

ODS2024

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ODS2024 - Book of Abstracts

The ODS2024 Organizing Committee

This book contains all of the abstracts accepted for presentation at the International Conference on Optimization and Decision Science, ODS2024, held in Badesi (SS) from September 9th to September 12th, 2024. The conference is organized within AIRO, the Italian Operations Research Society, with the support of DMI (Department of Mathematics and Computer Science, Università degli Studi di Cagliari). The conference theme is open in the fields of operations research, optimization, problem solving and decision making, and their applications. A special focus will be on the theme "Operations Research: closing the gap between research and practice". The book of abstracts contains over 190 contributions, 31 of which associated to papers accepted for publication in the AIRO Springer Series volume devoted to the conference. The contributions are organized into 4 parallel streams and about 43 sessions, 14 of which are invited sessions/streams. Three plenary sessions enrich the scientific part of the conference; they are given by world-renowned professors, and they are related to extremely topical and important issues. Abstracts are listed day by day, session by session.

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Dipartimento di Matematica e Informatica
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Invited Sessions

Topics in Combinatorial Optimization organized by Paolo Toth

Maritime Logistics & Intermodal Transport organized by Daniela Ambrosino

Optimization under uncertainty organized by Francesca Maggioni and Patrizia Beraldi

Fairness in Optimization Problems organized by Valentina Morandi

Scheduling organized by Paolo Detti

Healthcare organized by Roberto Aringhieri, Giuliana Carello and Elena Tanfani

Railway Transportation organized by Paolo Ventura

Recent Advances in Variational Inequalities and Equilibrium Problems organized by Patrizia Daniele and Laura Scrimali

ACHILLES PRIN and CN MOST PNRR Projects - on ecosustainable and innovative last-mile logistics solution organized by Claudio Sterle

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Session: Vehicle Routing 1

Monday September 9th 9:00am - 11:00am

Conference Center A

Chair: Maurizio Bruglieri

The Stochastic Team Orienteering Problem

Alberto Guastalla[1], Jean-François Côté[2] and Roberto Aringhieri[1]

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The Team Orienteering Problem (TOP) is a well-known combinatorial optimization problem that can be described through a complete graph in which each node has a profit and each arc has a cost. The objective is to find a set of m different routes collecting the maximal sum of profits from the visited nodes without exceeding a specific time budget for each of them. Each route must start from the source node and must end to the destination one. This abstract focuses on the stochastic version of the TOP: the Stochastic Team Orienteering Problem (STOP). We present a mathematical model for the STOP adapted from the compact formulation of [1]. We also consider a set of chance constraints to take into account the route feasibility. We test three different recourse function approximation schemes to formulate the objective function of the problem: (i) the Laporte and Louveaux [2] scheme, (ii) the Séguin [3] scheme and (iii) the Disaggregated [4] scheme. Furthermore, we present an exact algorithm to solve the problem based on a modified version of the classical Integer L-Shaped method enriched with valid inequalities to strengthen the LP relaxation of the model. We separate several families of valid inequalities grouped into three categories: (i) the ones that are able to cut off the infeasible solutions from the search space, (ii) the ones with the aim to bound the value of the objective function and (iii) the ones that strengthen the LP relaxation of the problem. To further tighten the value of the objective function, we present different bounds based on the continuous relaxation of the STOP itself. We further introduce two constraints liftings approaches to strengthen the formulation of the model. Finally, we describe the computational results of our solution method on the TOP literature instances making a comparison among the three approximation schemes.

Keywords: stochastic programming, team orienteering problem, exact algorithm, valid inequalities

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The Stochsatic Clustered Team Orienteering Problem

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Traveling and transportation are essential parts of human life, whether at a local or global scale. Accordingly, the field of Combinatorial Optimization described a wide variety of routing problems that extensively represent the complex logistic choices entailed by movement. Routing problems with profits model scenarios where decision-makers can choose which points of interest (POIs) to visit based on their perceived value or benefit, subject to budget constraints. In the Clustered Team Orienteering Problem (CluTOP), customers are grouped into clusters, and a profit is assigned to each cluster, which is earned only if all customers in the cluster are visited. A set of identical vehicles cooperates to maximize the total collected profit with respect to the limited travel time imposed on each vehicle.

As the real world presents many forms of uncertainty, this work addresses the CluTOP in a stochastic scenario, where travel times are modeled with random variables. To tackle the problem, we propose a sim-heuristic based on an Adaptive Large Neighborhood Search (ALNS). The ALNS uses the mean values to solve a deterministic snapshot of the instance. Afterwards, Monte Carlo simulation is used to evaluate such a solution in a stochastic environment.

To allow the decision maker to choose the best solution for their needs, the solutions with the best mean objective function can be given as output with a range of information such as mean, standard deviation and overall reliability.

Keywords: Orienteering problems, Stochastic, ALNS, sim-heuristics

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Touting occasional drivers for mid-haul delivery: a stochastic optimization approach

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Outlet villages became very popular in the last decades, since they group hundreds of fashion brand stores offering outlet stocks at discounted prices. Recently, they started to offer online purchasing services combined with home delivery, within a large area. However, offering this service may be extremely costly. We propose to exploit in-store customers, similarly to what is already practiced in last-mile delivery, [1], to perform mid-haul deliveries on their way back home. This would require small detours to serve customers who are even very far from the outlet with a huge savings for the company. The drawback of the system is that the presence of in-store customers willing to serve a specific area might be uncertain. To mitigate the effect of such uncertainty, we propose to adopt a touting strategy to incentivice frequent in-store customers to come to the outlet on a specific day and to perform, if needed, a mid-haul delivery on their way back, by offering them a discount voucher as compensation. The value of this compensation can be decided by the company, and it influences the probability of acceptance of the touting offer. Additionally, the company may exploit customers who express their interest to act as occasional same-day drivers (SODs), directly on site. A part of the orders is known in advance, whereas further orders may arrive along the day. Orders who cannot be fulfilled with neither touted nor SODs, must be served by the owned fleet. The company goal is to minimize the total cost, given by the owned fleet routing, the touting, and the compensation for SODs. We formulate the problem as a two-stage stochastic optimization problem, for which we provide an arc-based and a path-based formulations. We prove the effectiveness of using touting and SODs, alone and in combination, on different types of road networks. Furthermore, we analyze a real case analysis concerning an outlet village located in the North-West of Italy.

Keywords: Occasional Drivers, Stochastic Optimization, Touting

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Analysis of a pick-up and delivery system that uses lockers and crowdshipping to meet random requests

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We consider on a collaborative e-platform that receives requests for products from a collection of local businesses and then schedules the pick-up of the requested products from the local store and the subsequent delivery of these requested products to the e-shoppers' local locations. To facilitate the efficiency of this pickup-and-delivery operation, we consider the e-platform's use of parcel lockers and crowdsourced couriers to complement a dedicated fleet. Our work aims to analyze the operational impact of crowdshipping and parcel lockers for a same-day stochastic pickup-and-delivery problem facing an e-platform. We assume that an e-platform receives the customer requests randomly throughout the day. To provide delivery service, we assume there is a fleet of dedicated vehicles. Each dedicated vehicle is available for a daylong shift starting and ending at the depot. In contrast, when and how long each crowdshipper is available is unknown to the e-platform before their appearance. The objective is to minimize the cost of fulfilling customer requests over an operating day. To measure the cost of providing service, we minimize the sum of three components: (1) the total travel cost of the dedicated vehicles and crowdshippers (as function of travel time), (2) the total per-delivery fees paid to crowdshippers, and (3) the total lateness charge (as a function of the amount of time customer requests are delivered after their soft deadlines). We model our problem as Markov Decision Process that has a high-dimensional state, action, and outcome space. To identify a policy mapping an action to any observed state, we modify the approximate dynamic programming method in Stoia et al. [1]. To assess our solution approach in two distinct problem settings, we consider a set of data instances from Stoia et al. [1] in which requests arrive according to a non-homogeneous Poisson process with an average of 225 requests over a 10-hour workday.

Keywords: Markov Decision Process, Crowdshipping, Lockers

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Autonomous electric vehicle routing problem with battery recharging by drones using public transit

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The Autonomous Vehicle Routing problem with battery recharging by drones, using public transit consists of routing a fleet of autonomous electric vehicles (AEVs) with limited battery capacity for delivering orders to customers in the last-mile. To avoid service disruptions, due to the limited battery capacity, the AEVs can be recharged during the trip, when they stop at customer's locations for the delivery tasks, using drones equipped with wireless energy transmission technology [1]. Hence, drones can be seen as mobile chargers. In addition, drones can be launched from the depot as well as from some dedicated public stations. Indeed, we assume that there is the possibility for each drone to complete part of its journey on the top of the public lines [2]. We mathematically represent the problem as a Mixed-Integer Linear Programming (MILP) model, considering time windows, synchronization, and capacity constraints. The proposed framework is studied by solving the MILP and then analysing the potential of the new paradigm.

This work was supported by grants awarded by "European Union – Next Generation EU" under the "PRIN 2022 - PNRR" project: COSMO, CUP H53D23008850001 (Giusy Macrina); and under the "PRIN 2022" project: SMOTION (ID 2022EAECWJ), CUP H53D23002000006 (Francesca Guerriero), and CUP B53D23009270006 (Luigi Di Puglia Pugliese)

Keywords: Electric Vehicle Routing, Drone, Wireless Power Transmission, Public Transit Network

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Efficiently solving the Electric Vehicle Routing Problem with capacitated recharging stations

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According to the European Environment Agency (`https://www.eea.europa.eu/en`), a quarter of the total $C0_2$ emissions in Europe are due to the transport sector, 71% of which is due to road transport. To this purpose, several countries are promoting electric vehicles (EVs). However, due to their limited driving range, EVs may need to recharge along their trip. Since the recharging stations (RSs) are not currently widespread on the territory, and the recharge process takes time, we need properly planning the EVs' routes, including their stops at RSs.

In this context, the seminal work [1] introduced the Electric Vehicle Routing Problem with Time Windows with the aim of routing a fleet of EVs, each one starting from the depot and returning to it within a maximum time limit, serving customers on time, with possible stops at RSs, at minimum total travel distance. The EVs are assumed to be always fully recharged at the RSs. We instead address a variant in which partial recharges are also allowed. Moreover, unlike [1], we make the realistic assumption that the RSs have a limited number of chargers and then, when an EV arrives to an RS, it may not find any charger available.

We model the optimization problem as a Mixed Integer Linear Program (MILP). Moreover, we use the MILP formulation in a matheuristic framework to efficiently address also large-sized benchmark instances taken from [2].

Finally, we show that our method outperforms the results of [2].

Keywords: Vehicle Routing, Mixed Integer Linear Programming, Capacitated Stations, Partial Recharges, Matheuristic

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Session: AI4RAILS 1- Shunting, routing and speed profile optimization

Monday September 9th 9:00am - 11:00am

Conference Center B

Chair: Mathijs de Weerdt

Towards Safer Freight Rail Shunting: Integrating MILP and ML Classification Models in a Risk Management Framework

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This paper proposes a novel risk analysis framework for rail freight shunting operations, challenging the direct application of Machine Learning (ML) as input for operational decision-making. Our approach integrates ML model's performance metrics into a Mixed-Integer Linear Programming (MILP) model for shunting operation, improving the reliability and adaptability of rail yard management. A comparative analysis based on real data from the Luxembourgish rail freight company CFL Multimodal across various destinations reveals that a full-risk function approach significantly outperforms the ML input model, reducing the risk term and cancellation rates. This study demonstrates that utilizing a risk assessment framework mitigates the potential for operational inefficiencies and unfeasibility inherent in ML-dependent models, ensuring continuous data accuracy and operational robustness.

Keywords: Rail Freight Operations, Shunting Operations, Risk Management, Machine Learning, Mixed-Integer Linear Programming, Data- driven modeling

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Resource management based on decentralized collaborative train control method at stations

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The high-speed rail passenger station is a key node in the railway network, constraining the overall passing capacity of the railway network. Influenced by uncertain factors such as weather and passenger flow, trains do not strictly adhere to the timetable[1], often leading to multiple trains competing for the use of track switches and arrival-departure tracks. Existing methods for adjusting train operations and track utilization at stations mostly focus on current signal systems, and allocate station resources in the form of train routes, resulting in low utilization rate of resources (switches and tracks) in station[2]. To meet the future increased transportation demand on certain rail lines, it is necessary to improve the utilization rate of trackside resources.This study developed a decentralized collaborative train control framework, in which train-to-train communication is adopted for direct information exchange in between adjacent train services.A station resource management strategy is designed to manage the status and utilization process of station resources under the decentralized train control framework. A model integrating multi-train coordination and trackside resource control is developed, considering constraints such as timetable, route speed limits, safety tracking intervals in-between train services, and resolving resource competition issues. Each train is treated as an intelligent agent, which generates the operational tasks based on its own status (speed, position, timetable requirements, etc.) and determines its requirements for specific switch or track resources. Based on inter-agent communication and interaction within multiple train agents, a game theory method is employed to allocate resource occupation sequence, resolving competition and achieving the goal of better usage of switches resources in bottleneck areas[3]. Finally, a simulation based on the real-life data about the Hangzhou East High-speed Station is established based on AnyLogic platform to verify the proposed decentralized train control framework and station resource management method, the results have proven that the proposed method is able to enhance the resource utilization efficiency at stations.

