We revisit primal and dual methods for computing convex hull prices, and discuss the positioning of existing approximation methods in this taxonomy. We propose a dual decomposition algorithm known as the Level Method and we adapt the basic algorithm to the specificities of convex hull pricing. We benchmark its performance against a column generation algorithm that has recently been proposed in the literature. Our work also further studies the properties of convex hull prices and weight their relative advantages compared to other non-convex pricing schemes.

■ WD-13

Wednesday, 14:30-16:00 - U119

Decomposition approaches for MILP

Stream: Mixed Integer Linear Programming
Invited session
Chair: Javaiz Parappathodi

1 - An efficient Benders decomposition for the p-median problem
Cristian Duran Mateluna, Sourour Elloumi, Zacharie Ales

The p-median problem (pMP) is an important discrete location problem in which one must choose p locations from a set of candidate sites such that the sum of the distances between each client considered and its nearest open site is minimized. The (pMP) leads to applications where the sites may correspond to warehouses, plants, or shelters for example. More recent applications can also be found in clustering processes in databases, where sub-groups of objects, variables, persons, etc. are identified according to defined criteria. A great interest in solving large location problems has led to the development of various heuristics and meta-heuristics in the literature. However, the exact resolution of large instances remains a challenge.

In this work, we explore a Benders decomposition of an efficient formulation of the (pMP). We prove that the Benders cuts can be separated by a polynomial-time algorithm. We implement a two-phase decomposition algorithm with a branch-and-Benders-cut approach. We show that our approach provides betters results than the state-of-art method on about 200 benchmark instances and we can provide for the first time the optimal values for instances having up to 115.475 clients and sites.

2 - The Dantzig-Wolfe decomposition method on large scale complex systems
Rafael Castro-Amoedo

Reducing the complexity of supply chain problems is a challenging task. Oftentimes, to deal with the cumbersome number of variables and parameters, while overcoming runtime issues associated with MI(N)LP problems, aggregation techniques (e.g. clustering) or preselection of equipment are used. The original question is thus skewed, and researchers end up solving a problem that is not identical to the original. In this work, we explore the use of the Dantzig-Wolfe decomposition algorithm to address large and complex systems. Similar to other decomposition strategies, the original formulation is split into a master problem and several sub-problems, which are independent parts of the initial problem. Linking constraints and dual variables connect both dimensions and stopping criteria are implemented, based on both tolerance and number of iterations. Biomass conversion in Switzerland is used as a validation case study. It comprises units of conversion, based on thermodynamic models, and transport units, responsible to connect nodes in the network. We use this case study to show not only how our strategy, based on product and geographic decomposition has been used, but also to demonstrate the error that recurrent simplifications bring. Indeed, the method, leveraging on parallel optimization, can handle the desired level of data granularity, while reporting low CPU time.

3 - Tailored Benders Decomposition for Crowdsourced Humanitarian Vehicle Routing Problem
Javaiz Parappathodi, Claudia Archetti, Ivana Ljubic

There has been a significant increase in the frequency and severity of natural disasters, causing huge amount of monetary loss across the world. Given the limitation of the part of the emergency services to react to one-off unpredictable events, it is only logical to use crowdsourcing as effective tool for humanitarian relief. This paper defines the Crowdsourced Humanitarian Relief Vehicle Routing Problem and explores an exact solution method for the problem. Multiple possible formulations are compared and an approach based on Benders Decomposition, using properties of the problem is suggested. Additionally, the features of different formulations are compared to derive some interesting insights. Computational experiments are conducted to compare the effectiveness of different formulations to support the theoretical insights.

■ WD-14

Wednesday, 14:30-16:00 - U261

Metaheuristics for scheduling

Stream: Metaheuristics, Matheuristics
Invited session
Chair: Mariona Vila Bonilla

1 - Board Packing Problem (BoPP)
Tomas Attila Olaj, Gyorgy Dosa, Lars Magnus Hvattum, Zsolt Tuza, Gyula Abraham

We introduce a new problem, called Board Packing Problem (BoPP), which relates to the branch of facility location problems. The aim of the BoPP is to make profitable investments on some defined physical area with some given objects (called items). The board is modelled as a rectangular board with rows and columns. Each position on the board has an integer value representing some gain, that is obtained if the position is covered by some item. The items are represented as a set of rectangles with given size and cost. The objective is to purchase some items to place on the board to maximize the profit, which is the sum of the gained values of the covered cells minus the total cost of purchased rectangles. This problem models several natural optimization problems that arise in practice.

We introduce benchmark instances and make exhaustive computer examinations, as follows.

We give the mixed-integer programming models (allowing overlap or not allowing overlap) of the BoPP problem, and introduce an advanced evolutionary algorithm (EA) that efficiently can solve this NP-hard problem also for large instances. We compare the solution of the EA with the solution provided by CPLEX.

2 - Hybridization of PSO and PAES to minimize tardiness and flowtime in a hybrid flow shop with unrelated parallel machines

Eliana Maria Gonzalez-Neira, Johann Andrey Baez-Fuentes, Sebastian Llerena-Murcia, Santiago Andres Sierra-Ibañez, Genner Juan Pablo Valderrama-Paez

This work proposes a Particle Swarm Optimization (PSO) metaheuristic hybridized with the Pareto Archived Evolution Strategy (PAES) methodology to obtain the Pareto frontier of tardiness and flowtime in a Hybrid Flow Shop environment with unrelated parallel machines. The performance of the PSO-PAES was evaluated in comparison with the mathematical model, obtaining an average improvement of more than 20% in both objective functions, because after one hour of execution, the mathematical model could only find an optimal solution in 9 of 81 instances, and feasible solutions in the remaining 72 instances. The PSO, in less computational times than one hour, found better solutions than the mathematical model, in both objective functions, in 72 of the 81 small instances evaluated. Additionally, the PSO-PAES was executed for 288 large instances and its results were compared against those obtained by the dispatching rules Modified Due Date (MDD), for the tardiness function, and Shortest Processing Time (SPT) for the flowtime function. The average improvement given by the proposed PSO-PAES for flowtime was about 11.53% and for tardiness 13.83%. It is important to note that the largest instance of 100 jobs 8 stages had an execution time of 40 minutes, showing that the proposed PSO is applicable in real environments with good results and reasonable computational times.

3 - A new hybrid genetic algorithm to minimize cycle time for the Simple Assembly Line Balancing Problem

Mariona Vila Bonilla, Eduardo Álvarez-Miranda, Jordi Pereira, Harold Torrez-Meruvia

The Simple Assembly Line Balancing Problem is concerned with the assignment of tasks to different workstations of an assembly line, with the objective of maximizing its efficiency. This is usually achieved by either minimizing the number of workstations given a cycle time, or by minimizing the cycle time for a given number of workstations. Our work focuses on the resolution of the latter, which is known in the literature as SALBP-2, by means of a hybrid genetic algorithm.

The proposed algorithm uses a novel encoding system which encodes individuals of the genetic algorithm as instances of a modified problem (specifically, a problem which includes incompatibilities between tasks, SALBP-IBT). This problem contains, by definition, only a subset of the solutions of the original instance. Then, a dynamic programming based method with novel bounds is used to decode the individuals and test their fitness.

The computational experiments show that the algorithm is able to find several new best-known solutions in the reference set of benchmark instances used in the literature.

■ WD-15

Wednesday, 14:30-16:00 - U262

MCDA in Decision Support Systems

Stream: Decision Support Systems
Invited session
Chair: Pavlos Delias

1 - A DSS for joint improvement of inconsistency and incompatibility in a local AHP-Group Decision Making context

María Teresa Escobar, Juan Aguarón, José María Moreno-jimenez, Alberto Turón

This paper presents a DSS aimed at assisting decision makers when using AHP in local Group Decision Making contexts. Once a collective pairwise comparison matrix has been obtained by aggregating the opinions of individual decision makers, two relevant issues to validate the use of the collective matrix in the resolution of the decision problem are: (i) its inconsistency, which relates to the internal coherence of the collective matrix judgements; and (ii) its incompatibility with the individual judgement matrices, which relates to the internal coherence of the group. When the Row Geometric Mean is used as the prioritization method, both inconsistency and incompatibility can be measured, respectively, with the indicators known as GCI (Geometric Consistency Index) and GCOMPI (Geometric Compatibility Index). The DSS integrates two modules previously developed by the authors to improve independently the inconsistency measured with the GCI and the incompatibility measured with the GCOMPI. The DSS selects those judgements that may lead to a simultaneous improvement in inconsistency and incompatibility. Then, the DSS slightly modifies in relative terms these judgements. This procedure ensures that the new collective priority vector is close to the initial one and facilitates the acceptance of the new values by the decision makers. The use of the DSS will provide decision makers with valuable learning about the behaviour of the decision problem, facilitating its resolution.

2 - Digital Coaching Makes MCDM Solutions Usable for Line Managers

Christer Carlsson

A mantra is appearing in business magazines - that powerful, intelligent systems will be effective tools for the digitalization of industrial processes - but much less attention is paid to the fact that users need advanced knowledge and skills to benefit from intelligent systems - or even to manage to operate them at all. First, an effective transfer of knowledge from developers, experts and researchers to users (including management) will be needed; second, the daily use and operations of systems need to be supported, as automated, intelligent industrial systems are complex to operate; third, intelligent systems are attractive platforms for advanced tools (like mcdm algorithms) which are not readily usable for line managers, but who could benefit from the effective and productive solutions and answers they can produce. We need knowledge transfer both directly to the managers and through online support of daily operations. We look at this transfer as knowledge mobilization and will work out how the mobilization can be supported with coaching; this coaching needs to be digital, built around fuzzy ontology knowledge representation and offered online in intelligent systems. The digitalization of industry and industrial processes will require coaching on a scale not used before and human coaches are both scarce, too expensive to employ in large numbers and may not even be qualified to coach the type of knowledge mobilization we are addressing.

3 - Extended PROMETHEE algorithm with dependent criteria

Frantisek Zapletal

PROMETHEE is one of the most popular multi-attribute decision-making methods. It provides high flexibility for many types of decision-making problems. However, none of the PROMETHEE algorithms considers the dependence between criteria when finding the best decision. The author introduces the revised PROMETHEE ranking algorithm with both weakening and strengthening effect caused by positive and negative dependence between two criteria. If two criteria are positively strongly dependent and an alternative performs very well in terms of one of them, it is expected that its performance in terms of the second criterion would also be good (and vice versa). In this case, it is reasonable to weaken the final effect of these two criteria on the final ranking of the alternative (in comparison with the original algorithm). The opposite (strengthening) effect is applied in the case of negatively dependent criteria. The method preserves all advantages of the original PROMETHEE ranking algorithm, including user-friendliness. The proposed method is critically compared with the existing approaches that allow modelling the dependencies between criteria.