Keywords: Multi-train control, Station resource management, Self-organization, Multi-agent

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Replanning in Advance for Instant Delay Recovery in Multi-Agent Applications: Rerouting Trains in a Railway Hub

Issa K. Hanou[1], Devin Wild Thomas[2], Wheeler Ruml[2] and Mathijs de Weerdt[1]

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To minimize delays in a railway network, we want to prevent propagation by quickly reacting to changes. This study considers a railway hub, including scheduled trains passing through stations, shunting movements, and servicing operations. As many events can cause delays, like a prolonged maintenance task, replanning must be done as quickly as possible. Though when the duration of the delay is not yet known, no action can be taken. Therefore, we propose a new method for replanning that computes multiple plans in advance, so a single delay can be instantly handled without affecting the other trains.

We precompute plans for all possible starting times, based on different delays, so a train can simply select the appropriate plan once it is ready. For example, train A is set to depart at $t = X$ from its current platform, but it cannot depart yet. Train B will use the same switch as A at $t = Y$. So, train A has two possible plans: either it gets the safe signal to depart and crosses the switch before $t = Y$, or it waits until train B has passed. As the delayed train respects the routes of other trains, it can safely execute its plan once its start time is known. Then, it sends an update to other trains, so they can update their own set of plans independently and new delays can be handled.

We implemented this method using any-start-time planning and tested it using both actual railway hub layouts and scenarios in the Netherlands and fabricated instances. Our results show that trains can instantly execute a plan once the start time is known, as the lookup time is in the order of nanoseconds. Moreover, the recomputation time for railway hub layouts with 30 tracks and scenarios with 50 trains is only 10 seconds for all trains, which is less than a second if each train updates its plans in parallel.

Our method allows trains to act on delays in advance so they can rapidly return to their service after a delay without affecting other trains.

Note: This paper was accepted at ICAPS'24:
Hanou, I.K., Thomas, D.W., Ruml, W., and de Weerdt, M.M. *Replanning in Advance for Instant Delay Recovery in Multi-Agent Applications: Rerouting Trains in a Railway Hub.* (2024). In Proceedings: International Conference on Automated Planning and Scheduling (Vol. 34). *To be published in June 2024.*

Keywords: Railway Hub Planning, Railway rescheduling, Train Shunting, Train Routing, Delay Replanning

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Optimizing Train Speed Profile for Enhancing Headway and Running Time of High-speed Trains

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[2]National United Engineering Laboratory of Integrated and Intelligent Transportation, Southwest Jiaotong University, Chengdu, 610031, China

An increase in the velocity of high-speed trains necessitates a growth in the headway between successive trains, consequently impacting the capacity of the high-speed railway line. To address this contradiction, we propose an approach for simultaneously optimizing train headway and running time for high-speed trains. By establishing a Space-Time-Velocity (STV) grid, we introduce a unified model that encapsulates both the speed profiles and headways of trains across finely segmented spatial and temporal scales. This model facilitates the approximation of train positions, velocities, and accelerations by utilizing discretized time lattices, thereby allowing for the effective tracking of these variables through strategically defined intervals, further describing train driving strategies to bridge the gap between research and practice. To solve the challenges posed by model complexity, an Adaptive Large Neighborhood Search (ALNS) algorithm is developed with four specific operators, including random, bottleneck, greedy and study-insert strategies, to adaptively refine speed and acceleration profiles by combining different operators within the constraints of headway and running time, and enhancing the solution quality. Case studies have been conducted using real-world data from the Beijing-Shanghai high-speed rail line. The results indicate that our optimization techniques are capable of securing a minimum 148-second headway in 80 seconds while only increasing travel time by a marginal 3%, which gains the advantage over both the commercial optimizer and exhaustive approach in terms of computation time, thereby demonstrating both efficiency and precision.

Keywords: high-speed railway, train headway, train speed profile optimization, adaptive large neighborhood search

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Integrated Optimization of Energy-efficient Train Timetable and Rolling Stock Circulation Plan with Regenerative Energy Utilization

Songwei Zhu[1], Yihui Wang[1], Guodong Wei[2], Yi Zheng[1], Datian Zhou[3] and Nikola Bešinović[4]

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With the running and dwell levels considered, we investigate the integrated energy-efficient train timetabling and rolling stock circulation planning problem for a metro line, where the passenger demand is considered via the service pattern. A mixed integer non-linear programming model is proposed to minimize the headway variations, headway deviations, the number of required rolling stocks, and the net energy consumption. Specifically, the regenerative energy utilization is considered by the brake-traction overlapping times. After linearization, the energy-efficient timetabling problem can be solved by existing solvers. A two-step method is presented to enhance the computational efficiency. In the first step, the arrival times of train services at the first station are determined. In the second step, the timetable and rolling stock circulation plan are optimized according to the given arrival times at the first station. Two case studies with different service patterns are conducted based on the data of Beijing Yizhuang metro line. The computational results demonstrate that the two-step method can reduce the optimality gap sharply. Compared with the energy-efficient model without the consideration of regenerative energy utilization, the regenerative energy utilization of the model with regenerative energy utilization considered increases 25.64% and 35.95% in the two test cases, respectively.

Keywords: Energy conservation, rail transportation, rail traffic control, optimization methods

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Applying Multi-Agent Path Finding to the Train Unit Shunting Problem: a Comparison with Mixed Integer Linear Programming

Issa K. Hanou[1], **Mathijs de Weerdt**[1]

[1]Delft University of Technology

The Train Unit Shunting Problem (TUSP) is an NP-hard problem with different sub-problems. These are heavily intertwined as the routing depends on the track assignment, which depends on the matching of arriving and departing train units. We model the routing sub-problem as a Multi-Agent Path Finding (MAPF) problem, which finds routes for a set of agents (trains) given their starting and goal locations. When types of train units are used to group agents into teams, we can assign their goal locations dynamically [1]. Prior work has looked at constraints from the arrival and departure orders to narrow down the track assignment [2]. This way, we can integrate the solving of the routing and matching sub-problems, and also allow trains to reroute to a different parking track than their originally assigned track. State-of-the-art MAPF approaches are Constrained-Based Search and the Branch-cut-and-price algorithm, which add specific algorithmic insights for multiagent routing problems. Branch-cut-and-price is an optimal algorithm for creating conflict-free solutions to MAPF instances. The method combines search heuristics and Mixed Integer Linear Programming (MILP), proposing specific cuts for the MAPF problem [3]. The TUSP is currently solved with MILP formulations, extended with some specific heuristics and constraints [4]. Clearly, similarities between the MAPF approaches and state-of-the-art TUSP solvers can be identified. The question remains which insights from each method can be beneficial to the other? As MAPF solutions are guaranteed to be conflict-free and often also (close to) optimal, this could provide benefits over MILP formulations. The latter does not offer the same guarantees while an optimality gap remains. Though MAPF solutions have proven very efficient for many agents, the main challenge arises from the tight and constricted infrastructure as seen in a railway network [5]. Here, MILP insights could provide benefits to the MAPF solvers.

Keywords: Multi-Agent Path Finding, Mixed Integer Linear Programming, Train Shunting, Branch-cut-and-price

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Machine Learning

Monday September 9th 9:00am - 11:00am

Room Nautilus

Chair: Annabella Astorino

An efficient method for dynamical adjustment of the batch size for stochastic gradient methods in machine learning

Marco Boresta[1], Alberto De Santis[2] and Stefano Lucidi[2]

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In this work, we introduce a novel interpretation of the variance associated with batch gradient estimates in machine learning model training. By reevaluating this variance, we propose an innovative criterion for dynamically adjusting the batch size throughout the training process. This approach diverges from traditional methods by prioritizing a more detailed representation of variance behavior, leading to potentially more efficient and effective training regimes. We rigorously test our methodology against a series of problems, benchmarking it against current state-of-the-art methods to demonstrate its advantages and applicability. Our findings suggest a promising direction for improving model training efficiency by refining how batch sizes are adapted over time.

Keywords: Stochastic gradient methods, batch size selection

Polarized Classification Forest

Elena Ballante[1,2] and Silvia Figini[1]

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Random forest is an ensemble model defined by Breiman in 2001 [1] and has become extremely popular in the last twenty years. Its popularity is due to the simplicity of the concept, coupled with the significant advantages it introduces. In fact, the randomness of the algorithm efficiently avoids overfitting, reduces computational costs, while still allowing a definition of variable importance that somehow mimics the inference of parametric models.
For these reasons, it is not surprising that different modifications and generalizations of the original model were proposed over the years, such as [2,3].
The aim of this work is to deploy the advantages of Polarized Classification Tree (PCT) models [4] in a random forest scheme. The PCT model was defined by introducing a splitting criterion that generalizes the concept of impurity measure, coupling it with polarization measures to assess the informativeness and generalization capability of the covariates. Polarization measures are a class of indexes introduced in the socio-economic context by Esteban and Ray [5] to measure inequality in income distribution.
The resulting approach is named Polarized Classification Forest (PCF).
Preliminary results on simulated data considering different settings show that PCF achieves better or competitive performance compared to the standard random forest algorithm [1].
The main contribution of the work is integrating the advantages of the random forest approach with a more robust setting in terms of the generalization capability for the prediction.

Keywords: Classification trees, Polarization measures, Random Forest

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ML-based Adaptive Risk Parameters Tuning for Robust Optimization

Diego Maria Pinto[1], Marco Boresta[1] and Emanuele Pizzari[1]

[1]Istituto di Analisi dei Sistemi e Informatica (IASI) del Consiglio Nazionale delle Ricerche (CNR)

This paper introduces a novel approach that integrates Robust Optimization with Machine Learning (ML) to dynamically estimate optimal risk parameter' values for uncertain environments. By leveraging historical data and engineering informative features, we train an ML model to predict risk protection values tailored to each instance's characteristics. Unlike static approaches, our method offers adaptability and enhances decision-making in uncertain domains. Through experimentation, we demonstrate the efficacy of our approach in improving robustness and performance.

Keywords: Robust Optimization, Machine Learning, Risk Assessment

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Application of Artificial Intelligence Techniques in Battery Energy Storage Systems Optimization

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[2] Department of Mechanical, Energy and Management Engineering, University of Calabria, Rende, Italy

This study aims to optimize battery energy storage systems by using artificial intelligence techniques to predict energy consumption and production from renewable sources. We propose a strategy for identifying appropriate intervals for battery storage. Then, we employed two artificial intelligence techniques, namely Extreme Gradient Boost- ing (XGBoost) and the Long Short-Term Memory (LSTM), to make predictions on the dataset. The XGBoost technique demonstrated better performance. In addition, by identifying the best and worst days through prediction models, the risk associated with battery storage can be mitigated

Keywords: Optimization, AI Techniques, Battery Energy Storage Systems

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Large-margin approaches for Active Learning

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Developing a classifier can be a challenging task due to the requirement for a significant amount of labeled data, despite the abundance of unlabeled samples. In diagnostic imaging, for example, annotating medical images often requires expert knowledge. In such scenarios, Active Learning (AL) can be a valuable machine learning technique that aims at reducing the number of samples used during the learning phase while still achieving high accuracy. AL algorithms can effectively select the most informative data points based on a defined metric and send them to a human annotator, who can gradually add to the labeled data in the training set. This approach is often preferred because data annotation requires significant effort in terms of both costs and man-hours.

The principle of AL operates on the premise that not all data points are equally significant in training a classifier model. Therefore, it is important to prioritize selecting only the most pertinent data instances. In this research we investigate potential sampling strategies with a particular focus on large-margin approaches of Support Vector Machine (SVM) type. In particular, we explore the role of samples near the classifier boundary and compare supervised and semi-supervised techniques to measure model confidence. Preliminary numerical experiments support these inquiries.

Keywords: Nonsmooth optimization, SVM, machine learning

A decomposition algorithm for sparse and fair soft regression trees

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Politecnico di Milano

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In supervised Machine Learning (ML) models, achieving sparsity with respect to input features is important not only for feature selection but because it enhances model interpretability and may also improve testing accuracy. Another crucial aspect is to take into account fairness measures, which allows to guarantee comparable performance for individuals belonging to sensible groups.

We consider decision trees for regression tasks, which are widely used interpretable ML models. In [1] we recently proposed a new model variant for Soft Regression Trees (SRTs), which are decision trees with probabilistic decision rules at each branch node and a linear regression at each leaf node. Unlike in the previous SRTs approaches ([2,3]), in our variant each leaf node provides a prediction with its associated probability but, for any input vector, the output of the SRT is given by the regression associated with a single leaf node, namely, the one reached by following the branches with the highest probability. Our SRT variant exhibits the "conditional computation" property (a small portion of the tree architecture is activated when generating a prediction for a given data point), provides posterior probabilities, and is well-suited for decomposition. The convergent decomposition training algorithm we proposed in [1] turned out to yield accurate soft trees in short cpu time.

In this work we extend the SRT model variant and the decomposition training algorithm to take into account model sparsity and fairness measures. Experiments on datasets from the UCI and KEEL repositories indicate that our approach effectively induces sparsity. Computational results on different datasets show that the decomposition algorithm, adapted to take into account fairness constraints, yield accurate SRTs which guarantee comparable performance between sensitive groups, without significantly affecting the computational load.

Keywords: decision trees, decomposition algorithm, sparsity, fairness

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OR applications

Monday September 9th 9:00am - 11:00am

Room Rocce

Chair: Giovanni Righini

High Capacity Reversible Data Hiding in Radiographic Images with Optimal Bit Allocation

Davide Cavagnino[1], **Alessandro Druetto**[1], Marco Grangetto[1] and Maurizio Lucenteforte[1]

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Data hiding in digital objects comprises a set of frameworks, methods and algorithms aimed at embedding information into digital audio, images, etc. In case of covert communication between entities, the process is called *steganography* while embedding data for tamper detection, copyright protection, or extra data storing is called *watermarking* [1].

Algorithms for data hiding modify a digital object, called a *cover object*, to embed data and may be reversible [2] or non-reversible [3]: the choice depends on the application context because a reversible algorithm allows to restore the cover object after data extraction.

A large class of image watermarking algorithms operates on the intensity level histogram exploiting the image redundancy modifying pixel intensities to embed information called *payload*.

Histogram shifting represents a family of methods that operate in the spatial domain by modifying pixel intensity levels in appropriate portions of the image histogram to insert payload data. Ideally, the parts to be used are those characterized by a *high peak level* next to a *zero level*. This kind of approach is well-suited for radiographic images [4] where only a subset of gray levels is used, giving the histogram a "comb" structure. In that work, the payload was embedded using only a *local* optimization algorithm in order to maximize the payload size.

The primary goal of our study is to investigate if a meaningful payload improvement can be obtained taking into account the *global* characteristics of such "comb" structure. To this aim, in our work [5] we propose a combinatorial optimization procedure that considers all the contiguous zero-runs. Our approach applies to the image histogram an optimal shifting strategy that maximizes the total payload.

Obtained results show that the proposed approach has a better performance than the known algorithms in the literature. Hence, the presented work becomes the new reference for data embedding in images having the already mentioned characteristics.

Keywords: Combinatorial Optimization; Data Hiding; Watermarking

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Passively Cooled Base Stations: A Case of Robust Optimization

Yi Zhao[1] and Di Yuan[1]

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As an emerging technology, passively cooled base stations (PCBSs) for mobile communications offer low deployment cost and energy consumption. By its nature, however, dealing with the thermal issue becomes crucial, in particular as the heat dissipation efficiency is uncertain for an outdoor PCBS. We address the load and temperature management of a PCBS, aiming at throughput maximization, while preventing overheating. First, we show that the nominal problem is essentially a linear program (LP). We then discuss the role of adjustable robust optimization for addressing the uncertainty, and study the options of achieving adjustability via load or temperature, as well as schemes for problem-solving including reformulation, affine rules, and constraint relaxation. We show that it is possible to derive solutions that are robust and feasible for practice use, under a mild assumption. Furthermore, we validate our theoretical results by simulations

Keywords: Adjustable robust optimization (ARO), linear programming (LP)

Radio Resource Allocation Subject to Common Rate

Di Yuan[1] and Yi Zhao[1]

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Radio resource allocation in mobile communication systems has been widely investigated. However, most works neglect the fact that in real-life systems, the data rate on all channels allocated to a user has to be the same. We investigate channel allocation subject to common rate. As the channels differ in their quality, for each user the achievable rate varies by channel. Thus, allocating more channels does not necessarily increase the total rate, as the common rate is constrained to be the lowest one supported by the allocated channels. We take a mathematical optimization perspective with focus on modeling. We present several integer linear programming (ILP) formulations for the problem, including compact as well as non-compact models. Next, we provide a comparative study of the models' LP bounding performance, along with numerical results. Finally, we discuss LP-assisted problem-solving and the potential of developing ultra fast algorithms for practical use.

Keywords: Integer programming, mathematical modeling, radio resource management

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Quantum Approaches for Solving Logistics Optimization Problems

Alessia Ciacco[1], Francesca Guerriero[1] and Francesco Paolo Saccomanno[1]

Department of Mechanical, Energy and Management Engineering, University of Calabria, Rende, Italy

This study explores the effectiveness of quantum approaches in addressing combinatorial optimization problems [1], arising in the logistics domain. Specifically, our focus is on NP-hard problems, which are known to be unsolvable in polynomial time. Given the challenges posed by such problems, we explore the potential of quantum methods to address these optimization issues, for which classical approaches fail [2]. We begin with an introduction and mathematical formalization of the problem. Subsequently, we focus on identifying the most suitable quantum techniques to address the logistics problem at hand, taking into account its key characteristics [3][4]. We propose and compare alternative methods, providing a thorough analysis of the strengths and weaknesses of each considered approach. In order to demonstrate the effectiveness of the proposed quantum techniques in solving the considered problem, we perform some computational experiments.

Keywords: Combinatorial Optimization Problem, Logistics, NP-Hard Problems, QUBO, Quantum Algorithms

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The Multi-Zone Picker Routing Problem

Laura Lüke[1]

[1]Chair of Logistics Management, Gutenberg School of Management and Economics, Johannes Gutenberg University Mainz, Jakob-Welder-Weg 9, D-55128 Mainz, Germany

Despite ongoing automation initiatives, the predominant mode of operation in many warehouses remains manual, relying on a person-to-parts approach for picking. The process of collecting articles of customer orders from storage locations constitutes the majority of warehouse operating expenses and presents significant opportunities for cost reduction.

We consider a warehouse with parallel aisles that is split into multiple disjoint zones. A picker is assigned to each zone and each zone has a depot where picking tours start and end. Given a set of customer orders, the multi-zone picker routing problem (MZPRP) seeks minimum-length picking tours collecting the demanded articles such that each picking tour only operates within one zone. In addition, capacity restrictions of the pickers need to be respected which include a maximum number of items and a maximum number of different orders from which the collected articles originate. Concerning storage assignment, the scattered storage strategy (also known as mixed-shelves storage) is applied. Whereas with classic storage, each article is stored at a unique pick position, with scattered storage, an article can be stored at several pick positions in one or different zones within the warehouse. The MZPRP thus becomes a three-level optimization problem. While on the higher levels picker/zone assignment decisions and the selection of pick positions must be made, on the lower level picker tours for each zone are optimized.

To solve the MZPRP we use a network-flow model with covering constraints. This type of model was recently presented in [1] for a simpler single picker routing problem with scattered storage and is based on an extension of the state space of the dynamic-programming formulation by Ratliff and Rosenthal [2]. The model contains a network per zone and demand-covering constraints ensure that the requested articles are collected.

Keywords: picker routing, scattered storage, zoning

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Integrated optimization of building and curing in tires production

Raniero Bagozzi[1], **Giovanni Righini**[2] and Andrea Taverna[2]
[1] Pirelli Tires, Milan, Italy
[2] Dept. of Computer Science, University of Milan, v. Celoria 18, Milan, Italy

We address the problem of optimally planning the two main phases in tires production, namely building and curing. They are executed by different machines subject to specific constraints; furthermore, the buffer capacity between the two phases is limited. We present a mathematical model of the optimization problem, that turns out to be a computationally difficult MILP problem. Computational tests show that reducing the symmetries by variable aggregation allows to solve large-size instances arising in a real production plant to near-optimality within a reasonable amount of computing time.

Keywords: mixed-integer linear programming, production planning, scheduling

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Plenary: Paola Pellegrini

Monday September 9th 11:30am - 12:30pm

Conference Center A

Chair: Zhiyuan Lin

Hybrid OR-AI algorithms for Railway Traffic Management

Paola Pellegrini[1]

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Real-time railway traffic management is a challenging task that is mostly carried out manually today. Several models have been proposed in the literature, and OR techniques have been used for optimizing this task. A promising research direction consists in exploiting AI techniques in combination to OR ones for optimizing traffic. This talk will present three different approaches for hybridizing AI and OR for railway traffic management optimization. First, an Ant Colony Optimization-MILP algorithm will show how we can reduce the search space of instances to promising regions, and achieve their effective exploration. Second, a Graph Convolutional Network-MILP algorithm will allow optimizing traffic considering passenger demand prediction. Third, a consensus-MILP algorithm will make self-organizing traffic an actual option for the railway system. Some unexplored research directions on hybrid AI-OR approaches for railway traffic management will be sketched to conclude the talk.

Session: Topics in Combinatorial Optimization 1

Monday September 9th 2:30pm - 3:50pm

Conference Center A

Chair: Paolo Toth

A greedy heuristic for the equitable allocation of surplus food

Fuzail Dawood[1] and Jan H. van Vuuren[1]

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The strategic allocation of surplus food by foodbanks to vulnerable populations presents an opportunity to aid in the daily decision making of foodbank managers by assisting them in making three critical daily decisions in support of achieving operational efficiency. These decisions are which beneficiary organisations to serve, which food items to allocate to each beneficiary organisation, and the quantity of each of these items to supply to each beneficiary organisation on any particular day. In this paper, we present a greedy heuristic for the equitable food allocation among beneficiary organisations, constrained by the unpredictable nature of donations entering the foodbank warehouse. The strategic prioritisation of beneficiary organisations is considered in the heuristic, as are nutritional requirements, inventory management, and diverse nutritional distribution. The heuristic is aimed at addressing the challenge of utilising limited resources and supporting the critical decisions that foodbanks face on a daily basis towards meeting the demands of vulnerable populations. By applying the heuristic in a real-world case study, it is demonstrated that the allocation of food waste may increase the average quality of monthly deliveries across all beneficiary organisations by up to 13.40%.

Keywords: Multiple-resource allocation, greedy heuristic, foodbank, decision support

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A robustness analysis of trading strategy ensembling based on trader preferences

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Foreign exchange (Forex) trading algorithms require trading strategies involving the autonomous identification and exploitation of trading opportunities. Different Forex trading strategies are generally implemented in isolation, raising the question of whether diverse trading strategies can be combined in order to improve trading performance. It remains unclear, however, whether such a trading ensemble approach is capable of adapting to different trading styles based on predefined trading goals. Our aim in this paper is, therefore, to evaluate the robustness of the notion of Forex trading ensembling in respect of different trading preferences on an intra-asset level and on an inter-asset level. An empirical analysis is conducted on four different Forex currency pairs during which trading strategies are ensembled and different asset portfolios are created based on risk-averse and risk-seeking trading preferences. The results indicate that an ensemble design is indeed capable of adjusting trading decisions based on these two defined trading styles.

Keywords: Algorithmic trading, Risk utility, Portfolio management

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A Matheuristic approach for the Multi-vehicle Arc Routing Problem with Irregular Services

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This paper introduces a new matheuristic procedure designed to address the Periodic Multi-vehicle Arc Routing Problem with Irregular Services. The proposed method leverages an Iterated Local Search framework, integrating mathematical optimization with heuristic techniques to efficiently find high-quality solutions in the context of periodic routing.

The aim of routing problems is to design a number of vehicle routes that visit a given set of customers in order to service them. In the periodic routing problems the service occurs in some periods of a given time horizon. When the requirement of visit can be identified with the arcs or edges of the graph, we talk about Periodic Arc Routing Problems. In this paper, we study the Periodic Multi-vehicle Arc routing Problem with Irregular Services, extending the work of [1] and [2].

There is a fleet of vehicles. Routes have to be designed for each day of the time horizon in order to meet the service requirements, while satisfying a capacity constraint. The required elements correspond to links (either arcs or edges) of a mixed graph. Every required link has an own service plan that identifies the number of visits needed in sub-periods of the time horizon. This number is called frequency. In the setting we consider the service requirements can be irregular (different sizes of the sub-periods and different frequencies).

The goal is to minimize the total routing cost over the time horizon. In our work, we develop a matheuristic algorithm based on a new mathematical formulation where we associate a variable to each route and period. The size of this set of variables is clearly exponential; so, we devised a column generation approach in which we heuristically generate part of these variables within an iterated local search procedure. In each iteration, the algorithm alternates a phase in which new variables are generated and some old variables are deactivated, and a phase in which the model is solved by means of a general-purpose solver.