■ WD-16

Wednesday, 14:30-16:00 - U264

Risk and Efficiency Management in Financial Institutions

Stream: Risk Management in Finance
Invited session
Chair: *Aleš Kresta*

1 - Policy Effectiveness on the Global COVID-19 Pandemic and Unemployment Outcomes: A Large Mixed Frequency Spatial Approach
Ying Chen

We propose a mixed frequency spatial VAR (MF-SVAR) modeling framework to measure the effectiveness of policies conditional on the spillover and diffusion effects of the global pandemic and unemployment. We study the effects of two aspects of policy effectiveness, namely policy start date and policy timeliness, from a spatio-temporal perspective. The spatial panel data contain weekly new case growth rates and monthly unemployment rate changes for 68 countries across six continents at mixed frequencies from January 2020 to August 2021. We find that government policies have a significant impact on the growth of new cases, but only a marginal effect on the change in unemployment rates. A policy's start date is critical for its effectiveness. In terms of both immediate impact on the near term and total impact over the following four weeks, starting a policy in the 4th week of a month is most effective at reducing the growth of new cases. At the same time, starting in the 2nd or 3rd week is counterproductive for a one-time policy start date. In addition, our estimates suggest that the spillover and diffusion effects are much stronger than a country's temporal effect during a global pandemic, both for new case growth and changes in unemployment. We also find that new case growth influences changes in unemployment, but not vice versa. Counterfactual experiments provide further evidence of policy effectiveness in various scenarios and also reveal the main risk-vulnerable and risk-spil

2 - An Empirical Study of the Efficiency and Influence Factor of Selected OECD Life Insurance Markets
Biwei Guan

Efficiency has recently become a popular measure for assessing the state of the insurance industry and the competitiveness of insurance companies. The goal of this paper is to examine the efficiency of 10 OECD life insurance markets from 2014 to 2019, as well as to offer methods for improving the efficiency of potentially inefficient markets and find out the factors that influence efficiency. To uncover the associated outcomes, we use a three-stage data envelopment analysis, stochastic frontier slack regression, Malmquist index, and multiple linear regression model. The Greek life insurance market is the least efficient, followed by Hungary; the German life insurance market is efficient. The improvement of total factor productivity in most life insurance markets is due to the support of its technical efficiency change. The log of total assets and the ratio of return on equity has a positive influence on technical efficiency; the debt to ratio has a negative influence on technical efficiency. And the largest impact on technical efficiency is total assets with the highest confidence level, followed by return on equity and debt to assets ratio.

3 - Risk quantification of interest rate changes in mortgage offerings
Aleš Kresta

Mortgages are typical loans that the banks provide to their retail clients. Due to the fact that clients provide real estate as collateral to secure them, the risk of default is relatively low compared to other active products. However, during the mortgage lifetime, the client can react to the changes in market interest rates. The typical example is the possibility of early repayment of the mortgage, which will be applied especially if the market interest rate decreases. Another typical example can be found in the mortgage contract offerings. In the moment of mortgage approval, the bank specifies the interest rate, makes a commitment to the client and waits for the client's decision. The bank virtually underwrites an implicit option to a client who either can exercise it by signing the mortgage contract or the option expires worthless. However, during that time the market interest rates can increase, which will cause a decrease in the value of the contract or even cause a loss for the bank. In our contribution, we focus on this situation. We apply standard financial methods to valuate the risk represented by implicit option written to clients when their mortgage is originated. To valuate the described implicit option the paper valuates the underlying mortgage contract as a coupon bond using Hull-White trinomial tree method.

4 - Robust portfolio dominance for different investors' preferences
Tomas Tichy

Drawing inspiration from the concept of almost stochastic dominance, in our research we aim at studying families of stochastic orders that are able to capture the preferences of investors who have an "almost" delineated attitude toward risk, covering preferences from the first order stochastic dominance to the second, and beyond. Moreover, we plan to focus on parametric families of distribution, which may be especially suitable to model financial data, and derive dominance conditions with respect to their parameters. Such parametric approach can be also extended to an inferential framework, in order to test dominance relations between a pair of empirical distributions. Finally, we aim at applying the developed methodologies to portfolio selection problem.

■ WD-17

Wednesday, 14:30-16:00 - U356

OR for Developing Countries

Stream: OR for Development and Developing Countries
Invited session
Chair: *Elise del Rosario*
Chair: *Olabode Adewoye*
Chair: *Gerhard-Wilhelm Weber*

1 - Financial engineering and operations research: the relationship and implication for developing countries
Olabode Adewoye

An evolving area called the Financial Engineering (FE) is a multidisciplinary field that combines financial theory with mathematics, operations research (OR), statistics, computer programming, aimed at solving financial issues and also devise new financial products. In this work effort is made to use the simple number e to generate the formula B(t) if the interest is compounded k times per year and continuously. The role of Financial Engineering (FE) and Operations Research (OR) in solving financial problems particularly as regards investment in a challenging time; challenges of FE in Developing countries with Nigeria as a case study and E- currency are presented. It is observed that OR provide the models for the decision making in financial engineering and the slow pace of FE in developing countries are largely due the environment of FE of which weak currency also contributed.

2 - Enhancing digital road networks for better operations in developing countries
Valentijn Stienen

An accurate digital representation of road networks is essential for network analyses, such as routing optimization and optimal resource allocation. Digital road networks can be created or extended using geospatial data from satellite imagery, dedicated road mapping vehicles, or GPS trajectories. However, the quality of these data sets varies significantly across geographies, with lower-income regions often having poorer data quality. The methods to create or extend digital road networks therefore need to be adapted accordingly. Current methods are not well-adapted to lower-income regions with sparse geospatial data and, as a result, road networks are often poorly represented digitally in these regions. Here, we introduce a method that accurately extends and combines large, existing road network representations, for regions with sparse geospatial data. Using two practical case studies (in rural Indonesia and Timor Leste), we show that our method efficiently uses scarce geospatial data to extend digital road network representations. Our method significantly improved the digital road network representations for smallholder farmers in Indonesia, where only 40% of the origin-destination pairs in our scarce dataset were previously digitized, and for the optimization of geospatial accessibility to healthcare in Timor-Leste, where the extended road map increases the percentage of people located in the vicinity of a hospital by approximately 5%.

3 - Food grains supply chain optimization for PDS operations in India
Atul Sharma, Namita Nanda, Nomesh Bolia

This paper investigates the food grain supply chain problem of the public distribution system in India, the largest distribution machinery of its type in the world. Currently, the movement plan is made over monthly phone calls among zonal managers without a rigorous modeling framework to optimize movement operations. Our approach aims to prepare an optimal annual movement plan based on which the monthly operations can take place. A mathematical programming model is formulated accounting for additional capacity requirements. Storage capacity optimization is accounted for since FCI is required to hold a huge inventory of food grains over a significant time in order to meet the TPDS and buffer stock requirements. The model is ready to implement because, unlike previous work, it incorporates the capacity constraints of the warehouses and railheads, minimum buffer requirements by states, procurement and allocation restrictions. Policy changes being considered are evaluated using the model and developing multiple relevant scenarios. The results of these scenarios illustrate the scope of optimization of the food grains transportation network with existing storage capacity as well as an efficient way of adding capacity. Also, it is observed that the result further improves when the additional capacity to warehouses is allowed. Overall, it highlights that well-meaning policy changes can lead to sub-optimal results unless accompanied by sound scientific analysis.

■ WD-18

Wednesday, 14:30-16:00 - U358

Cutting and packing session 4

Stream: Cutting and Packing
Invited session
Chair: Julia Bennell

1 - Mixed pallet loading optimisation with stability constraints
Hannu Rummukainen, Harri Vartiainen

Boxes of mixed sizes can be loaded on a pallet automatically by robotized palletizing systems. The locations, orientations and loading order of the boxes can be determined reasonably well by heuristic optimization algorithms. However, most published algorithms have only very limited consideration of dynamic pallet stability, i.e., how well the pallet holds together when moved without external support. The objective of this work was to develop a practical pallet loading algorithm to minimize the number of pallets for the given set of boxes, with both hard and soft constraints on pallet stability. We developed heuristic measures of static and dynamic pallet stability, based on geometric considerations and the level of binding between successive layers. We implemented the stability measures in a multi-level algorithm based on an integer programming column generation heuristic, in which loading patterns for individual pallets were constructed by a beam search algorithm that performed box insertions at projected extreme points. The pallet construction algorithm also regularly performed local improvement by push operations. We customized the insertion and push operations to respect stability constraints and to maintain a robot-packable loading order. The top-level algorithm employed a separate physics-based simulation to validate the constructed pallets, re-planning any pallet that would fall over when moved in simulation. Test results are reported on a public benchmark data set.

2 - 3D palletization pattern generation for enabling cross-docking automation
António Ramos, Pedro Rocha, Elsa Silva

Effective approaches for improving consumer demand forecasting and supply-chain responsiveness to consumer demand are critical to reduce the quantity of in-transit inventory and its average lead-time, thus lowering storage space requirements and associated costs. Real world uncertainty produces large variability in lead-time which constantly disrupts scheduling plans, affecting the reception of items by delay or anticipation. To minimize these disturbances, increased storage space at cross-docking warehouses is required (to store items until palletization and expedition). The logistic center processes (selection, picking, packaging and dispatching) can be improved by implementing an automated cross-docking mixed-palletizing system, complemented with approaches that enhance scheduling flexibility and the sequencing of products. This requires creating the 3D palletization patterns in real-time as soon as items start to arrive, and palletizing them in a compact, stable and safe (to handle and transport) pallet configuration. This problem is a variant of the problem known in literature as the Distributer's Pallet Loading Problem and is tackled by a heuristic solution based on genetic algorithms that considers sequence viability, pallet stability and balancing, operational safety during loading and unloading, and mitigation of damages during transportation.