Keywords: Arc-routing, Matheuristic, Service quality

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A risk-averse latency location-routing problem with stochastic travel times

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The location-routing problem (LRP) combines two well-known combinatorial optimization problems: the facility location problem (FLP), and the vehicle routing problem (VRP). In this talk, we focus on a recently investigated variant of the LRP: the latency location-routing problem (LLRP) introduced in [1]. Given a set of customers and a set of potential locations for the depots, we seek to determine where to open the depots and how to design the routes for serving the customers minimizing the latency, i.e. the sum of the arrival times at the customers. Although the LLRP has recently received much attention (see, e.g., [2, 3, 4]), an important gap still exists which is related to the need to hedge against uncertainty. In this talk, we seek to fill this gap by investigating the LLRP with stochastic travel times (LLRP-STT). The problem is cast as a two-stage stochastic program. The ex-ante decision comprises the location of the depots. The ex-post decision regards the routing, which adapts to the observed travel times. A risk-averse decision-maker is assumed, which is conveyed by adopting the latency CvaR(α) as the objective function. The problem is formulated mathematically, and an effective multi-start variable neighborhood search algorithm is proposed for tackling the problem when uncertainty is captured by a finite set of scenarios. This procedure is then embedded into a sampling mechanism so that realistic instances of the problem can be tackled, namely those arising when the travel times are represented by random vectors with an infinite support. Finally, several insights are provided based on the results of a series of computational tests performed to assess the methodological contributions provided by this work.

Keywords: Location routing problem, Latency, Uncertain travel times

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Session: OPTSM 1 – Pricing and Fare Evasion

Monday September 9th 2:30pm - 3:50pm

Conference Center B

Chair: Raffaele Pesenti

A Particle Swarm Optimisation approach for the Network Pricing Problem

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The Network Pricing Problem (NPP) is a well-known NP-hard family of bi-level problems (1). In general terms, it can be defined as the problem in which an authority owns a set of toll paths and imposes tolls on them in an attempt to maximise his/her revenues. The users travelling on that network seek to minimise their costs. The NPP presents several variants, most of which can be reformulated as a single-level mixed-integer linear programming problem. However, their exact solution tends to become computationally intractable when the number of paths and users increases (4, 5). In this work, we propose a novel evolutionary approach based on particle swarm optimisation (PSO) capable of tackling large-scale instances of two of the main variants of the problem, named *arc pricing* (2) and *path pricing* (3). The PSO is a popular evolutionary algorithm which is particularly suited for continuous problems, as in the case of NPP. According to our preliminary tests made on a set of benchmarks widely used in the literature, our PSO approach shows satisfactory results, providing good quality solutions, ranging between a gap of 3% and 20% to the optimal solution, but requiring a smaller computational effort compared to the exact solver, in particular when applied to large instances. These findings suggest the opportunity to further investigate the potential and the capabilities of our PSO approach for intrinsically difficult bi-level problems.

Keywords: Network Pricing Problem, Bi-level optimisation, Particle-Swarm-Optimisation

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Pricing and scheduling in multi-modal railway network considering competition and cooperation relationships

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The multi-modal railway network, including high-speed rail (HSR), intercity rail (ICR), suburban rail (SUR), and urban rail transit (URT), is attracting increasing attention due to its reliability and social benefits. Various rail transit modes will cooperate to provide multi-modal travel services to long-distance passengers but also present a competitive situation since they have overlapping service passenger demand. However, in most studies on ticket pricing and train scheduling problems, the compete-cooperation relationships among these four rail transit modes, have not been considered. Therefore, this study presents a multi-leader-follower game model to integrate ticket pricing and train scheduling (line planning and timetabling) considering the compete-cooperation relationships in the multi-modal railway network. It incorporates the simulation-based passenger assignment model as its lower-level programming; its upper level is a decision-making model, to obtain an approximated Nash equilibrium solution among various railway operators. An improved Nash Q-learning algorithm is developed to determine the approximated Nash equilibrium solution for the proposed multi-leader-follower game model in an iterated simulation process. The proposed method is evaluated in a case study based on the multi-modal railway network in Jiangsu province and Shanghai in China. Our results indicate that the proposed method can effectively optimize ticket pricing and train scheduling problems in the multi-modal railway network under different compete-cooperation scenarios. Railway operators tend to improve the service frequency of the lines managed by multiple corridors or multiple operators in the cooperation strategy, to decrease the operation cost and save the travel cost for passengers. Moreover, a feasible cooperation strategy for the multi-modal transportation system is to motivate passengers with short-distance trips to use urban transport modes (like SUR and URT), and reserve more available seats of intercity transport modes (like HSR and ICR) for passengers with long-distance trips.

Keywords: multi-modal railway network; pricing and scheduling; competition and cooperation; leader-follower game model; Nash Q-learning

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Moving towards real-time prevention of fare evasion in public transportation

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The evasion of fares poses a significant challenge for Transit Agencies (TAs) and Public Transport Companies (PTCs) worldwide, particularly in Proof-of-Payment Transit Systems (POP-TSs) ([1],[2],[3],[4]). Existing research on fare evasion risk is limited, often relying on econometric models that focus on specific time periods of interest (e.g., [5]). This study aims to improve the effectiveness of the assessment of fare evasion risk and advance the planning of potential real-time deterrence strategies.

This study starts from the framework in [5], that identifies the factors affecting fare evasion and risk exposure, considering both the frequency and severity of potential outcomes. It then employs Artificial Neural Networks (ANNs) to examine the complex interconnections between these factors and estimate a fare evasion risk index for each route segment.

Next, the risk index is assessed across various time intervals to determine periods of relevant evasion risk. These predictions are prioritized and visually represented with time-dependent markers, thus highlighting routes requiring immediate attention due to high-risk evasion.

Several real-time deterrence strategies are simulated by data from fare inspection logs, passenger surveys, and probability distributions collected over three years.

In conclusion, this research offers practical insights for TAs/PTCs to address fare compliance issues and can be seamlessly integrated into existing bus transit management systems.

Keywords: Public Transportation, Fare Evasion Risk, Artificial Neural Networks

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Fare evasion control policies for public transport systems

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The public transport (PT) system of the city of Venice has a complex organization due to the specific characteristics of the area.

The mission of the PT is to provide a service to a population of about 850,000 inhabitants (about 50,000 living in the historic center, and about 25,000 the rest of the lagoon islands) and to the tens of millions of annual visitors that the historic center of the city.

In particular, PT is provided by buses, trams on rails on the mainland and for connections between the mainland and the historic center in the lagoon. On the other hand, within the lagoon, PT is carried out by waterbuses ("vaporettos") and ferries in the canals and an automated people mover to connect the historic center with the port area.

For services in the lagoon, fares are differentiated between residents and visitors. The number of passengers carried per year varies by several orders of magnitude, from a few thousand on the buses serving the outlying areas to tens of millions on the vaporettos.

Finally, the peaks of demand depend on the type of passenger. For example, the vaporettos experience a peak in demand from residents around 8:00 am and from visitors around 10:00 am. In contrast, the evening peak practically coincides for both types of passengers, and this is also a cause for complaint by the residents of the lagoon city. For this reason, some vaporetto stops provide differentiated access for residents and tourists.

The aim of this research is to define a set of control policies to fight the fare evasion and in particular to organize the control agents shifts.

The control agents move in groups of two or three, using the same vehicles they control for their movements, and must take into account that (see also [1,2,3]):

- The flow of passengers is very directional during different hours of the day.
- The evasion rate is higher in the suburbs than in the city center, but there are usually far fewer passengers in the suburbs.
- Evaders, especially juveniles, are sometimes in contact with each other, for example through mobile phones.

Keywords: Public Transportation, Fare Evasion, Planning

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Session: Networks 1

Monday September 9th 2:30pm - 3:50pm

Room Nautilus

Chair: Alberto Ceselli

Branch-Price algorithm for Maximum Flow Minimum Reload/Changeover Cost Problem

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Edge-labeled graphs can be useful for modeling heterogeneous physical infrastructure and its associated properties in various network flow problems [1], where labels can represent cables with different bandwidths or technologies in telecommunication networks or different carriers in transportation settings. The penalty or the time needed for the transition through a node via two different labels can be represented as a reload [2] or changeover cost [3]. Quantifying the costs of making these structures work together effectively can improve service quality, reduce mandatory maintenance requirements, and mitigate the costs of finding a valid solution. This study introduces the Maximum Flow Minimum Reload/Changeover Cost Problem (MFMC), which aims to find the maximum flow between a source node and a destination node while minimizing the total involved reload cost. We define the problem and study its theoretical properties, complexity, and approximability results. Additionally, we provide a Mixed-Integer Linear Programming formulation and solve it using a tailored Branch-Price algorithm.

Keywords: Branch and Price, Maximum Flow, Reload Cost, Changeover Cost

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Polynomial-size Formulation for Edge Coloring Problems on Forests

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An *edge coloring* of a graph G is an assignment of colors to the edges of G so that two incident edges receive distinct colors. In particular, one is often interested in determining an actual edge coloring with the minimum number of colors so to explicitly assign tasks to machines over time. In the general case, this problem is known to be **NP**-Hard, however, if G is bipartite, one can solve this problem efficiently, through constructive algorithms [4]. One drawback of this "algorithmic" approach is that it often involves sophisticated implementation. Moreover, finding edge coloring that minimize a generic objective function on bipartite graph is known to be **NP**-Hard [1].

The *edge coloring Polytope* of a graph G is the convex hull of all the possible edge coloring of G. In this work, we prove that a natural formulation of the edge coloring polytope on forests is polynomial in size and is described by a totally unimodular matrix. The interest towards this result is twofold. On one hand, it allows to use linear programming techniques to solve edge-coloring problems. On the other, it gives a polynomiality proof for all edge coloring problems on forests. Moreover, our results extend or improve different known results such as the max-edge coloring problem on forests [1] and the minimum-sum edge coloring on forests [3] and multicycles [2].

Keywords: edge coloring, polyhedra, totally unimodular matrix

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Balancing reliability and costs of networks: the Generalized Coloured Shortest Path Problem

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In this work, we propose a Generalized variant of the k-Colour Shortest Path Problem (k-CSPP) that considers the possibility of balancing the length and the number of colour required to compute a path. This problem, namely the Generalized Coloured Shortest Path Problem (GCSPP), involves identifying a path on a weighted edge-coloured graph that is, at the same time, the shortest and the most reliable according to a measure of choice. The GCSPP can be applied to a variety of real-world scenarios, ranging from TLC network reliability to smart paths in urban environments. To solve this problem we introduce a three-phase matheuristic approach. In the first one, a heuristic procedure is used to generate an upper bound for the problem; in the second phase, a graph reduction algorithm is applied. Finally, in the last phase, an integer linear programming (ILP) model is solved. The proposed approach is thoroughly tested on sets of benchmark instances. We perform a deep analysis of the ratio between the weight of the colours and the length of the path that shows the effectiveness of the proposed approach. Since this is the first work that analyses the GCSPP we perform an additional analysis applying our technique to the k-CSPP providing a comparative analysis with the state-of-the-art algorithm, as proposed by Cerrone et al. [1]. To perform this evaluation, we set the number of colours found by our method as a constraint for the k-CSPP and, subsequently, compared the lengths achieved for the single-objective problem [2]. Results obtained state that our approach outperforms the previous algorithm in terms of solution quality and computation time balancing the number of colours and the path length, indeed the previous method can only reach almost the same solution but requires more computation time.

Keywords: Shortest Path; Multi-Objective; Coloured Graph

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Constructive and local search heuristics for a vertex bisection problem

Michele Barbato[1], Nicola Bianchessi[1] and **Alberto Ceselli**[1]

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We consider the following Vertex Bisection Problem (VBP). It is given an undirected graph having two special nodes marked as source and sink. We search for a partition of the nodes of the graph in two parts, each containing half of the nodes of the graph (plus or minus one, when the number of nodes is odd), and each containing either the source or the sink node. Our aim is to find one of these partition which minimizes the number of nodes in the source part having adjacent nodes in the sink part.

Such a VBP has many applications in network optimization. For instance, in networks having strict data governance requirements, our VBP models the search for configurations in which a minimum number of network nodes need to be fortified to ensure data separation between source and sink.

Our VBP is NP-Hard. It has been studied in the literature from both an exact and a heuristic optimization point of view. We propose a new set of constructive heuristics, which are simple in structure, but show to be competitive with state of the art ones. We combine constructive heuristics with local search. Finally, we propose a tabu search scheme to escape local minima.

Experiments on instances from the literature indicate our approach to be effective in terms of both computing time and quality of solutions.

Keywords: Vertex Bisection Problems, Constructive Heuristics, Local Search, Tabu Search

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Session: Decision Support Applications Shaping Smart Cities and Sustainable Urban Environment: Challenges and Solutions of SMART3R-FLITS, E-ins, WEAKI-TRANSIT and GATE projects and beyond

Monday September 9th 2:30pm - 3:50pm

Room Rocce

Chair: Chiara Garau

The planning of DRTs in low transport demand areas: the case study of the biggest Italian islands

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The last decade has been characterized by a greater diffusion of on-demand transport services (DRTs) for passengers and/or goods in Italy. Characteristics of the service, such as flexibility, weak demand area implementation, variability of the travel purposes (i.e., tourism, business, health care) and the possibility of being easily booked by different segments of the population, mean that this service can become complementary to local public transport and other services. Full integration of DRTs and public transport avoids unjustified cost increases, facilitates the operations of administrative staff, and improves the user experience in modal choice. Effective intermodality therefore allows the deployment of MaaS (Mobility-as-a-Service) on a large scale, while still some critical issues are evident in the development of rural or inland areas. The objective of this research is to evaluate the factors that can improve the development of DRTs services in the Sicily and Sardinia regions, starting from previous experiences in similar case studies. This research highlights the need to develop more flexible transport services and better decision support for public transport service managers and local governments for the development of more sustainable mobility.

This research has been supported by the MIUR (Ministry of Education, Universities and Research (Italy)) through a project entitled WEAKI TRANSIT: WEAK-demand areas Innovative TRANsport Shared services for Italian Towns (Project code: 20174ARRHT/CUP Code: J74I19000320008), financed with the PRIN 2017 (Research Projects of National Relevance) program. Activities also supported by the MUR (Italian Ministry of University and Research) through SMART3R-FLITS: SMART Transport for Travellers and Freight Logistics Integration Toward Sustainability (Project protocol:2022J38SR9_03, CUP Code: J53D23009330008), financed by the PRIN 2022(Research Projects of National Relevance) programme.

Keywords: transport decision-making, flexible mobility, DRT, Italian insular context

Sustainable Cities through Urban Digital Twins: Sofia City's Journey from Data to Decision Intelligence

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In the quest for sustainable urban development, the fusion of Urban Digital Twins (UDTs) and Data spaces has emerged as a game-changing paradigm. They enable smart data sharing, advanced analysis and simulations, data-driven and evidence-based decisions in many city aspects, such as urban planning, transport and mobility, air quality, etc. GATE City Digital Twin Pilot Project aims to implement the first UDT of Sofia, Bulgaria, as an innovative solution that scales to real-world problems, enabling design, exploration, and experimentation with the urban environment and processes. An open, standard-based, semantic 3D city model is under development, integrating data from heterogeneous sources and further used for simulation, analysis and visualisation by applying the basic idea of the digital twin – "design, test and build first digitally". The potential of the UDT for intelligent decision-making is unveiled through real-world use cases inspired by the sustainable development goals to mitigate climate changes, enhance active mobility and improve urban environmental conditions, fostering healthier, safer and inclusive cities and communities.

This research work has been supported by the GATE project, funded by the Horizon 2020 WIDESPREAD-2018-2020 TEAMING Phase 2 programme under grant agreement no. 857155.

Keywords: Data-driven decision-making, Data sharing, Semantic 3D city models, Smart and sustainable cities, Urban digital twins

Defining a roadmap for policymakers and practitioners to analyze the impact of Renewable Energy Sources on Ecosystem Services

Beniamino Murgante[1], Alfonso Annunziata[1], Shiva Rahmani[1] and Rossella Scorzelli[1]
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The emerging conflicts between CO2 reduction policies, highlighted each year during the COP meetings, and the preservation of natural and ecosystem values on the local scale pose significant challenges. Global policies encourage a transition toward a low-carbon economy, with Renewable Energy Sources (RES) playing a crucial role in this development process. However, RES are not inherently green and, if inappropriately located, can significantly impact Ecosystem Services. Nature provides humanity with a wealth of benefits essential for our well-being and long-term survival, known as "Ecosystem Services." Scientists use computer simulations to map these services and find ways to balance short-term economic gains with lasting environmental health. This involves understanding complex interactions between biodiversity, human activities, and the physical environment. A key concept is "multifunctionality," the ability of ecosystems to provide multiple benefits simultaneously, which makes them incredibly valuable to society. Geographers and urban planners have adopted the concept of Ecosystem Services as a powerful tool for analyzing natural resources and their connection to human populations and the economy. Despite numerous successful applications, achieving a standardized approach to integrating Ecosystem Services into planning remains challenging. This presentation represents a preliminary step in developing a framework to provide a roadmap for policymakers and practitioners to analyze the impact of Renewable Energy Sources on Ecosystem Services. The framework will define criteria for sustainably locating these installations. This work is part of a broader research project, "Definition of a Guidelines Handbook to Implement Climate Neutrality by Improving Ecosystem Service Effectiveness in Rural and Urban Areas." The main aim is to develop a decision support system to identify the most suitable actions to reduce energy consumption and mitigate climate effects in urban areas based on analyzing the urban fabric and the impact of various types of land development on the supply of Ecosystem Services.

Keywords: Climate Neutrality, Ecosystem Service Effectiveness, Renewable Energy Sources, Urban Fabric

References

The Multiscale Strategic Planning Model of Fractalopolis Applied to the Metropolitan City of Cagliari in Sardinia (Italy)

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The Fractalopolis model is a GIS-based approach of urban modelling that is both strategic and adaptive for simulating and evaluating future scenarios of development. It integrates multifractal theory, central place theory, and urban planning theories. This approach provides useful insights for creating creative scenarios at various levels by integrating central and peripheral areas, by effectively combining spatial contexts and practices, green corridors, transport connections, and residents' accessibilities to amenities. This model is explained by considering as a case study the Metropolitan City of Cagliari. The significance of this case study lies in its pioneering application of the Fractalopolis model to a coastal and island environment. The findings of this research are under the SMART3R-FLITS and e-INS projects and have the potential to provide valuable insights for the identification of innovative approaches to scenario development in coastal zones already planned.

This study was carried out within the "e.INS – Ecosystem of Innovation for Next Generation Sardinia" funded by the Italian Ministry of University and Research under the Next-Generation EU Programme (National Recovery and Resilience Plan – PNRR, M4C2, INVESTMENT 1.5 – DD 1056 of 23/06/2022, ECS00000038). This study was also supported by the project "The implementation of a multi-fractal development plan for urban adaptation for the ecological transition. Comparisons between the Metropolitan City of Cagliari, Italy and Besançon, France", founded by the program "Bando 2023 Mobilità Giovani Ricercatori (MGR)," financed by the Autonomous Region of Sardinia (under the Regional Law of 7 August 2007, n. 7 "Promotion of Scientific Research and Technological Innovation in Sardinia"). This study is supported also by the MUR through the project SMART3R-FLITS: SMART Transport for Travellers and Freight Logistics Integration Towards Sustainability" (Project protocol: 2022J38SR9; CUP Code: F53D23005630006), financed with the PRIN 2022 (Research Projects of National Relevance) program. This research was granted by PNRR-M4C2- I1.1 – MUR Call for proposals n.104 of 02-02-2022 - PRIN 2022 – ERC sector SH7 - Funded by the European Union – Next GenerationEU.

Keywords: Multi-fractal Strategic Adaptation Plan, Shaping Smart Cities, Decision Support Applications, SMART3R-FLITS, e-INS

Session: Traveling Salesman Problem

Monday September 9th 4:15pm - 5:15pm

Conference Center A

Chair: Nicola Bianchessi

Expected linear-time strategies for finding the best 2-OPT move on nearly random TSP tours

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A 2-OPT move [1] for the Traveling Salesman Problem [2] removes two edges from a tour and replaces them with two new ones. The move is *improving* if the new tour is shorter than the previous one. The best 2-OPT move is the one yielding the largest decrease in the tour length. The obvious algorithm for finding the best 2-OPT move is a quadratic time enumeration of all possible moves by a nested-for loop.

Following a similar approach as we used in [3], we describe alternative strategies for finding the best 2-OPT move which, experimentally, are observed to take linear time on random and nearly-random tours for randomly generated and TSPLIB instances [4]. To analyze the time complexity of our algorithms, we introduce a family of heuristic procedures for finding the best 2-OPT move. We prove that: (i) for any probability p, there is a heuristic in the family which can find the best move with probability at least p in average-time $O(n)$; (ii) on those instances on which a heuristic finds the best move, the exact algorithm finds it in a smaller time. Notice that linear-time is indeed an optimal complexity for this problem, since to find the best move there are at least n edges to look at. The effectiveness of our procedure applies mostly to the first part of a local search [5] convergence (roughly, for two thirds of the local search), but when the current tour approaches a local optimum the complexity degenerates to that of the usual quadratic algorithm.

Keywords: Traveling Salesman Problem, 2-OPT, Local search

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Extended formulations for the Electric Asymmetric TSP

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The Electric Traveling Salesman Problem (ETSP) is a variant of the traditional TSP in which the vehicle is assumed to be equipped with limited battery. Therefore, the vehicle needs to be recharged along the route and, for this purpose, a set of recharge stations is given. Each station has potentially different unit cost for energy and multiple visits to the same station are allowed. The aim is to visit all the customers once, minimizing the overall cost of recharged energy. We consider an asymmetric version of the ETSP (EATSP). We also consider the possibility that traveling along some arcs of the underlying graph implies a negative consumption of energy. This corresponds to traveling along downhill roads with vehicles that can recharge their batteries. We propose an extended formulation for the problem, having one variable for each possible sequence of customers which can be visited with no recharges from one station to another. Furthermore, we modify such formulation in a less intuitive form that requires fewer variables and constraints. We compare these two approaches theoretically and experimentally.

Keywords: TSP, electric vehicles, partial recharges, extended formulation

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Branch-price-and-cut algorithms for the min-max multiple Traveling Salesman Problem

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Nowadays, the leading exact algorithms for solving many classes of vehicle-routing problems (VRPs, [1]) are branch-price-and-cut (BPC) algorithms [2]. In most of the cases, however, the objective function of the problem tackled is the minimization of the total distance travelled by all vehicles (min-sum objective) or similar. Nonetheless, min-max objectives are likewise quite common in VRPs, as they might lead to more realistic models. In fact, minimizing the length of the longest route tends to balance the length or cost of the planned routes. Moreover, if the travel times are proportional to the travel distance, these objectives try to minimize the time at which the last customer is served. Thus, here, we systematically investigate if and how column generation can be successfully applied to address min-max VRPs. To this aim, we consider the min-max multiple Traveling Salesman Problem (min-max mTSP) [3]. This is mainly motivated by the fact that the contributions arising from the study should be easily extensible to the several generalizations of the problem. The few BPC algorithms proposed in the literature to address min-max VRPs rely on path-based formulations that give rise to formally distinct column generation subproblems, one for each vehicle, but sharing the same feasible region, at least at the beginning of the solution process. In order to solve the min-max mTSP, by exploiting the possibility to define properties that uniquely determine the representative vertex for a path, we propose a BPC algorithm that is build on a path-based formulation with a single column generation subproblem. Experimental analyses show the efficacy of the proposed BPC algorithm. Moreover, our analyses highlight some key components to be included in BPC algorithms for vehicle-routing problems with min-max objective.

Keywords: vehicle routing, min-max objective, column generation

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Session: Traveling Salesman Problem

Monday September 9th 4:15pm - 5:15pm

Conference Center B

Chair: Nicola Bianchessi

Advanced Railway Monitoring Through industry X.0 Technologies

Malak Saiem[1], Guillaume Lebonvallet[1], Hichem Snoussi[1], Faicel Hnaien[1]

[1]Université de Technologie de Troyes, LIST3N team

Introduction

The emergence of industry X.0 has been a game changer for the assessment of condition and health monitoring of railway turnout systems [1]. With sensors integrated into the railway framework we are able to collect huge amount of data enabling a more nuanced analysis of equipment health. Our research is focused on identifying anomalies and assessing of system deterioration using advanced data analysis techniques leading to refined frequency of maintenance inspections thereby improving safety and reliability[2]. This work is presented in the frame of the RAILMON project which aims to develop a new monitoring system for the maintenance of railway networks.

Approach

Through an illustrative use case conducted on an industrial dataset, our work explores the use of autoencoders for diagnostics and fault detection for time series data in railway systems. Different architectures have been tested on two different real- life datasets :

- The first dataset contains power, voltage and electrical intensity signals measured during the manipulation of the turnout.
- The second dataset contains vibrations signals measured by an accelerometer placed on the tie near the crossing of the turnout.

Perspectives

The models will be compared in terms of quality, performance and cost. A solution will be proposed for each use case in regards with the constraints of the application.