3 - Heuristics for the semi-online three-dimensional packing problem
Sara Ali, António Ramos, Maria Antónia Carravilla, José Fernando Oliveira

The semi-online three-dimensional packing problem (3D-PP) is an NP-hard optimization problem that arises in many real-world situations, such as warehouse picking and packing. In this type of problem, similarly to offline problems, complete information about items and their order is known to the packer. However, as in online problems, items should be packed without changing their sequence. Despite the numerous practical applications of semi-online 3D-PPs, most of the literature has concentrated on offline environments. The literature is quite sparse concerning heuristic methods that can be applied to solve semi-online problems. Therefore, due to the crucial role of heuristic methods in finding effective solutions for real-world-sized problems in a reasonable amount of time, one of the main contributions of this study is to develop several unique semi-online heuristics with complementary performance on different sets of problem instances. But, despite the advantages of heuristics, their performance is usually instance-dependent, and they have restricted generalization capabilities. Therefore, it has long been acknowledged that there is no single heuristic that performs well on all types of problem instances. Another contribution of this study is to develop an algorithm selection approach to predict the most appropriate heuristic for solving an unseen problem instance.

4 - Optimisation Models for Sustainable Fashion
Nesma ElShishtawy, Julia Bennell, Pammi Sinha

The fashion industry has grown exponentially over the last few decades and with it, the consumerism behaviour that is driven by fast fashion has grown and led to unsustainable systems from raw material extraction to end of use. Moreover, most of the discarded garments are at only 30% of their expected lifecycle. Upcycling provides a middle-ground design-oriented solution to the problem of post-consumer waste that would optimise the lifecycle of discarded garments. However, conventional upcycling production tends to be time-consuming which makes the upcycled garments retail at a high price, posing the need to optimise the upcycling production processes. To the best of our knowledge based on the literature research in the area of up-cycling, there is no marker making algorithm that can provide a good source to automate and facilitate the up-cycling production process. This research aims at developing an optimization algorithm to solve the irregular packing problem of a multiple heterogeneous large object placement problem (MHLOPP), where irregular pieces needed to be nested on irregular large objects with no overlap. The main objective of this research is to assess the value of developing an upcycling marker algorithm against using a conventional up-cycling approach.

■ WD-19

Wednesday, 14:30-16:00 - Y228a

Multi-dimensional queueing systems and scheduling

Stream: Performance Evaluation of Queues
Invited session
Chair: *Joris Walraevens*
Chair: *Sarah Dendievel*
Chair: *Arnaud Devos*

1 - Scaling limits for closed product-form queueing networks
Lucas van Kreveld, Onno Boxma, Jan-Pieter Dorsman, Michel Mandjes

We consider a general class of closed product-form queueing networks, consisting of single-server queues and infinite-server queues. Even if a network is of product-form type, performance evaluation tends to be difficult due to the potentially large state space and the dependence between the individual queues. To remedy this, we analyze the model in a Halfin-Whitt inspired scaling regime, where we jointly blow up the traffic loads of all queues and the number of customers in the network. This leads to a closed-form limiting stationary distribution, which provides intuition on the impact of the dependence between the queues on the network's behavior. Both an analytic approach and a probabilistic one are discussed.

2 - Exact analysis of retrial queues with constant retrial times
Dieter Fiems

We consider the M/D/1 retrial queueing systems with constant retrial times, which constitute a natural abstraction for optical fibre delay line buffers. Drawing on an equivalence with polling systems, we find explicit expressions for the distribution of the number of retrials, and the probability generating function of the number of customers in orbit.

The state space of this queueing system is rather complicated: we need to track the time when the customers in orbit retry. However, the results are strikingly simple. The number of retrials follows a geometric distribution, while the orbit size decomposes into two independent random variables: the system content of the M/D/1 queue at departure times and the buffer content of the M/D/1 queue when customers start service. Our approach starts with a discretisation step which translates the retrial queueing system in an exhaustive polling system with a rather specific arrival process. This polling system however retains the branching property such that the probability generating function of the state of the polling system satisfies a functional equation. We then show that this functional equation allows for an explicit solution. Finally, we obtain the results for the retrial queue, by studying the discrete-time polling system when the slot length approaches zero.

3 - Multivariate asymptotics for a class of two-dimensional queueing models
Arnaud Devos, Joris Walraevens, Dieter Fiems, Herwig Bruneel

We consider a class of discrete-time two-queue systems. Each queue has one server, who can serve exactly one customer per time slot. We assume that the two queues are coupled via the arrival process. In our case, this means that the numbers of customers entering queue 1 and queue 2 during a slot are not necessary mutually independent. Consequently, the numbers of customers present in queue 1 and queue 2 are not necessarily independent either. The analysis of the two-dimensional queue-length process is known to be hard, as no exact closed-form results being available in the general case. We present an intriguing condition for the input process that is sufficient to obtain the following asymptotic result. We derive the conditional distribution of number of customers in queue 2, given that the number of customers in queue 1 goes to infinity. We show that this distribution coincides with that of the number of customers in an elementary discrete-time queueing model. We make use of generating functions along with singularity analysis to obtain this result.

■ WD-20

Wednesday, 14:30-16:00 - Y228b

Dynamical Systems and Mathematical Modeling in OR 3

Stream: Dynamical Systems and Mathematical Modeling in OR
Invited session
Chair: *Michael Dreyfuss*
Chair: *Katsunori Ano*

1 - Fuzzy Core Equivalence in Large Economies: A Role for the Infinite-Dimensional Lyapunov Theorem
Nobusumi Sagara, M. Ali Khan

Classical core theory in exchange economies deals with the situation where agents have only one of two alternative possibilities: whether to join or not to join a coalition – there is no option for varying degrees of commitment to, and participation in, more than a single coalition. On the contrary, fuzzy core theory proposed by Aubin allows for the partial participation of agents in coalitions where the attainable outcomes of the allocations of goods depend on the degree of commitment and participation of the agents, thereby modelling a more pluralistic conception of decision-making and identity formation. The need for this is evident from even the casual observations of group behavior.

We present the equivalence between the fuzzy core and the core under minimal assumptions. Due to the exact version of the Lyapunov convexity theorem in Banach spaces, we clarify that the additional structure of commodity spaces and preferences is unnecessary whenever the measure space of agents is "saturated". As a spin-off of the above equivalence, we obtain the coincidence of the core, the fuzzy core, and the Schmeidler's restricted core under minimal assumptions. The coincidence of the fuzzy core and the restricted core has not been articulated anywhere.

2 - Sliding Modes in the Management of Renewable Resources
Thorsten Upmann, Anton Bondarev

The presence of tipping points in ecological systems implies abrupt changes in the dynamics of the ecosystem. In these piecewise-smooth dynamical systems sliding dynamics, i.e., dynamics on the switching boundary, have been reported for population models. However, the question whether or not, and if so under which conditions, sliding dynamics may occur in an optimally controlled system have not yet been studied. We explore this issue in a simple harvesting model with two regimes, and find that optimal sliding may occur if regular steady states do not exist. Hence, sliding dynamics may be part of an optimal policy.

3 - Why we trust the mediocre: A Markovian approach to the Trust Game
Michael Dreyfuss

We model a stochastic, infinite horizon, version of the trust game as a Markov decision problem. Because the trustor faces a safe alternative on each decision node, her problem involves a threshold rule. We draw on the threshold property to develop a novel decomposition of the effect of the model's primitives on the steady state quantities and employ it to establish a counterintuitive relationship between the trustor's mean propensity to trust and trustees' probability of running successful projects. We further find that when honest trustees tremble, even a miniscule increase in the tremble rate is sufficient for trust to vanish. Additionally, when opportunistic trustees behave strategically, we find that the trustor's decision problem maintains its Markovian nature. Simulations indicate that the optimal reciprocation rate of opportunistic trustees is strictly greater than zero. We also find that the Markovian benchmark is a good approximation for the non-Markovian version of the game.

■ WD-21

Wednesday, 14:30-16:00 - Y229a

Behavioural issues in human resources, marketing, finance, and systems

Stream: Behavioural OR
Invited session
Chair: *Menelaos Tasiou*

1 - How the Internet of Things is affecting employees working routine - a scenario-based experiment
Marlen Rimbeck, Hannes Reil, Jutta Stumpf-Wollersheim, Michael Leyer

More and more objects in organizations are equipped with sensors and actuators, enabling them to capture information from their environment, and to analyze and transmit this information to a processing system. Driven by the associated increase in data availability, employees at the individual level can get a feeling of being in control over smart objects in their daily working routine. Contrary, based on the collected data, smart objects take over decisions and extend surveillance possibilities at the organizational level. Thus, the so-called Internet of Things (IoT) forces organizations to rethink their processes and revise the definitions of work. However, there is a lack of literature regarding the impact of IoT in organizations on the individual and the organizational level, which we address in our research. We used scenario-based designs to survey 1,002 employees regarding the effects of IoT in production and administrative working environments. Our results indicate that IoT significantly affects individual process orientation and administrative conditions of employees. While our results reveal that employees feel more independent and autonomous using IoT, the way an organization or the employees make decisions is not affected. Thus, we contribute to the management perspective by showing how to accompany the technical introduction of IoT at the individual employee level. Hence, we extend the research that focuses on the examination of ICT from a work design perspective.

2 - Price dynamics and synchronous trading driven by stickiness in decision making: A laboratory experiment
Hayette Gatfaoui, Jorgen-Vitting Andersen, Philippe de Peretti

We run a series of 10 experiments to investigate how individual decision making translates into aggregate price dynamics. Within a bounded rationality setting, we focus on synchronization among agents, possibly creating price bubbles. We adopt a new methodology that represents each experiment as a temporal network. We then extract information using time-evolving intra and inter communities' relationships, each community being formed by one kind of trader. We first show that agents have a natural tendency to stick to one community. Differences in average degrees of stickiness between buyers and sellers totally match with the outcome of experiments (R2=0.99). Moreover, if sticky agents are central in the network, stickiness induces synchronization and then speculative bubbles. In this latter case, very few agents drive the price dynamics. Looking at decision making, we note that they respond very poorly to past information, thus suggesting a reinforcement learning process. Focusing on agents' gender, the outcomes of experiments with only females are much more predictable using very limited information, i.e. using only the first 20 trades out of 60. Therefore, trades made by females are less risky. At last, we find that the degree of risk aversion and heterogeneity of risk profiles play little role in explaining aggregate price dynamics. Such inertia, referred as stickiness in decision making, has key implications concerning the understanding of financial markets' dynamics.

3 - Social traits and credit card default: A two-stage prediction framework
Menelaos Tasiou

Over the past years, studies shed light on how social norms and perceptions potentially affect loan repayments, with overtones for strategic default. Motivated by this strand of the literature, we incorporate collective social traits in predictive frameworks on credit card delinquencies. We propose the use of a two-stage framework to segment a market into homogeneous sub-populations, in terms of social traits and perceptions at the regional level, on which predictive models are fitted at a second stage. We apply this framework to a big dataset of 3.3 million credit card holders of a UK bank during the period 2015-2019. We find that segmentation based on social traits yields efficiency gains in terms of both computational and predictive performance compared to the whole population. This finding holds and is sustained in the long run for different sub-samples, lag counts, class imbalance correction or alternative clustering solutions on the basis of individual and socio-economic attributes.