Keywords: Fault Detection, Degradation Measurement, Autoencoder, Railway turnout system, Industrial application, Sensor Data, Industry X.0

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Train unit passenger demand estimation and clustering using Dempster-Shafer theory

Chuhan Yin[1], Zhiyuan Lin[1], Ronghui Liu[1], Jin Liu[1]

[1]Institute for Transport Studies, University of Leeds, Leeds, UK, LS2 9JT

The Train Unit Scheduling Problem (TUSP) [1] focuses on allocating train units to fulfil a given timetable, incorporating unit coupling and decoupling to optimise usage and meet passenger needs. Although scheduling typically assumes the existence of accurate passenger demand figures, determining such demand data is often challenging as they are influenced by various information such as passenger count surveys, demand prediction models, historic provisions and absolute minimums required by the authorities. There could be conflicting results among different sources, and it may not be appropriate to simply apply an average value. Another difficulty is the existence of incomplete or imperfect data. Furthermore, operators might encounter the empty carriage predicament, where a carriage remains largely unoccupied just to meet passenger demand due to upward rounding. Finally, many UK train operators consider different levels of capacity provisions [2], e.g., a bare minimum that must be satisfied and a higher level that is to be achieved as much as possible. In this work, we present a novel approach in deriving passenger demand for the TUSP from various sources (e.g., prediction models, bare minimum, manual schedules) using the Dempster-Shafer (DS) theory. The DS theory is a mathematical framework for modelling epistemic uncertainty, providing a way to combine evidence from different sources to calculate degrees of belief in various hypotheses. It allows the explicit representation of ignorance and conflicts enabling decision-making with partial and uncertain information, In addition, the DS theory can be utilized to measure the degree of belonging to data points to clusters, accommodating uncertainty and partial knowledge. Passenger demand values for timetabled trains are derived using the DS theory and clustered into different groups allowing ambiguity or overlaps. There results will be eventually used for TUSP with two levels of demand requirements.

Keywords: Train unit scheduling, passenger demand estimation, Dempster-Shafer theory, demand clustering

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Neural Relational Inference and Graph Neural Network for real-time demand prediction in rail networks

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Having rail traffic management systems reactive to demand fluctuations is critical for reliability and for user-centred operations [1]. Leveraging on the increasingly available access to smart card and fleet operations data in urban rail, we propose a machine learning framework for estimating real-time originto- destination (OD) passenger flows. We also include planned train schedules (Real-Time Traffic Plans, RTTPs) as inputs, such that predictions (1) account for expected and desired arrival times at the destination, thus enabling passenger delay measurement and (2) passenger assignment and associated transfers for a given RTTP. We formulate the OD demand prediction problem as a supervised machinelearning problem. To capture spatial correlations between demand across OD pairs, we use a graph neural network (GNN) where each OD pair corresponds to a node in the graph, and the connections between nodes represent dependencies between the observed demand in those nodes. We extend the current literature by employing neural relational inference (NRI) for defining the GNN adjacency matrix [2], avoiding pre-defined static heuristics. The adjacency matrix is determined dynamically through a neural network, the Encoder, taking as input the features for each OD-pair and outputs the probability of each link being "active". The Encoder then defines the graph that the GNN will use in the Decoder neural network (Fig. 1). We use a gated recurrent unit (GRU) in the Decoder to capture temporal dependencies.

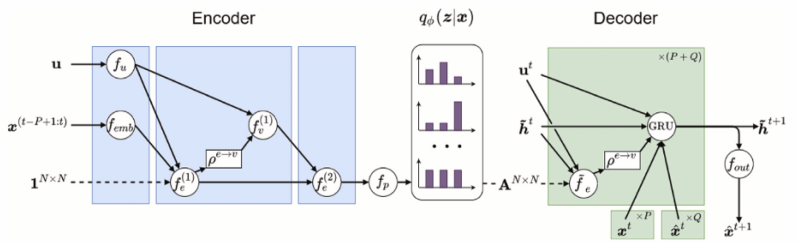


Figure 1: Architecture of the NRI model used for OD demand prediction. u denotes global features, x denotes local features, $q(z|x)$ represents the probability distribution of each active link, while A denotes the adjacency matrix derived from $q(z|x)$

We apply our method to the demand prediction of Copenhagen's suburban railway high-demand OD pairs, using smart card, train arrivals at stations from realised operations, weather and other context data. Our method obtained the lowest prediction error compared to a vanilla graph convolution network and a state-of-the-art complex architecture [3]. This sets the venue for integrating reliable passenger flow estimates in the next generation of traffic management systems [4].

Keywords: Real-time rail traffic management, demand prediction, neural relational inference

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Session: Networks 2

Monday September 9th 4:15pm - 5:15pm

Room Nautilus

Chair: Luca Mencarelli

Customizing characteristics of multi-queue multi-server systems

Olga Grinchtein[1] and Johan Karlsson[1]

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We adopt reinforcement learning approach to automatically optimize waiting time, according to constraints, in a queueing system with limited exibility by changing priorities and/or connections between servers and queues. We use constraint solver to generate priorities of queues that satisfy constraints. Simulation of queueing system with limited exibility is used to obtain reward.

Keywords: queueing system, reinforcement learning, optimization

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Assessing the Impact of ESG on Customer Loyalty and satisfaction within the the Mobile Industry: An integration of Structural Equation Modeling and Data Envelopment Analysis

Clara Viseu[2] and Carla Henriques[1]

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[2]Polytechnic Institute of Coimbra, Coimbra Business School, INESCC and CEBER

The impact of Environmental, Social, and Governance (ESG) practices on customer loyalty and satisfaction in the mobile industry is a growing area of interest. ESG practices refer to responsible business practices that companies adopt to contribute to the development of their communities and the environment, while also fulfilling their legal and financial obligations. The adoption of ESG practices has been shown to positively influence customer loyalty and satisfaction, as consumers increasingly prioritize social and environmental values in their purchasing decisions. A key motivation for the growing emphasis on customer satisfaction and loyalty (CS&L) is that higher CS&L can lead to a stronger competitive position, resulting in larger market share and profitability. This study investigates the relationship between ESG practices and customer loyalty in the Portuguese mobile industry. The research employs a combination of structural equation modeling and data envelopment analysis (DEA). The constructs of the structural model, such as ESG, CS&L, trust, and corporate brand image, are treated and used as input and output indicators of the DEA model. The results of this study provide valuable insights for mobile industry stakeholders seeking to improve customer loyalty through better service quality and ESG practices.

Keywords: ESG, Customer satisfaction, Customer loyalty, DEA, Mobile phone sector

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Delay Constrained Routing: the Multi-Flow Single-Path Case

Antonio Frangioni[1], Laura Galli[1] and **Luca Mencarelli**[1]

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Delay Constrained Routing (DCR) is an optimization problem arising in computer networks with stringent Quality of Service (QoS) scheduling requirements. IP packets are subject to several types of delays when traversing the network; we consider the routing problem where the QoS requirement consists in guaranteeing a controlled flow-specific worst-case end-to-end delay of any packet of each given flow. Depending on the scheduling algorithm employed in the routers, worst-case delay formulae can be devised of the bandwidth (a.k.a. reserved rate) allocated for the flow over each arc of its (unique) origin-destination path. The (single-path) multi-flow DCR problem can then be modelled as a multicommodity-type problem with nonlinear constraints depending on the reserved rate on the chosen arcs, and it is clearly a hard problem since it generalises the nonsplittable multicommodity flow one. Even the single-flow DCR problem is hard, since it generalises the constrained shortest path one, but it can be solved efficiently enough for realistic-sized instances thanks to previously developed modelling and algorithmic approaches. We show how to leverage the latter to construct a Lagrangian approach and explore the quality of the obtained information on a set of realistic DCR instances.

Keywords: Lagrangian relaxation, Heuristics, Mixed-integer non-linear programs

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Session: Maritime Logistics & Intermodal Transport

Monday September 9th 4:15pm - 5:15pm

Room Rocce

Chair: Daniela Ambrosino

Impact of a machine learning-based optimization model in defining storage rules in maritime container yards

Daniela Ambrosino[1,2] and **Haoqi Xie**[1,2]

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The daily throughput of the maritime terminal has been increasing significantly over the years due to the development of new technologies and naval gigantism. This situation requires novel methods to solve decision-making problems. Among all the areas in maritime transportation, the research attention has been moving from the seaside to the storage yard [1], where the inbound and outbound containers are stored and handled by the material handling equipment. The current work focuses on a tactical-level problem, called the stacking strategy problem, in an export yard designed under a European configuration. Following the consignment strategy that requires storing homogeneous containers together in the same blocks composing the yard, a core decision intricacy is the definition of such homogeneity, denoted as the storage rules which are the different combinations of containers' characteristics (size, type, destination, and weight). A previous work [2] has proved that the weight of containers, especially the weight classes and their upper/lower bounds will draw more impacts on the space utilization in the storage yard and, thus, must be managed carefully. In the present work, various unsupervised learning algorithms are used to fit the distribution of containers based on the historical data and cluster similar containers considering their characteristics. The agglomerating results are treated as input values to a set of decision variables in a new and more compact integer linear programming model, derived from that proposed in [2] and used to evaluate how different rules influence space utilization in the yard. This new approach will provide an emerging paradigm distinguishing itself from the common weight classification (Light, Medium, and Heavy) in the literature and a new insight into the integration of machine learning and optimization models. Preliminary results, also focusing on the comparison of the here proposed approach and the previous one, are given.

Keywords: Maritime Yard Management, Stacking Strategies, Machine Learning, Integer linear Programming

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An ALNS for multi - commodity location - network design problem with vehicle selection in City Logistics

Francesco Contu[1], Teodor Gabriel Crainic[2], Massimo Di Francesco[1] and Enrico Gorgone[1]

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We investigate a location - network design problem arising in the field of city logistics [1], [2]. A fleet of containers must be moved from a port to facilities, where pallets are unpacked from containers, transhipped into different vehicles and moved to their final destinations within the city (customers). We must select facilities and vehicles, assign containers to facilities, determine the paths of the selected vehicles and the flows of pallets. A mixed integer programming formulation is proposed for this problem. An Adaptive Large Neighborhood Search meta-heuristic is proposed: the problem is decomposed into two sub-problems, that are solved sequentially. In the first sub-problem, location and assignment decisions are considered; in particular, it is decided which facilities are opened and to which of these the containers are assigned. In the second sub-problem, considering the availability of pallets obtained by solving the first sub-problem, it is decided which vehicles are used in order to deliver the pallets to the customers. Each sub-problem is addressed by a specific ALNS: the first, denoted as $ALNS_1$, changes container-to-satellite assignments; the second, denoted as $ALNS_2$, modifies routes in the second tier, considered a fixed facility and container assignments configuration obtained from the first ALNS. The proposed algorithm is compared to an exact branc-and-cut based algorithm.

This study was carried out within the MOST – Sustainable Mobility National Research Center and received funding from the European Union Next-GenerationEU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) – MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.4 – D.D. 1033 17/06/2022, CN00000023). This manuscript reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.

Keywords: City Logistics, location, network design

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A comparison of solution approaches for the port rail shunting optimization: a case study

Daniela Ambrosino[1,2], Veronica Asta[2] and Camilla Traversa[2]

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The focus of this study is to optimize the shunting operations in the port area for the transfer of trains to maritime terminals and viceversa, with the aim of managing all activities with the available resources while minimizing train dwell times. Two methods were used to schedule and optimize these activities. The two methods were then compared, in terms of computational time and goodness of solution. Preliminary results are given.

Keywords: maritime container terminal, port rail management, heuristic approaches

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Session: Topics in Combinatorial Optimization 2

Tuesday September 10th 8:30am - 9:50am

Conference Center A

Chair: Paolo Toth

Optimisation of reinforcement learning Forex trading algorithms based on technical indicators

John Spencer de Wit[1] and Jan H. van Vuuren[1]

[1] Stellenbosch Unit for Operations Research in Engineering, Department of Industrial Engineering, Stellenbosch University, Private Bag XI, Matieland, 7602, South Africa

Reinforcement learning has recently gained significant attention in the domain of financial trading due to its success in sequential decision-making problems as in the Forex market, for example. The intricate nature of learning achieved by these algorithms, however, often obscures the rationale behind their decision-making processes, raising concerns of opacity and unpredictability. These concerns hinder their application in high-stake domains. Explainable artificial intelligence is a relatively recent field that has emerged to overcome these shortcomings and is concerned with techniques that facilitate interpretability of the results returned by black-box models. In this vein, a novel optimisation procedure is proposed in this paper, which leverages Shapley values and the resulting increase in interpretability, to select the most appropriate technical market indicators aimed at increasing algorithmic trading performance on the Forex market, based on deep reinforcement learning. The utility of this approach is demonstrated in the form of a case study which involves the training and evaluation of two deep reinforcement learning agents, namely a Deep Q-network agent, and a Proximity Policy Optimisation agent.