■ WD-22

Wednesday, 14:30-16:00 - Y229c

Logistics II

Stream: Supply Chain Management
Invited session
Chair: *Neslihan Özlü*

1 - Multi-objective Optimization and User Preferences in a Military Logistic Deployment Setting
David Raz, Sofia Amador Nelke, Shaked Maayani, Ohad Zahavi

In this work we address the logistic deployment of the Iron Dome system, a mobile air defense system deployed by the Israel Defense Forces (IDF). The logistic envelope of deployment includes hundreds of containers, deployed at multiple sites according to operational needs by dozens of vehicles. Other than a relatively standard problem of optimal placement of containers on vehicles according to the size and capacity of loading, and transporting them efficiently to the deployment sites, the problem exhibits two contradicting objectives, viz. cost of operation and deployment time. Vehicles are required to make multiple rounds of deployment, and employing more vehicles allows for reducing the number of rounds, decreasing the overall deployment time, at higher cost of operation. The problem was expressed using a Multi Objective Integer Linear Programming (MOILP) model using both the e-constraint (reservation) technique and the weighted-sum technique. The resulting solution space agrees with the multi-objective literature and exhibits an "efficiency curve" or "pareto-optimal front". User preference and operational interpretation of such results, especially in the military context, are rare in the literature. We conducted a prospective study among the relevant population to examine user preferences, but the results were inconclusive.

2 - Buffering variability in stochastic cyclic inventory routing
Birger Raa, Tarik Aouam

We study the cyclic inventory routing problem in which a geographically dispersed set of retailers with stochastic demand rates is replenished from a single depot. An infinite horizon is considered, and a fixed-partition policy is adopted that partitions the retailers into subsets that are always replenished together in the same route. Thus, routes must be designed, and their cycle times chosen such that routing costs and inventory costs are balanced. Furthermore, the retailer demand variability must be buffered to obtain a certain service level. A complication occurs when the cumulative demand per cycle of the retailers in a route exceeds the limited vehicle capacity. This results in shortfall because retailers are not fully replenished, which affects the service level and cost balance. We deal with the demand variability and the resulting shortfall by providing a combination of buffers during the route design: slack vehicle capacity, backup vehicle capacity, and safety stock at the retailers. An approximate method is presented for determining the safety stock levels and is integrated into a state-of-the-art metaheuristic solution approach for cyclic inventory routing. Computational experiments show that demand variability can be buffered cost efficiently in a cyclic planning approach and that demand variability and shortfall should be taken into account during the route design rather than in a postprocessing step.

3 - Performance evaluation of a serial push-pull multi-echelon supply chain system with multiple parallel non identical retailers operating under stochastic supply and demand
Stelios Koukoumialos, Giannis Papagiannis, Michael Vidalis, Alexandros Diamantidis

This work examines a push-pull multi-echelon supply chain system with N stages. The last stage consists of multiple parallel non identical retailers that serve the external demand. The rest system consists of an arbitrary number of stages serially connected. Each stage supplies its downstream stage and it gets material from its upstream stage. Every stage faces supply uncertainty regarding both replenishment lead time and quantity delivered. The replenishment rate of every stage to its immediate downstream stage has a random delay that follows the Coxian-2 distribution. The flow of materials towards the downstream stages is driven by a continuous review inventory control policy (s,S). If the upstream stage has insufficient stock, then the orders are partially satisfied and the rest products are lost. Among the parallel retailers priority to fulfill the replenishment order has the retailer with the smallest index. Moreover, each retailer satisfies a Poisson distributed external demand of one product unit. The considered system is modelled as a continuous time Markov process with discrete states. The structure of the transition probabilities matrix among the various states is explored and a computational algorithm to calculate the stationary probabilities for any combination of the system parameters is also developed. Using these probabilities, various performance measures are evaluated. Additionally, the effect of the system parameters on its performance is explored.

4 - Once Bitten Second Shy? The Effect of Supplier Exposure and Rare Events on the Timing of Orders
Neslihan Özlü

An industrial purchaser is exposed to a variety of low-probability and high-impact risks that can disturb their operations from their usual suppliers that they trust. The way purchasers handle these situations and mitigate risks is not straightforward due to the complexity of feedback they get from their previous transactions. Using 50K observations of purchase instances, we examine the mechanism behind purchasers' order timing by adding safety times to avoid late deliveries. We examine the impact of exposure to suppliers and rare events throughout the history of experiences of the purchasers. We split up the interactions of the purchasers and suppliers to individuals and others in the analysis. Specifically, we disentangle the timing of the orders with the specific suppliers as opposed to all others. We find that rare events in the past impact safety time decisions for the current order, but not in the same way from individual versus other purchaser-supplier relationships. Furthermore, exposure to the specific suppliers has a substantial impact on the current order. We mainly observe that purchasers consistently rely on the history of the self-experienced orders. Our findings inform the risk-mitigation actions in an operations setting by highlighting the lasting effects of usual and unusual circumstances in the history of experiences. As a result, purchasers can develop pre-disruption evaluations and develop optimal time-allocation strategies for the critical suppliers.

■ WD-23

Wednesday, 14:30-16:00 - Y307

CBBM 1

Stream: EWG CBBM, EURO working group on Computational Biology, Bioinformatics and Medicine
Invited session
Chair: *Marta Szachniuk*
Chair: *Aleksandra Swiercz*

1 - Virxicon - a database for efficient search and analysis of viral sequences
Marta Szachniuk, Kaja Gutowska, Jarosław Synak
The pandemic caused by the SARS-CoV-2 virus has increased interest in the world of RNA viruses. In a short time, a great deal of data on viral sequences and structures began to arrive, along with programs to analyze them. At the same time, the need for repositories that collect such data, systematize them, perform statistical analyses, and allow downloading classes of viral sequences has increased. Until now, there has been no bioinformatics tool that offers all these options in a single system. Therefore, we have developed Virxicon - a lexicon of viral data that addresses such a need. Virxicon is available at https://virxicon.cs.put.poznan.pl. During the lecture, we will present the concept of the database and the effect of its implementation.

2 - The control of cholesterol metabolism - modeled and analyzed using stochastic Petri nets
Agnieszka Rybarczyk, Dorota Formanowicz, Marcin Radom, Piotr Formanowicz
Cholesterol is essential for all cells in the body and is involved in many fundamental biochemical pathways. Hence, its homeostasis is tightly controlled and any disruption of lipid metabolism can promote the development of atherosclerosis, which is the major cause of morbidities and mortalities worldwide. In order to investigate the cholesterol metabolism disturbances and their influence on the atherosclerosis development and progression, a stochastic Petri net based model has been build and then analyzed. First, t-invariants and MCT-sets have been generated, then knockout and simulation based analyses have been conducted. The application of systems approach that has been used in this research, enabled for an in-depth analysis of the studied phenomenon and allowed to draw valuable biological conclusions.

3 - RNAloops: a database of RNA multi-branched loops
Maciej Antczak, Jakub Wiedemann, Maciej Miłostan, Marta Szachniuk
RNAs are often used in the development of specialized therapeutic solutions. The function of the RNA structure results directly from its 3D fold. Unfortunately, the accuracy of the RNA 3D models obtained using in silico methods does not always allow for their practical application in biochemical experiments. The published results of the RNA-Puzzles competitions indicate that reliable modeling of non-canonical base pairs and forming long-range interactions still remains a challenge. Moreover, the topological complexity and spatial properties of the multi-branched loops impact significantly the quality of

the modeling process. Multi-branched loops are topological motifs in RNAs comprising double-stranded regions (helices) linked together by single-stranded fragments. A spatial relationship between any two adjacent helices is described using the corresponding Euler angle values. The identification and classification of multi-branched loops is a complex process. Therefore, we developed a new database providing detailed information about multi-branched loops extracted from all experimentally determined RNA 3D structures and specialized mechanisms for their search as part of a user-friendly web interface. In the longer term, we believe the tool will support the improvement of the quality of the predicted 3D RNA models, and thus the designing molecular molecules with specific properties.

■ WD-24

Wednesday, 14:30-16:00 - Y307a

Artificial Intelligence & OR in Military, Defense, and International Security

Stream: OR in Military, Defense, and International Security
Invited session
Chair: *Nikolaos Matsatsinis*
Chair: *Mette Wagenvoort*

1 - Evaluation of benefits of autonomous unmanned systems in littoral surface action group operations using multi-criteria decision analysis
Lauri Vasankari, Kai Virtanen

The accelerating trend of artificial intelligence and unmanned autonomous systems in the field of maritime operations requires estimating the impact of foreseeable changes on performing military operations. For instance, during this decade, unmanned surface vehicles (USVs) have been estimated to enter service in the US Navy (USN). The main research and development of combatant USVs is conducted by major naval powers and their blue water navies, but the same principles apply to confined battle spaces of littoral warfare. The Baltic sea theatre is a confined operation area, with shallow waters and short distances to land, creating a multi-layered threat environment of high operational tempo. In such an environment, the estimated benefits of the USN vision of distributed fleet architecture seem prominent. In order to evaluate the benefits of USVs in littoral surface warfare, we compare currently possible and envisioned surface action group architectures containing also USVs. The comparison is carried out using a multi-criteria decision analysis model, the additive value function, as well as using a Salvo combat model representing anti-ship missile battles. The multi-criteria comparison conducted reveals substantial potential of USVs in enhancing small navies' naval power.

2 - The Effect of Uncertainties on the Makespan of Deterministically Constructed Ship-to-Shore Schedules: A Simulation Study
Mette Wagenvoort, Paul Bouman, Martijn van Ee, Kerry Malone

When the navy is planning an operation on land, e.g., after a natural disaster, resources are transported from large amphibious ships to the shore using connectors: smaller ships and helicopters. Planning such an operation while minimising the makespan, the duration of the operation, is known as the ship-to-shore problem. The decisions in this problem are two-fold, namely it has to be decided when each connector departs for each of its trips as well as what resources are transported in each of these trips. Besides satisfying the demand at the shore, constraints related to the ordering of the resources and the number of connectors that can be (un)loaded at the same time exist. This problem is NP-hard.

Many factors can affect the execution of the plan. A change in weather conditions affects the connectors' travel speed, a connector can get stuck in the sand at the shore, or loading resources on the connector at the amphibious ship takes a bit longer. These events cause a delay and/or block an (un)loading spot longer than planned.

To evaluate the effect of such uncertainties on the actual makespan of an operation, we construct a simulation in which schedules constructed using deterministic parameters are executed, while uncertainties in the speed and (un)loading time manifest themselves. We use schedules constructed by a greedy heuristic and a branch-and-price algorithm using data from the Royal Netherlands Navy.

■ WD-25

Wednesday, 14:30-16:00 - Y308

Design and Improvement of Automated Warehousing Systems

Stream: Warehouse Design, Planning, and Control
Invited session
Chair: *Mahsa Alirezaei*

1 - Trends in the modeling of automated storage and retrieval systems
Edgar E. Córdoba-Sarmiento, Edwin Garavito, Laura Y. Escobar-Rodríguez

In recent years, automatization has taken on a relevant role in the low-skilled operations of different productive sectors. One of the most impacted sectors is related to logistics where it significantly influences product handling, warehousing, and shipping processes. In this context, Automated Storage and Retrieval Systems, AS/RS, become an ideal solution for logistics warehousing systems. Such implementation allows inventory management based on storage and retrieval orders optimizing the use of available physical space and material handling processes, and improving system performance in terms of storage and retrieval times, material flow, energy consumption, operating costs, and other associated variable measurements. In this work, we studied AS/RS from a mathematical and analytical perspective of the models, involving their physical and control characteristics and how they affect the modeling approach. This study allows the identification of trends in the modeling of automated storage and retrieval systems as well as methodologies for model validation. It is noticeable the need of new knowledge in analytical and mathematical models leading to potentially novel research studies.

2 - Automated vehicle fleet management in relentless production - a case study in semi-conductor manufacturing
Júlia Bergmann, József Váncza, András Kovács

The relentless production strategy of semi-conductor manufacturers requires the optimization of their special internal logistics systems. Such logistics systems are not only very complex with numerous specific rules and exceptions, but also, they must serve a large shopfloor via dispatching Automated Guided Vehicles (AGVs). Decomposition of this enormous problem into smaller subproblems by segmenting the transportation tasks can be a solution. The segmentation is achieved via modularity maximization which clusters the nodes of a network optimally. Networks with high modularity have high edge density between the nodes within clusters but sparse density between nodes in different clusters. In our earlier approach, nodes of the internal logistics network were the stations, and the edge weights were given by the material intensity flow and the distances. Now we propose a new segmentation logic which concentrates on the logistics tasks; the result is a task-oriented segmentation. For this, we start with the historical material intensity flow, and we transform it into a new network that represents the relationships between the logistics tasks. The construction of such a network is not well-defined, our job is to compare and contrast different kinds of strategies. The task-relationship network is then submitted to the segmentation phase performed by modularity maximization. The techniques are evaluated on a simulation model inspired by a real-life shopfloor of a semi-conductor.

3 - The adoption of robots for last-mile logistics in indoor environments
Junsu Kim, Hosang Jung

This research introduces the adoption of robot-based last-mile logistics in indoor environments, i.e., the pickup of returned items and delivery of ordered items conducted by indoor robots. Given the rapid pace of robot technology development, the logistics industry increasingly adopts robot technology. Especially the importance of effective and efficient last-mile logistics solutions is growing with the proliferation of mobile shopping, and robots are a good alternative. To efficiently enable last-mile logistics with robots in indoor environments, two main issues need to be solved: 1) reasonable and realistic robot travel times in a given building must be estimated, and 2) a mathematical model for robot routing optimization needs to be prepared. We thus propose a calculation method to estimate the robot travel time considering robot movement in a building and a mathematical model based on the multi-trip robot routing problem with pickup and delivery. Additionally, a sensitivity analysis is conducted to assess the operational issues of robot-based last-mile logistics. The suggested approach is expected to offer practical insights into the appropriate use of robots for the organization in logistics.

4 - Velocity control of autonomous mobile robots in robot-assisted order picking systems
Mahsa Alirezaei

The use of robot-assisted order picking systems in warehouses is increasing. In these systems, human order pickers collaborate with autonomous mobile robots (AMRs). The AMR typically transports multiple containers inside a picking area and stops in front of each picking location, where a human order picker must pick the specified item. AMRs can travel to the next picking location and depot autonomously and reduce the unproductive walking distance of the order pickers. The academic literature on this topic typically assumes a constant speed of both pickers and AMRs. However, in practice, the speed of AMRs can vary. Besides being limited by their maximum velocity, safety rules require lower speed in close proximity to human pickers. Consequently, when AMRs are close to human order pickers, their speed will reduce. If the distance between the nearest human picker is large enough, they can move faster. This research investigates the collaboration of multiple order pickers and multiple AMRs and particularly investigates the implications of speed-adaptation on the throughput of the warehouse and the walking distance of the order pickers. This is an interesting problem, as there exists a tradeoff: by maximizing the distance between pickers and AMRs, AMRs can operate at their maximum speed. However, this may lengthen the travel times of robots and pickers, as detours might be needed to avoid encounters. We are going to develop a mixed-integer linear program to address this problem.

■ WD-27

Wednesday, 14:30-16:00 - Y313

Statistical learning in Big Data

Stream: BIGMATH - Mathematics for Big Data
Invited session
Chair: Alessandra Micheletti

1 - Gaussian Processes for shape modelling and registration
Filipa Marreiros Malveiro Valdeira

Gaussian Processes are a powerful framework to perform shape modelling and registration in a unified manner. We will present this framework from both a theoretical and practical point of view, looking at recent developments, as well as their limitations. We will then introduce a novel probabilistic registration problem for this setting, together with its application to the challenging case of ear modelling.

2 - CUR decomposition for matrix triplets
Perfect Gidisu, Michiel Hochstenbach

A CUR matrix factorization approximates a data matrix using a subset of its columns and rows. As a result, a CUR decomposition guarantees the interpretability of the reduced data matrix. One may employ this factorization as an unsupervised feature selection technique. Although a CUR decomposition can be used in several applications, it may still not be suitable for some applications. For example, multi-view dimension reduction problems, data perturbation problems with nonwhite noise, or a setting with two or three matrices where the goal is to find a low-rank representation of one matrix relative to the others. We propose a generalization of a CUR decomposition to cope with the simultaneous factorization of three matrices.

3 - Group pattern detection of longitudinal data using a functional statistics framework
Rongjiao Ji, Alessandra Micheletti, Nataša Krklec Jerinkić

Estimations and evaluations of the main patterns of time series data in groups benefit large amounts of applications in various fields. Different from the classical auto-correlation time series analysis and the modern neural networks techniques, in this paper we propose a combination of functional analysis of variance (FANOVA) and permutation tests in a more intuitive manner for a limited sample size. First, FANOVA is applied in order to separate the common information and to dig out the additional categorical influence through paired group comparison, the results of which are secondly analyzed through permutation tests to identify the time zones where the means of the different groups differ significantly. Normalized kernel functions of different groups are able to reflect remarkable mean characteristics in grouped unities, also meaningful for deeper interpretation and group-wise classification. In order to learn whether and when the proposed method of FANOVA and permutation F-test works precisely and efficiently, we compare the estimated kernel results with the ground truth on simulated data. After the confirmation of the model's efficiency from simulation, we apply it also to the RAVDESS facial dataset to extract the emotional behaviors of humans based on facial muscles contractions (also called action units (AU) technically in computer graphics), by comparing the neutral performances with emotional ones.

4 - A novel Robust Balancing Technique based on SMOTE
Rasool Taban, Maria do Rosário Oliveira, Cláudia Nunes

Imbalanced data is a common characteristic in many situations. In problems involving classification, regression, or anomaly detection learning patterns from classes where a small number of observations are available may bias the results. In addition, datasets coming from real problems may have atypical observations or outliers. Balancing techniques are a common strategy to overcome imbalanced data, but the presence of outliers may lead to bias and poor results, especially when one uses classical methods. In this paper, we propose a robust approach to imbalanced classification - which we call RM-SMOTE - that combines the idea of SMOTE with robust Mahalanobis distance. We suggest to automatically down-weight atypical Minority class observations in such a way that potentially outliers from this class have a low chance to be selected in the resampling step. The performance of the RM-SMOTE is evaluated using synthetic data with different levels of contamination, as well as benchmark imbalanced datasets. The results indicate the superiority of RM-SMOTE when handling different proportions of outliers while balancing the dataset. In cases where the observations are not linearly separable, this superiority is more significant in comparison to its competitors.

■ WD-28

Wednesday, 14:30-16:00 - Y405

Data Mining and Statistics 2

Stream: Data Mining and Statistics
Invited session
Chair: *Marino Widmer*
Chair: *Olabode Adewoye*

1 - Aggregating and simplifying causal networks for scenario generation
Teemu Seeve

The development of scenarios is an established approach to structuring strategic uncertainty and supporting long term decision making. These scenarios can be built based on combinations of levels of uncertainty factors describing, e.g., alternative political or technological developments. The combinations of levels is then used as the basis for scenario narratives, which are compelling, plausible stories about how the future might unfold. Often, these narratives are associated with graphical networks that describe the causal relationships between events described by the scenarios. This structuring is typically done in a relatively informal way. In this talk we develop a method for a bottom-up development of a causal structure for uncertainty factor level combinations representing a scenario. The method first aggregates a set of assessed graphs from a group of experts. Then, the aggregate graph is simplified with an optimization model such that those edges of the graph that the experts most agree upon are selected. This optimization model can be tailored to identify simplified graphs of varying degrees of cyclicity, so that alternative representations of scenarios between acyclic and ones with possible feedback loops can be explored.

2 - Interpretation of Hierarchical and Non-Hierarchical Belief-Rule-Base
Swati Sachan, Jian-Bo Yang, Dong-Ling Xu

A belief-rule-base (BRB) model provides interpretable computer-aided decision support in various business and health care domains. A BRB system can have a non-hierarchical and hierarchical structure. A non-hierarchical BRB has only one level and one rule-base. The explosion of rules is the major issue of a single level BRB. A hierarchical BRB has more than one level and has a narrow and tall structure. It has more than one rule base called a sub-rule-base. Each level in hierarchical BRB consists of a series of sub-rule-base. This paper presents a methodology to interpret a hierarchical BRB structure that breakdowns decision-making into computationally manageable sub-rule-bases. A sub-rule-base contains a small number of interpretable rules. The sub-rule-bases in the first hierarchical level focus on evidence from a subset of attributes in a dataset. The higher level describes the combined evidence from sub-rule-bases in the preceding level. The contribution propagation approach is utilized to interpret the non-linear hierarchical transformation of decisions. Its application is demonstrated in loan decision-making.