Keywords: Reinforcement learning, Shapley values, Explainable Artificial Intelligence, Forex trading

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The Cost-benefit Trade-off between Problem-specific and Algorithm-specific Meta-learning

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In this paper, we consider the meta-learning problem of meta-heuristic optimisation performance prediction as a foundation underlying the task of algorithm selection for solving optimisation problems. The relative effectiveness of a problem-specific versus an algorithm-specific meta-learning approach is ascertained in the illustrative context of the celebrated knapsack problem. Leveraging the notion of fitness landscape analysis, our algorithm-specific approach incorporates neighbourhood structures induced by metaheuristic perturbation operators. Employing a random forest model, we conduct a comprehensive empirical analysis, contrasting algorithm-specific and problem-specific meta-learning. Two renowned metaheuristic search paradigms are considered — that of simulated annealing and that of a genetic algorithm — each with various hyperparameter and perturbation operator configurations. The numerical results provide insight into the cost-benefit trade-off between problem-specific meta-learning and algorithm-specific meta-learning. It is found that algorithm-specific information yields superior meta-learning performance, but incurs a greater computational cost during meta-feature extraction.

Keywords: Meta-learning, fitness landscape analysis, metaheuristic optimisation

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An improved variant of the Iterated Inside Out algorithm for solving the optimal transport DOTmark Instances

Roberto Bargetto[1], Federico Della Croce[2] and Rosario Scatamacchia[3]

[1] DIGEP, Politecnico di Torino, Italy

The optimal transport (OT) is one the most paradigmatic network optimization problems [2] and consists in finding the minimum cost transportation plan that moves quantities of a single item from a set of sources to a set of destinations, where for each pair source/destination (i,j) a unit transportation cost holds. The interest in OT has been renewed recently because of machine learning and artificial intelligence applications requiring the computation of the distance between pairs of images with source and destination quantities being pixel intensities. A set of image processing instances, called DOTmark, is nowadays the benchmark for OT [4]. Recently, a novel exact algorithm for solving OT, called iterated Inside Out (IIO), has been proposed. The strength of this method relies on the fact that potentially many pivoting operations are performed for each computation of dual multipliers and reduced costs. Here, we propose a variant of IIO specifically tailored to the DOTmark instances. This variant solves these instances exploiting the peculiar structure of the transportation costs: these costs depend on the couple of indexes (i,j) of the related variables and present strong regularity in the way they increase or decrease according to a change of index i or j. Given the dual multipliers of the current basic solution, the described structure of costs enables the algorithm to predict from scratch the positivity of a large set of reduced costs and avoids their computation. Also, it enables to detect the presence of non basic variables with negative reduced costs within a relatively small subset of variables. The proposed approach computes, at each iteration, an ad-hoc subset of neighbor reduced costs that guarantees the optimality of the final solution but strongly reduces the total number of reduced costs to be computed.

Keywords: Transportation problem, DOTmark instances, Exact Approach

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Optimal location of capacitated charging stations

Carlo Filippi[1], Gianfranco Guastaroba[1], Lorenzo Peirano[1] and **Maria Grazia Speranza**[1]
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A massive use of electric vehicles is nowadays considered to be a key element of a sustainable transportation policy and the availability of charging stations is a crucial issue for their extensive use. Charging stations in an urban area have to be deployed in such a way that they can satisfy a demand that may dramatically vary in space and time. In this paper we present an optimization model for the location of charging stations that takes into account the main specific features of the problem, in particular the different charging technologies, and their associated service time, and the fact that the demand depends on space and time. To measure the importance of incorporating the time dependence in an optimization model, we also present a simpler model that extends a classical location model and does not include the temporal dimension. A worst-case analysis and extensive computational experiments show that ignoring the temporal dimension of the problem may lead to a substantial amount of unsatisfied demand.

Keywords: Location, charging stations, mixed integer programming

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Session: AI4RAILS 2 – Maintenance

Tuesday September 10th 8:30am - 9:50am

Conference Center B

Chair: Corneliu Cotet

Railway Wheel Impact Force and Alert Prediction using Machine Learning Models

Gajendra Malviya[1] and Shripad Salsingikar[1]

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The Wheel Impact Load Detector (WILD) sensor measures the force exerted by the railway wheel on the rail track. If the force exerted is beyond a threshold value, the wheel needs inspection. The Problem Solving Competition 2017 organized by INFORMS Railway Application Section, asked participants to predict the force exerted by wheel, when a currently empty rail car would be loaded in the next trip. Further, convert the predicted force value into an alert, if the value is more than the threshold value. We present machine learning models to address the above problem along with results. We label the predicted output into two classes. Records with predicted force greater than or equal to the threshold value as 1 else 0. %True Positives detected were found to be very low (0%-6%), which results in poor prediction of critical event. Instead of predicting critical event based on predicted force valued, we label the actual/training records, thereby converting the prediction problem into a classification problem. We apply various classifiers to classify whether the record is critical or not. We apply filtering, data pre-sampling, cross-validation and hyperparameter tuning. As the resultant labeled data is highly imbalance, we apply Synthetic Minority Oversampling Technique (SMOTE) and Cost Sensitive learning techniques to increase True Positives and reduce False Alarms. Random Forest classifier with SMOTE turned out to be the best among all classifiers with %True Positives as 85.76%, %False Alarms as 8.27%.

Keywords: Wheel Impact Load Detectors, kips, classification, cost sen- sitive learning, SMOTE

Denoising mobile inspection device route through graph-matching algorithm

Valentin Leveau[1], Waleed Ragheb[1] and Romain Chailan[1]
[1]RAILwAI, R&D, Montpellier , France

In the railway maintenance context, inspection wagons are equipped with sensors measuring infrastructure characteristics all along their course, s.a. track geometry. To finely analyze and model changes over time, acquired measurements must be located in a fixed frame of reference. However, various sources of uncertainties can arise from each location sensors (e.g. GPS, odometer, etc.). These make it difficult to accurately project the locations of measurements towards the ground-truth reference frame. In this work, we present an approach to consolidate the precise route taken by the inspection device. Our method combines i) a technique based on both statistical learning and simple heuristic pattern detection techniques to detect switches from longitudinal track geometry measurements, ii) a method for interpolating positions between those identified reference patterns. As nodes of the infrastructure topology mesh, switches are strategic components to detect because they give valuable information on the route such as track changes. Because this solution heavily depends on the reliability of the switch recognition system, performance is highly sensitive to false positive / false negative rates. We propose to use a priori knowledge on the topology of the infrastructure to consolidate the switch detection system and increase the capacity to estimate the true route taken by the inspection wagon. We cast the problem into a distancegraph matching formulation, i.e. weighted graphs whose nodes are switches and edges are weighted by the measured / reference distance between the switches. We evaluate the most likely route as the sub-graph of the entire infrastructure's topology whose distance from the graph among the different switches detected by the machine learning model is the minimum. We quantitatively evaluate our approach on various routes and infrastructures by comparing it with a classical map-matching [1] process with patrimonial data. Results are then discussed.

Keywords: Graph Optimization, Route, Sensor Uncertainty

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Maximizing the Efficiency of Railway Maintenance Operations Through Integrated Simulations

Waleed Ragheb[1], Valentin Leveau[1], Romain Chailan[1]

[1]RAILwAI, R&D, Montpellier , France

Railway infrastructures degrade with various parameters such as traffic, environmental conditions, and lifetime. Therefore, strict maintenance is required to ensure the safety, reliability, and continuity of service. In turn, maintenance planning is one of the most crucial aspects for infrastructure agencies to deal with the available resources and constraints, be they financial, material, or human. In this abstract, we introduce a new framework for optimizing maintenance strategies which consists of two main components: the simulator and optimizer. Our proposed simulator offers a comprehensive representation of rail logistics, spanning conceptual and detailed planning, and maintenance activities. Potential infrastructure defects are modeled using several defect profiles and degradation models. These models take into account the uncertainty and variability in different input parameters such as weather conditions and traffic loads. We achieve this by exploring several probabilistic and stochastic models. The Monte Carlo simulator models different types of maintenance acts that access different resource profiles each with its corresponding availability and cost. At the backbone, we propose to customize the Flatland simulator [1] which is designed mainly to manage dense traffic on complex railway networks. The main objective of optimizing the maintenance strategy is to minimize a cost function concerning numerous constraints. The essential type constraints comprise the global budget for maintenance operations and intervention budget defined by certain topologies. Some other constraints come from the railway code of safety as periodic maintenance (preventive maintenance) of major components in the infrastructure. Moreover, resource availability plans which could come with different costs play an important role in designing a visible maintenance strategy. We demonstrate advanced Machine Learning and metaheuristic optimizations to get a set of optimal maintenance schedules.

Keywords: Railway Maintenance, Monte Carlo Simulation, Machine Learning, metaheuristic Optimization

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Navigating uncertainty: Synthesizing cross-sector decision-making dynamics to enable AI in rail infrastructure management

Corneliu Cotet[1], Peter Kawalek[1] and Tom Jackson[1]

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This paper is part of a groundbreaking research initiative (Seasonal Agnostic Railway Model) dedicated to the development of an automated decision-making system for rail infrastructure and operations management, applying AI methodologies to navigate the multifaceted challenges endemic to rail systems. The imperative for this innovation is illustrated by the 2020 Stonehaven derailment, which brings to light the critical demand for resilient, adaptable rail systems equipped with proactive, agile decision-making capabilities to safeguard safety, ensure service continuity, and optimize cost-efficiency. Employing cybernetics as a foundational research approach, this project delineates strategic frameworks designed to enhance decision-making processes, risk management, and maintenance optimization amidst prevailing data uncertainties and dynamic environmental shifts. A significant portion of the research involved engagement with Tokyu Corporation, a rail operator based in Tokyo. This interaction underscored their success in employing real- time disruption identification and mitigation strategies, thus reinforcing the indispensability of adaptive decision frameworks, extensive training regimes, and the integration of heterogeneous data sources in augmenting the reliability and sustainability of rail systems. Progressing beyond this foundation, the investigation extends into a nuanced examination of decision-making dynamics, specifically addressing the challenges posed by weather-related uncertainties and urgency-driven decision imperatives. The study encompasses comprehensive interviews with domain experts from a variety of sectors—aviation, maritime, highways management, air force, disaster management, logistics, agriculture, nuclear energy, medicine, and racing—previously identified as facing analogous uncertainties. Through the application of a rigorous qualitative research methodology, the endeavour aims to deepen our comprehension of adaptive decision-making mechanisms, aspiring to synthesize these findings into a practical, AI-enhanced decision-making framework for the rail sector. Far from merely broadening the existing corpus of knowledge, this research represents a deliberate synthesis of a wide array of experiences and strategies, casting light on the fundamental principles of decision-making resilience and efficacy in uncertain contexts.

Keywords: decision-making, uncertainty, rail infrastructure resilience, cross-sector analysis, AI frameworks

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Session: Networks 3

Tuesday September 10th 8:30am - 9:50am

Room Nautilus

Chair: Carmine Cerrone

A Carousel Greedy Approach for the Colorful Components Problem

Claudia Archetti[1], Francesco Carrabs[2],Raffaele Cerulli[2] and **Domenico Serra**[2]

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This study tackles the Minimum Colorful Components problem (MCC), proposing a new Carousel Greedy (CG) algorithm based on edge-contraction operations and enhanced by a local search procedure. The MCC problem is a graph partitioning problem, defined on vertex-colored graphs. The objective is to find a minimum subset of edges whose removal results in a graph partitioned into the minimum number of colorful components, where each component contains at most one vertex with the same color. The problem finds applications in various fields, mainly in the field of bioinformatics [1, 2].

The CG framework refines traditional greedy approaches by starting with an initial solution provided by a greedy algorithm and iteratively improving it, by making new selections and discarding older ones. Our approach extend the classic CG framework [3], incorporating an edge-contraction strategy. This strategy contracts the endpoints of an edge into a single vertex or component if the endpoints have different colors and can coexist within the same colorful component. When CG discards an older choice, which consists in the contraction of an edge, it reverses this contraction, freeing the vertices that were merged. During this process, a local search is employed to determine if the released vertices can be integrated into other existing components.

We compared our approach with a mathematical model, using two sets of instances: the former available in the literature and the latter generated by us in random way. The computational results show that our approach outperforms the other algorithms, proposed for the MCC problem, and its effectiveness makes it potentially suitable for other graph partitioning problems.

Keywords: Carousel Greedy, edge-contraction, vertex-colored graph, colorful component

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Exact approaches for the colorful components problems

Claudia Archetti[1], **Martina Cerulli**[2] and Carmine Sorgente[2]
[1]ESSEC Business School of Paris, Cergy-Pontoise, France
[2]University of Salerno, Salerno, Italy

We study the *colorful components* framework, historically motivated by comparative genomics in bioinformatics [1]. Given a vertex-colored graph $\mathcal{G}$ any connected component of $\mathcal{G}$ is said to be *colorful* if all its vertices have different colors. We address three problems related to these particular components of a graph: the "Colorful Components" (CC), the "Maximum Edges in transitive Closure" (MEC), and the "Minimum Colorful Components" (MCC) problems.