3 - "Ebru" arts in the times of modern OR, and of our interior or exterior layers
Gerhard-Wilhelm Weber, Suryati Sitepu

This art of "marbling" supposedly was invented in Central Asia in the 13th century. Then it spread to Persia, China, India, and Anatolia where artists and calligraphers used this so-called "Ebru" art to decorate books, decrees and official correspondences. Ever since, the forms and technologies of "Ebru" became perfected more and more. In recent years we working on a use of the "computer" as an "extended brush", so to speak, an "extended hand" and an "extended arm", for supporting us human in trying out and testing, in a reaching out for filigree and diversity, usefulness and appeal. In fact, we use and advance the diverse offers of modern mathematics and computer science, especially the theories of inverse problems and forward problems, of deep learning and machine learning, of artificial intelligence. "Ebru" art, especially if supported by our scientific methods, reveals a high diversity, creativity, expressivity and broad applicability, in relations with layered structures and their interactions in space and time. Such combinations of art and science will be able to pleasantly serve in modeling and visualizing what happens inside of humans and between them, in all the 5 states of matter, and overall creation. We elaborate on "Ebru" art as an OR tool of design, modelling, expression, marketing, communication, entertainment and communication, and generalized space-time shift and travel.

4 - Improving sales forecasting combining key account managers inputs and models such as SARIMA, LSTM and Facebook Prophet
Agneta Ramosaj, Marino Widmer

Sales forecasting is important for a company to plan its production. The quality of its forecasts has an influence on the finances and the products availability. The impact for a company may result on an immobilization of the cash flows by leading to a high stock level or opposite to out-of-stock impact. The purpose of this paper is to find the suitable model, which predicts the best company sales forecasts and leads to a better accuracy of sales forecasts or a better production plan. The proposed method includes an adjustment of the predictions models by including the key account managers (KAM) expertise as qualitative method of forecasting. This adjustment is analysed through different time series forecasting techniques such as exponential smoothing, seasonal autoregressive integrated moving average (SARIMA) and Facebook Prophet. These time series forecasting techniques were compared in parallel to neural network approach such as long-short term memory (LSTM). Comparisons were made with root mean square error (RMSE) but also through the residual stock (RS) in order to analyse if the forecasts were too optimistic or too pessimistic. The proposed model is considered to be dynamic: everytime an adjustment of the qualitative inputs is done, it could influence directly the values proposed by the different quantitative methods.

■ WD-29

Wednesday, 14:30-16:00 - M1

Decomposition for Large Scale Inventory Applications

Stream: Industrial Production, Planning and Inventory Management
Invited session
Chair: *Stefan Minner*

1 - An exact column generation algorithm for the lot-type design problem
Jörg Rambau, Miriam Kießling, Sascha Kurz

We consider a fashion discounter distributing its many branches with integral multiples from a set of available lot-types. The lot-type design problem (LDP) [Gaul et al. 2010] asks: which (integral) multiples of which (integral) lot-types (assortments of sizes) should be supplied to a set of branches in order to meet a (fractional) expected demand as closely as possible? There is a compact LDP-model; however, its integral gap is so large that it cannot be solved for most practical instances. On the other hand, the tightest LDP-model known so far [Gaul et al. 2010] can have billions of variables. (For 12 different sizes, reasonable for lingerie or children's clothing, there are 1,159,533,584 different lot-types, if we assume at most 5 items of each size and a total number of items in a lot-type between 12 and 30.) Thus, not for all instances the tight model can be fed to a computer statically. We show how the tight model, which can be interpreted as a Dantzig-Wolfe decomposition of the compact model, can be solved by Augmented Subproblem Grinding, which is a new Branch-and-Cut-and-Price variant, well-suited for tight models. Computational results on real-world instances as well as on randomized stress-tests show that for the tight LDP-model dynamic column generation speeds up the solution by a factor of more than 100 on average compared to the solution of the static model and solves instances (up to 9,867,114,720,320 variables) that cannot be solved statically at all.

2 - **Strategic Inventory Placement in Large-Scale Multi-Echelon Networks: A Sampling-Based Approach**
Stefan Minner, Josef Svoboda

Supply networks depend on a reliable internal material allow for process stability and cost-efficiency. The strategic placement and sizing of safety stock under demand uncertainty pose a challenging, non-linear stochastic optimization problem. Solution approaches often require distributional assumptions and parameter estimation. We build on recent advances in data-driven inventory optimization to propose a novel approach for safety stock planning in multi-echelon inventory networks based on the guaranteed service model. Errors from distributional assumptions and parameter estimation are reduced via a non-parametric approach based on historical demand and feature data. A general, acyclic multi-echelon network model operating under a periodic review base stock policy under service level constraints is considered. The optimization problem is formulated as a mixed-integer linear program and solved with mathematical programming solvers and Benders decomposition. In numerical experiments, we show that the mixed integer programming approach is scalable by solving the large-scale supply chain networks for 38 real-world industry supply chain networks with assembly, distribution, and general structures. The medium-sized networks are solved to optimality with Benders decomposition.

3 - **Flow Formulation of the Stochastic Guaranteed Service Model with Demand Propagation**
Dominik Kamp, Jörg Rambau

The Stochastic Guaranteed Service Model with Demand Propagation (SGSM-DP) aims at a cost-optimal safety stock allocation in multi-echelon distribution networks with emergency supply options. It can be stated as a mixed-integer big-M-linearized program. As such it suffers from a considerable integrality gap, which renders the use of general-purpose solvers intractable for real-world problem instances. In this talk an alternative formulation of the SGSM-DP based on dynamic flows with backward-time arcs (F-SGSM-DP) is presented. It maintains a substantially smaller integrality gap at the cost of a larger set of variables. Nevertheless by the new F-SGSM-DP significantly deeper networks with heavier parameters can be solved to optimality in reasonable time than by the equivalent SGSM-DP. Therefore, the F-SGSM-DP makes it possible for the first time to evaluate optimal solutions of the SGSM-DP for realistic inventory networks within a dynamic simulation environment. Applying the Dantzig-Wolfe decomposition to the large scale F-SGSM-DP is a promising approach to further reduce the computation time by a path-based column generation.

4 - **Inventory control in production-inventory systems with random yield and rework**
Danja R. Sonntag, Peter Berling

A single-stage make-to-stock production-inventory system under random demand and random yield is considered, where defective units are reworked. We examine how to set cost-minimizing production/order quantities in such imperfect systems, which is challenging because a random yield implies an uncertain arrival time of outstanding units and the possibility of them crossing each other in the pipeline. To determine the order/production quantity in each period, we extend the unit tracking/decomposition approach, considering the possibility of order-crossing, which is new to the literature and relevant to other planning problems. The numerical study reveals that a proposed state-dependent policy can reduce inventory-related costs compared to the base-stock policy by up to 6% and compared to an existing approach from the literature by up to 4.5%. From a managerial perspective, the most interesting finding is that a high mean production yield does not necessarily lead to lower expected inventory-related costs.

■ WD-31

Wednesday, 14:30-16:00 - M240

Variational analysis and applications to optimization

Stream: Variational analysis and optimization
Invited session
Chair: Abderrahim Hantoute

1 - **Amenability and hyperbolic programming**
Vera Roshchina

Hyperbolicity cones and hyperbolihedra are versatile convex objects defined via purely algebraic terms. They are known to be at least as general as spectrahedra, and have a special derivative structure that provides an algebraic scaffolding that helps in studying the geometry of these objects.

Hyperbolicity cones satisfy many good properties, for instance, they are facially exposed and facially dual complete (nice). The focus of this talk is to demonstrate that hyperbolicity cones are also amenable and to showcase some of the fun derivative-based techniques that are used in the proof.

The talk is based on collaborative work with Bruno Lourenço (The Institute of Statistical Mathematics, Japan) and James Saunderson (Monash University, Australia).

2 - **New optimality conditions in robust optimisation**
Abderrahim Hantoute

We provide new optimality conditions for convex robust optimization problems in infinite dimensional setting. Our conditions involve continuity type criteria that extend the usual constraint qualification of ordinary convex optimization.

3 - **Extensions of the constant rank qualification constraints condition to nonlinear conic programming**
Hector Ramirez

We present new constraints qualification conditions for nonlinear conic programming that extend some of the constant rank-type conditions from nonlinear programming. As an application of these conditions, we provide a unified global convergence proof of a class of algorithms to stationary points without assuming neither uniqueness of the Lagrange multiplier nor boundedness of the Lagrange multipliers set. This class of algorithms includes, for instance, general forms of augmented Lagrangian, sequential quadratic programming, and interior point methods. We also compare these new conditions with some of the existing ones, including the nondegeneracy condition, Robinson's constraint qualification, and the metric subregularity constraint qualification. Finally, we propose a more general and geometric approach for defining a new extension of this condition to the conic context. The main advantage of the latter is that we are able to recast the strong second-order properties of the constant rank condition in a conic context. In particular, we obtain a second-order necessary optimality condition that is stronger than the classical one obtained under Robinson's constraint qualification, in the sense that it holds for every Lagrange multiplier, even though our condition is independent of Robinson's condition.

4 - **Universal bounds for fixed point iterations via optimal transport metrics**
Mario Bravo

We present a self-contained analysis of a particular family of metrics over the set of non-negative integers. We show that these metrics, which are defined through a nested sequence of optimal transport problems, provide tight estimates for general Krasnoselskii-Mann fixed point iterations for non-expansive maps. We also describe some of their very special properties, including the so-called convex quadrangle inequality that yields a greedy algorithm for computing them efficiently.

This is joint work with Roberto Cominetti and Thierry Champion

■ WD-33

Wednesday, 14:30-16:00 - F102

Game Theory, Solutions and Structures VI

Stream: Game Theory, Solutions and Structures
Invited session
Chair: Paolo Zappala

1 - The roll-out of new mobile technologies as a timing game
Paolo Zappala, Matthieu Chardy, Rosa Figueiredo, Francesco De Pellegrini

When adopting a novel mobile technology, a mobile network operator faces the dilemma of determining which is the best time to start the installation of next generation equipment onto the existing infrastructure. In a strategic context, the best possible time for deployment is also the best response to competitors' actions, subject to normative and material constraints and to the customer's adoption curve. We formulate in this paper a finite discrete-time game which captures the main features of the problem for a two players game played over a prescribed finite horizon. Under mild assumptions on the time scale at which operators decide on the installation, we provide a methodology to obtain the subgame-perfect equilibrium for the resulting extensive form game. Our numerical results provide insights on the possible optimal tradeoffs for an operator between fixed costs and installation strategies.

2 - Considerations on ownership and strategic use of Power-to-Gas: a case study of the North-Western European electricity and gas markets
Camille Megy, Olivier Massol

Accommodating a large proportion of RES in power systems raises system stability concerns and affects power system economics. Against this background, power-to-hydrogen (PtH) technologies - and the flexibility they provide - are expected to facilitate the operation of renewable-dominated electricity systems. Developing investments in electrolysis is thus a core component of the European Union's hydrogen strategy, and a sizeable deployment of PtH asset is projected by 2025-2030. Yet, the ownership structure of PtH assets (involving either existing electricity producers, gas retailers, foreign gas producers or independent private players) and its implications on the future market outcomes have so far little been examined. The purpose of this study is thus to explore whether these alternative ownership structures matter or not in imperfectly competitive gas and electricity markets. We develop a mixed-complementarity problem that conveys a stylized representation of the Northwestern European power and gas system and the market-coupling role of PtH. In particular, we account for possibly imperfectly competitive markets. The model is solved numerically under a set of alternative ownership structures. The results documents the impact of PtH ownership on:(i) the operation of PtH assets, (ii) the observed market outcomes in both power and gas markets, and (iii) the associated distributional effects by examining the distribution of net social welfare across market participants.

■ WD-34

Wednesday, 14:30-16:00 - T003

OR and Ethics in Healthcare and Sustainable Development Goals

Stream: Ethics and OR
Invited session
Chair: R Kazakov
Chair: Ulrike Reisach
Chair: Cindy-Ricarda Roberts

1 - Fostering engagement in AI design to aid communication decisions in the NHS
Christina Phillips

We describe ongoing research that uses a Human Centric Analytics (HCA) approach to foster engagement that positively impacts both an AI design and the communicators who are likely to use it. Through a series of workshops, weekly research meetings, and an iterative design of classifiers to perform Natural Language Processing on social media posts we have created outputs that are being bought together with decision makers. The 'citizen panel' workshops informed the research design, and the design of the classifiers, the classifiers informed the workshops to create a dialogue between the possibilities afforded by AI and the thoughts and experiences of citizens. Bringing our finding together with decision makers whose job it is to communicate health messages to the public creates an opportunity to fit the classifiers into a landscape of knowledge and measurement such that health communicators can assess how their messages are landing and how they can best design and target information.

2 - Artificial Intelligence for Skin Cancer Classification
Sarah Haggenmüller

Several studies have shown the potential of artificial intelligence (AI)-based models for skin cancer classification. However, successful translation of these findings into clinical practice is yet to be achieved. We therefore analyzed the current state of research on studies comparing AI and human experts with particular reference to their potential clinical relevance. We reflected the actual impact and forthcoming challenges expected with the implementation of AI into dermatological care by assessing three main aspects: test set characteristics (holdout/out-of-distribution data set, composition), test setting (experimental/clinical, inclusion of metadata) and representativeness of the participating clinicians. All reviewed studies demonstrated superior or at least equivalent performance of AI in comparison to human experts. However, almost all studies were carried out in highly artificial settings. Test sets mainly consisted of holdout images and did not represent the full range of patient populations and melanoma subtypes encountered in clinical practice. To increase clinical relevance, future comparisons should be conducted under less artificial settings and validated with external testing.

3 - Gender insights within the EURO OR community
Annunziata Esposito Amideo, Paula Carroll

This work reports on the outcomes of a survey carried out as part of the EURO WISDOM Forum research agenda on "gathering data to model the OR network of actors" to "stimulate a conversation around how OR can be utilised to help create a diverse and inclusive future". The survey was carried out in 2021 and aimed to identify some of the reasons people choose to pursue a career in OR, explore the participation in OR sub-disciplines by gender, map any potential emerging challenges to participation, and, eventually, create insights into different OR career paths. To the best of our knowledge, WISDOM has been the first to produce a survey to enquire over a gender dimension within the EURO OR community. This research first provides a description of the survey: questions mostly explored respondents' background (e.g., caring responsibilities, career break avail, OR sub-discipline expertise, employment circumstances), career progression (e.g., time since PhD award, motivations associated to either an institution "change" or "no change" decision), and participation in OR (e.g., authors' ordering convention, perceived or experienced challenges to build a career in OR). Then, the emerging themes in gender and OR are discussed based on descriptive and predictive analytics techniques. Finally, building on this analysis, some propositions are laid out to further enhance EDI in OR within EURO.

■ WD-35

Wednesday, 14:30-16:00 - T004

Railway Planning

Stream: Transportation
Invited session
Chair: Dennis Huisman

1 - How (not) to Evaluate Passenger Routes, Timetables and Line Plans

Rolf Van Lieshout, Kevin Dalmeijer

Accurate evaluation of the service quality of public transport is imperative for public transport operators, providers of competing mobility services and policy makers. However, there is no consensus on how public transport should be evaluated. We fill this research gap by presenting a structural approach to evaluate three common manifestations of public transport (route sets, timetables and line plans), considering the two predominant route choice models (shortest path routing and logit routing). The measures for service quality that we derive are consistent with the underlying routing models, are easy to interpret, and can be computed efficiently, providing a ready-to-use framework for evaluating public transport. As a byproduct, our analysis reveals multiple managerial insights.

2 - Railway crew scheduling: A case study of Indian Railways

Akshat Bansal, Anoop K P, Narayan Rangaraj

This research considers crew planning for long-distance passenger trains of Indian Railways, one of the most extensive rail networks in the world. The problem is to find the minimum number of crew duties required to operate all trains while satisfying the operational constraints and crew-related rules. This study implements exact and heuristic-based approaches and tests their performance through computational experiments over real data sets of the Mumbai Division, which comes under the Central Railway zone of Indian Railways and comprises three major sections. The exact approach is a two-step methodology: step-I is a constraint programming model that generates feasible crew duties, and step-II is a set covering problem formulation that finds an optimal set of duties. However, as the problem is NP-hard, finding an exact solution for practical scale problems is challenging. Thus, a heuristic algorithm is proposed that extends the idea of a one-dimensional bin-packing problem to the crew-scheduling setting with substantial modifications. The algorithm is computationally efficient and is capable of generating good quality solutions. The heuristic results on a test case show a possibility of reducing the actual crew deployment by about 12%. Further, a comparison between integrated and section-wise crew planning has been drawn. Given the broad coverage of scheduling rules, the heuristic can be extended to other rail networks with slight modifications.

3 - Operational Railway Crew Planning with Individual Sharing-Sweet-and-Sour Rules

Twan Dollevoet, Bart van Rossum, Dennis Huisman

At Netherlands Railways (NS), the Sharing-Sweet-and-Sour rules ensure a fair division of attractive and unattractive work over the various crew bases. In the current crew planning process, however, these rules are enforced in the tactical planning phase only, and are no longer incorporated in operational planning. Moreover, the rules on crew base level do not necessarily guarantee a fair division of work between individual crew members. To tackle these two issues, we propose to (i) formulate Sharing-Sweet-and-Sour rules on the individual level and (ii) consider them explicitly in the operational planning phase. We formulate the operational crew scheduling problem with individual Sharing-Sweet-and-Sour rules, and propose a sequential solution approach with a feedback mechanism to ensure that these rules are met at the end of the planning horizon. We compare this approach to the current planning process by evaluating its performance on a real-life instance from NS.

■ WD-37

Wednesday, 14:30-16:00 - V001

Reverse Logistics

Stream: Vehicle Routing and Logistics
Invited session
Chair: Sonja Rosenberg

1 - A two-phase methodology to solve a Sensor Placement Problem in Waste Management based on a Vehicle Routing Problem with Detours

Carolina Soares de Morais, Daniele Vigo, Tania Ramos, Ana Paula Barbosa-Póvoa

Waste Management faces inefficient solid waste collection and transportation due to an incapacity of accurately allocate resources to waste demand. More efficient collection routes can be designed if sensors are used to communicate the amount of waste inside bins. As the cost of implementing this technology is still very high, we investigate how to select a sample of bins to monitor, considering the investment cost and the value of information provided by sensors. To solve a sensor placement problem in waste management, we propose a two-phase methodology that separately addresses the tactical decision on which bins to monitor and the operational decision on how to design collection routes based on information transmitted by installed sensors. In the first phase, the least and most conservative bins from small clusters of nearby bins are selected to be monitored. Then, in the second phase and depending on real-time information transmitted by the installed sensors, a Clustered VRP with Detours is operationally solved to decide the detours to be taken from a skeleton of set routes that are regularly performed to visit non-monitored bins. A real-world problem is solved using the proposed methodology, and three scenarios are assessed by a cost-benefit analysis: 1) no sensors - all bins are visited regularly; 2) sensors in all bins - bins are visited when it is required; 3) a set of bins is monitored - a regular route is performed and, when it is required, a detour is taken.

2 - The Location of Collection Centers for Used Electric Vehicle Batteries

Deepak Gautam, Amit Ranjan Verma, Nomesh Bolia

Concerns about environmental consequences, fossil fuel dependency, and global warming have prompted calls for the rapid and widespread adoption of electric vehicles (EVs) for the full range of mobility needs worldwide. Nevertheless, managing the end-of-life batteries discarded from EVs after their first life is a major future challenge. Collection of these batteries for their potential after-use and recovery of constituent elements is critical for mitigating the impact of extensive mining, high expected demand, and cost. A structured reverse logistic network is required to collect these used batteries back from customers. This work includes a case study for Delhi (India), where possible collection centers must be located. Set covering and p-median, the classical facility location problem variants, are used to formulate the problem. The methodology provided in this study calculates the number and location of collection centers needed in an urban setting. The objective is to locate collection centers to collect used batteries to allow customers to access the centers within an appropriate threshold distance while respecting real-world life constraints. For this purpose, a mathematical programming model is developed and solved using CPLEX 12.10 solver as well as the Artificial Bee Colony technique where relevant. Computational results provide the optimal infrastructure designs for new policies that governments and other stakeholders may adopt.

3 - An Integrated Strategic and Tactical Optimization Model of a Dynamic Reverse Network for EoL Traction Batteries applied for an OEM in Germany

Sonja Rosenberg, Simon Glöser-Chahoud, Sandra Huster, Frank Schultmann

Electric vehicles (EVs) are a pillar of sustainable future mobility. However, the increasing market penetration of EVs will lead to an equal growth of End-of-Life (EoL) traction batteries that should be treated according to circular economy principles. Recycling, reconditioning, and repurposing are some discussed recovery options. Developing efficient reverse networks for EoL traction batteries is considered a major barrier by industry and research to be solved in the upcoming years. We, therefore, present a dynamic MILP for EoL traction battery network design that includes a multi-period, multi-layer profit maximization. In our model, the strategic decisions of location choice and processing capacity expansions are taken at so-called design periods. In contrast, product flow allocation to open plants and decisions about processing choices are taken more frequently on tactical planning horizons. The possible EoL treatment routes depend on the quantity and quality of the returned batteries, and costs are decreasing with increasing production capacities and varying among product types. These formulations allow accessing some of the significant challenges when optimizing a fast-growing EoL product market. We apply the developed model to a case study to demonstrate how an OEM of electric vehicles can set up an efficient reverse network for its products in Germany.

■ WD-38

Wednesday, 14:30-16:00 - V002

Transportation modeling II

Stream: Transportation
Invited session
Chair: Oscar Téllez

1 - Rethinking cyclic structures in liner shipping networks

Daniel Wetzel, Kevin Tierney

Liner shipping networks are a central feature of modern supply chains that consist of cyclical, periodic services operated by container ships. This specialized, cyclical structure eases planning for both shipper and carrier, but the combination of cyclical planning with the available time windows at ports can lead to inefficient sailings. We propose to relax the cyclical assumption and allow ships to move between services to avoid inefficient connections without interruption to container flows. From the view of a shipper, the cyclical and periodic properties of the services still hold, and the liner carrier can offer a more efficient overall network. The resulting optimization problem consists of a combined vessel routing problem and cargo allocation problem, resulting in large and difficult instances. We model the problem using mixed-integer linear programming and use column generation to efficiently find solutions. We show using real-world data that giving flexibility to a liner network can result in a significant cost reduction over standard cyclical schedules.

2 - Optimization model to design the crew training plan in an airline

Pablo Lechuga, Rafael Torres Escobar

Populations, flows and manpower hours are considered in the manpower planning problem. The objective is to project the structure of the categories with actual conditions that satisfy the operational needs. In this application, the populations are crew categories, flows are hiring's and transfers between categories depending on the career path, and manpower hours are the aircraft ours related with the crew need required to operate the aircrafts. The application use transfers as integer decision variables and continuous decision variables to describe de slack in the manpower hours. The classic approach for this kind of problem is a probabilistic model like the Markov chain but this application uses a deterministic model to evaluate scenarios that don't depend on previous events giving the flexibility to create scenarios depending on different future possible environments. The use of the tool helped to reduce the evaluation time of a scenario from days to minutes and possible actions to reach the manpower hour's goal by finding the best solution of transfers to reduce the inefficiencies.

3 - Robust workload balance for postal services with stochastic customers and service times

Oscar Téllez, Véronique François, Yasemin Arda

Postal delivery services are an essential part of our lives. They are ensured by couriers who perform daily rounds in fixed geographic areas called districts. Districts are typically defined for a long period of time based on the expected demand. However, usual demand variations can negatively impact the couriers' workload, either by exceeding their shift duration, or by creating a largely unfair workload distribution among couriers on certain days. The objective of this research is to design robust districts so that the workload of couriers remains balanced when considering stochastic customers and service times. The problem is modeled as a two stage stochastic program. In the first stage, districting decisions are made by creating routes that cover all of the customers. In the second stage, the workload balance is estimated considering that those routes are followed by the couriers while skipping the absent customers. In this problem, vehicles are uncapacitated. However, a maximum route duration related to the couriers shift time is defined using a chance constraint formulation. The routing problem is modeled as a node, edge, and arc vehicle routing problem with stochastic customers and service times. This research is conducted in partnership with the Belgian postal service company, bpost. Numerical analyses are performed on instances with stochastic information based on realistic data. In addition, the robustness of the districts is evaluated by means of simulations.

4 - Student selection model to reduce a school bus fleet

Javiera Auad, Macarena Duran, Hernan Caceres, Rajan Batta

In the United States, a large proportion of students attend school using their local public school bus transportation system, which is typically managed at a district level. However, without proper planning, school buses can suffer a significant unbalanced workload, ultimately leading to inefficiencies. Motivated by the case of a school district of Western New York, we explore the effect of reducing the fleet size to increase system overall efficiency. To achieve this, we explore the option of offering a monetary incentive to a selected group of students, in exchange for using alternative transportation modes to get to their schools. We define the optimization problem of finding the smallest set of students to whom the incentive would be offered such that the bus fleet is reduced in one unit. We propose a two-stage algorithm that first solves the School Bus Routing Problem (SBRP) to determine the minimum number of buses to serve all the students subject to itinerary constraints. Then a second step solves a variant of the SBRP that maximizes the number of students served given a reduced bus fleet, where the non-selected students constitute the group that would be compensated with the monetary incentive. We apply our algorithm for different fleet sizes in a case study of the Williamsville Central School District in New York State, where the current bus utilization ranges from 22% to 77%.

Wednesday, 16:30-17:30

■ WE-01

Wednesday, 16:30-17:30 - A

Christina Pagel

Stream: Plenaries
Plenary session
Chair: Marc Sevaux

1 - An overview of the Covid-19 pandemic and a reflection of the interconnectedness of systems
Christina Pagel

In May 2020 I joined the group Independent SAGE, a group of scientists who are working together to provide independent scientific advice about the state of the pandemic in the UK and internationally. From the summer of 2020 onwards, I have been giving regular updates on the latest Covid situation in the UK during Independent SAGE's live streamed weekly briefings and we have released over 30 reports covering different aspects of the pandemic. This has meant that I have had a ringside seat in the changing landscape of government policy, scientific advice and the evolution of the virus. I have also learned a great deal from my Independent SAGE colleagues and others about public health, health inequalities, virology, epidemiology and behavioural science. In this talk, I will reflect a systems perspective has often been lacking in response to the pandemic, both nationally and internationally, and how this exacerbated problems through negative feedback loops which contributed to drive transmission and poor health outcomes.

Wednesday, 17:30-19:00

■ WF-01

Wednesday, 17:30-19:00 - A

Closing session

Stream: Opening and Closing
Plenary session

Additional educational activities for OR-Analytics - the link to Development

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Track(s): 23

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Track(s): 21

Applications of OR

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Track(s): 26

Behavioural OR

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Track(s): 21 38

BIGMATH - Mathematics for Big Data

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Track(s): 27

Combinatorial Optimization

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Track(s): 6 8 39

Cutting and Packing

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Track(s): 18

Data Driven Decision Making

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Track(s): 5

Data Envelopment Analysis and Performance Measurement

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Track(s): 20

Data Mining and Statistics

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Track(s): 28

Data science and Analytics (contributed)

Track(s): 28

Data Science Meets Optimization

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Track(s): 5

Decision support (contributed)

Track(s): 15

Decision Support Systems

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Track(s): 15

Deep Learning and Applications

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Track(s): 5

Demand and Supply in Consumer Goods and Retail

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Track(s): 24

Discrete Optimization and Algorithms (contributed)

Track(s): 13

Dynamical Systems and Mathematical Modeling in OR

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Track(s): 20

Emerging Research and Specific Applications of OR

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Track(s): 25

Energy Management

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Track(s): 14

Ethics and OR

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Track(s): 34

EURO Doctoral Dissertation Award

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Track(s): 2

EURO Forums Plenary Session

Dolores Romero Morales
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Track(s): 1

EURO Prize for OR for the Common Good

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Track(s): 2

EWG CBBM, EURO working group on Computational Biology, Bioinformatics and Medicine

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Track(s): 23

EWG HOpe, EURO working group on Humanitarian Operations

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Track(s): 26

Financial Risk Measurement and Management

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Track(s): 7 10

Game Theory and Operations Management

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Track(s): 33

Game Theory, Solutions and Structures

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Track(s): 33

Humanitarian and Healthcare applications (contributed)

Track(s): 38

Industrial Production, Planning and Inventory Management

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Track(s): 29

Keynotes

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Track(s): 1

Location Analysis

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Track(s): 25

Lot Sizing, Lot Scheduling and Production Planning

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Track(s): 31

Machine Learning and Mathematical Optimization

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Track(s): 3 4

Making an Impact

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Track(s): 8 39

Mathematical Models in Macro- and Microeconomics

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Track(s): 32

Metaheuristics, Matheuristics

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Track(s): 14

Mixed Integer Linear Programming

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Track(s): 9 13

Multiobjective Combinatorial Optimization

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Track(s): 7

Multiple Criteria Decision Analysis

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Track(s): 7 11

Network Optimization

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Track(s): 14

Numerical Optimization Methods with Inexact Evaluations of Objective Functions and/or Derivatives

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Track(s): 27

Opening and Closing

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Track(s): 1

Operational research in financial and management accounting

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Track(s): 17

OR Education

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Track(s): 20

OR for Development and Developing Countries

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Track(s): 17

OR in Energy

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Track(s): 7 12

OR in Military, Defense, and International Security

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Track(s): 24

OR in Sports

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Track(s): 19 23

OR Journals

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Track(s): 2 13

ORAHS: OR in Health and Healthcare

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Track(s): 16 34 36 38

Performance Evaluation of Queues

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Track(s): 19

Plenaries

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Track(s): 1

Pricing and Revenue Management

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Track(s): 23

Problem structuring and soft OR

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Track(s): 31 39

Project Management and Scheduling

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Track(s): 30

Queueing and Stochastics (contributed)

Track(s): 24

Real Option Analysis

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Track(s): 16

Risk Management in Finance

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Track(s): 16

ROADEF/EURO Challenge 2022

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Track(s): 30

Set Valued Models in Finance

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Track(s): 16

Shared Mobility

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Track(s): 38

Smart Mobility and Logistics

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Track(s): 34

Software for Optimization

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Track(s): 17

Specific Applications of OR in Agriculture, Forestry and Fisheries

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Track(s): 23

Splitting and ADMM Methods

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Track(s): 27

Stochastic and Robust Optimization

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Track(s): 18

Stochastic Dynamic Programming and Learning Policies

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Track(s): 28

Supply Chain Management

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Track(s): 22

Sustainable Development and Green Technologies

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Track(s): 32

Sustainable Supply Chains

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Track(s): 22

Transportation

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Track(s): 35 38

Variational analysis and optimization

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Track(s): 31

Variational Inequalities, Equilibria, Games and Multilevel Optimization

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Track(s): 33

Vector and Set Optimization

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Track(s): 30

Vehicle Routing and Logistics

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Track(s): 37

Warehouse Design, Planning, and Control

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Track(s): 25

YoungWomen4OR

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Track(s): 32

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3-6 JULY
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