In social networks, where nodes represent individuals and edges represent connections (e.g., friendships, interactions), all three problems can be used to determine the most influential connections linking distinct (colorful) and cohesive (connected) communities. By guaranteeing the colorfulness of the communities through the removal of specific edges, as in the CC problem, a social network aims to mitigate the risk of echo chambers, where users predominantly interact with similar individuals. Maximizing the number of edges in the transitive closure in the MEC problem means promoting the propagation of information through the community, ensuring that a node can be reached by others through a sequence of edge. Instead, by minimizing the number of colorful components, the MCC problem helps prevent the isolation of users within small disconnected groups. When considering cyberspace networks of devices with various types of connections (e.g., permissions, data flow), identifying a subset of edges to remove while ensuring that the network remains in connected colorful components helps optimize the network's resilience to cyber threats.

We formulate CC, MEC, and MCC problems as integer nonlinear problems. We linearize these formulations and enhance them with valid inequalities. We further provide a formulation to determine the maximal colorful component and we propose bounds on the cardinality of the colorful components set. The formulations are computationally evaluated to demonstrate the efficiency of the proposed approaches.

Keywords: Graph problem, Colorful components

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A Kernel Search Approach for the Rainbow Steiner Tree Problem

Francesco Carrabs[2], Renata Mansini[1], Lorenzo Moreschini[1] and **Lorenzo Tomasetti**[1]

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Given an undirected edge-colored graph with non-negative edge length, the aim is to find a minimum Steiner Tree that uses at most one edge for each color [1]. The problem, called Rainbow Steiner Tree Problem (RSTP), is known to be NP-hard and can be used to model different real-world applications such as in wireless connectivity. Given the complexity of the underlying problem, we develop a simple variant of the Kernel Search algorithm [2][3] based on the multicommodity flow formulation with rainbow constraints as described in [1].

Comprehensive work has been done on the Kernel search framework to enhance its effectiveness over the discussed problem. We test our approach on benchmark instances and compare its performance with both state-of-the-art algorithms and MIP solvers. Preliminary results are very promising.

Keywords: Steiner Tree, Edge-colored graphs, Kernel Search

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A Branch & Bound algorithm for the Rainbow Spanning Forest Problem

Carmine Cerrone[1], Raffaele Dragone[1] and Anna Sciomachen[1]

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In this paper, we present a Branch & Bound algorithm for solving an NP-hard combinatorial optimisation problem, denoted as Rainbow Spanning Forest Problem (RSFP). The RSFP consists of finding a spanning forest of an undirected, edge-coloured graph G with the minimum number of rainbow components, where a rainbow component of G is a subgraph of G that has all the edges with different colours. The proposed method is capable of determining the optimal solution within 0.4 seconds for small instances, thus proving to be computationally competitive with respect to the methods used by the most recent optimisation libraries and commercial SW environments available.

Keywords: Branch& Bound, Rainbow Spanning Forest, Edge-Coloured Graph

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Session: Optimization under uncertainty 1

Tuesday September 10th 8:30am - 9:50am

Room Rocce

Chair: Giovanni Micheli

Network dual reoptimization policies and bounds for a class of Markov decision processes

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We consider finite-horizon Markov decision processes with finite endogenous states but high-dimensional and continuous exogenous state space, which is the typical setting when dealing for instance with the valuation of multiple-exercise financial and real options. The least squares Monte Carlo is a popular approximate dynamic programming method that tackles such problems by computing a low-dimensional value or continuation function approximation [1], but it may lead to high optimality gaps. A forecast-based reoptimization heuristic that iteratively replaces stochastic quantities with forecasts and solves a deterministic optimization problem is also common but not well suited to handle irreversible decisions [2]. To overcome these shortcomings, we develop a network-dual reoptimization framework that leverages network flow algorithms and employs a novel class of partial information relaxations. Our framework provides both a new policy and a dual bound and we establish that: (i) the decisions taken by our policy are equivalent to solving a scenario-based two-stage stochastic program but computationally more efficient since scenarios are solved independently; and (ii) our dual bound is tighter than the known penalized perfect information bound [3]. Numerical experiments on two energy real option applications dealing with commodity production and fleet upgrade show that our network-dual reoptimization policy outperforms forecast-based reoptimization by 10–20% and least squares Monte Carlo by to 2–5%, while our dual bound improves by less than 1%.

Keywords: Markov decision processes, reoptimization, information relaxation, network flows, energy applications, real options

References

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Joint Discount and Replenishment Parametric Policies for Perishable Products

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Managing perishable items in a retail setting is a challenging but relevant problem, in terms of profitability on the one hand, and food waste reduction on the other hand. The problem is strongly affected by uncertainty, mainly due to demand size and consumer attitude towards items of different characteristics. Moreover, consumers freely choose their preferred items, and inventory issuing cannot be tightly controlled. To encourage purchases of non-fresh items and reduce waste while improving profits, discounts might be introduced on older items [1]. In this setting, we consider a joint discount and replenishment problem in a discrete periodic review fashion for the sale of a perishable product, characterized by limited deterministic shelf life, replenishment lead times, and stochastic demand. Furthermore, customers decide what to buy according to a linear discrete choice model. The decisions that we consider are: how many new items to order, the age of the items to be discounted, and how much discount to offer. In this context, we compare four *parametric policy function approximations* [2]. They mix the constant order policy and the base stock one with some easy discounting policies, optimizing their parameters using a simulation-based optimization framework. To evaluate their performance in terms of revenue and quantity of scraped items, we consider four types of realistic instances for a grocery retailer characterized by products of different shelf life and variance of demand. Experiments show that best results are achieved by a base stock policy that discounts products of different ages based on a threshold: if the quantity of the inventory of a given age is greater than a threshold it applies a discount, otherwise no discount is proposed. This policy can increase the average reward by up to 8%, on average, with respect to policies that do not discount.

Keywords: inventory control, perishable product, discount, parametric policy function

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A Stochastic Programming approach for the Vehicle Routing Problem with Divisible Deliveries and Pickups

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In today's e-commerce landscape, companies face the intricate task of managing not only the efficient delivery of ordered goods but also the handling of return requests—commonly known as Reverse Logistics. Specifically, alongside regular delivery operations, companies must address both mandatory and delayable return requests. Clearly, to increase customer satisfaction and speed up the return of goods to the market, the latter type of request should be fulfilled for at least a certain proportion.

We investigate a stochastic variant of the Vehicle Routing Problem with Divisible Deliveries and Pickups [1], where the optional return demand is subject to uncertain positive variations, simulating real-world scenarios [2]. The objective is to minimize the overall cost by strategically routing a homogeneous fleet of vehicles that fulfill mandatory deliveries and pickups while ensuring that a minimum percentage of optional pickups is also met. By doing so, we prevent an excessive accumulation of pickup requests for future days.

To address this uncertain environment, we propose a novel formulation based on two-stage Stochastic Programming (SP) with recourse that considers freight adjustment, the possibility of detouring a vehicle to the depot to unload goods before continuing its route, and spot-market pick-up operations. Then, we approximate the problem through a scenario-based deterministic equivalent approach and conducted several experiments by using different probability distributions to simulate the variation of optional requests and by fixing different minimum percentages of optional requests. During the conference, we will propose computational results, ad-hoc SP measures, and interesting managerial insights useful to wisely face the impact of uncertainty in similar settings.

Keywords: Reverse logistics, Two-stage stochastic programming with recourse

References

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Equilibrium models to analyze TSOs-DSOs coordination architectures in two-stage energy markets under uncertainty of demand and renewable generation

Giovanni Micheli[1], Maria Teresa Vespucci[1], Gianluigi Migliavacca[2] and Dario Siface[2]

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[2]RSE Milano, Italy

The current massive installation of distributed resources in electricity distribution systems makes these systems active dispatching subjects. At the same time, the need to compensate for the intermittent generation of an ever-increasing amount of renewable sources creates the need to acquire more and more ancillary services. Flexible resources in the distribution system could be enabled to provide these services not only within the perimeter of the distribution network to which they are connected but also for the benefit of the transmission system. However, to this end, Transmission System Operators (TSOs) and Distribution System Operators (DSOs) should mutually coordinate their dispatching actions. One of the most important aspects of this coordination is the set-up of an efficient market architecture that could limit the exercise of market power.

This work presents an innovative approach based on game theory to compare different TSOs-DSOs coordination models for the acquisition of ancillary services provided by resources connected to distribution networks. Several coordination architectures are considered: some characterized by coordinated management of the markets by TSOs and DSOs, others characterized by local markets, managed either sequentially or independently. For each coordination architecture, the mathematical problem of dispatching in electricity markets is formulated as a two-stage stochastic sequential game, with the first stage being the day-ahead market and the second stage the ancillary services market. A Nash equilibrium solution is obtained by iteratively solving the profit maximization problem of each market player. Numerical tests carried out on a CIGRE benchmark network show how coordination architectures that allow resources connected to distribution networks to provide ancillary services to the transmission system may result in higher system costs during peak-load hours.

Keywords: Equilibrium models, Two-stage energy markets, TSOs-DSOs coordination, Stochastic programming

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Session: Fairness in Optimization Problems

Tuesday September 10th 10:00am - 11:00am

Conference Center A

Chair: Valentina Morandi

A fair shift scheduling and re-scheduling optimization framework in call centers

Vittoria Crotti[1], Valentina Morandi[2] and Maria Grazia Speranza[2]

[1]Multiprotexion Group [2]University of Brescia

Multiprotexion is a company that deals with the surveillance of international transport vehicles and facilities. The company provides multiple services including the 24/7 operational centre to manage alarms received from the drivers and sensors. One big issue is related to guaranteeing a high level of service for the 24/7 operations center by ensuring a proper coverage through the entire time horizon and to ensure a certain level of fairness for operators. According to [1], shift scheduling formulations involve assigning operators to shifts based on the required number of operators for each shift. This assumption could be reasonable when the amount of people needed throughout the day is stable or demand curves overlap the shift time slots. Unfortunately, this does not apply to security operational services, as evident in our case study, or in call centers in general, where call volumes can change dramatically by the minute. Moreover, as assessed in [2] ,previous literature on fairness in shift scheduling focuses solely on penalties/scores for unwanted shifts for operators. In fact, when scheduling operators to shifts, unfairness could also be linked to other factors such as refused requests for days-off, how much they have been penalized in the past and in the current schedule and many others. In addition, when a disruption occurs and a rescheduling phase is needed, unfairness issues could arise when shifts with a lower score are assigned to operators or when a day-off is transformed in a working day for on call operators because of a lack of personnel. To these aims, the company designed and implemented two optimization models, one for the long-run schedule and one for managing disruptions, which are not rigidly bound to shift time slots and take into account several unfairness factors. Results show that the optimized assignment is fair for operators while better covering the real needs of the operations center.

Keywords: Fair schedule, rescheduling, workers' demand coverage

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Tactical workforce sizing and scheduling decisions for last-mile delivery

Claudia Archetti[1], Minakshi Punam Mandal[1] and Alberto Santini[2]

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Data Science Centre, Barcelona School of Economics

We tackle the tactical problem of workforce sizing and shift scheduling of a logistic operator delivering parcels in the last-mile segment of the supply chain. Deliveries are performed by hired couriers or outsourced/crowdsourced. Service is performed through satellites which are associated with service areas. Areas are further grouped into regions. We assume that hiring decisions must be taken at the tactical and regional level, i.e., a courier is hired for a specific region and an extended period. Assignment of couriers to satellites (and, therefore, to areas) happens on the operational level according to the needs of the logistic operator. The logistic operator must decide how many couriers to hire in the mid-to-long term in each region and which area to assign them in the short term to minimise the combined labour costs and expected outsourcing costs. Our working hypothesis is that the relevant decisions are affected by two main trade-offs: workforce size and shift stability. A large workforce is able to deal with demand fluctuations but incurs higher fixed costs; by contrast, a small workforce might require excessive outsourcing to third-party logistic providers. Stable shifts, i.e., with predictable start times and lengths, improve worker satisfaction and reduce turnover; at the same time, they might be less able to adapt to an unsteady demand. Through an extensive computational campaign based on a novel mathematical formulation, we test these assumptions. We find that extreme shift stability is, indeed, unsuitable for last-mile operations. On the other hand, introducing a very limited amount of flexibility achieves similar effects as moving to a completely flexible system while ensuring a better work-life balance for the workers. Several recent studies in the social sciences have warned about the consequences of precarious working conditions for couriers and have recommended stable work schedules. Our work provides a decision-support tool to achieve this objective without sacrificing the company's bottom line.

Keywords: Last-mile delivery, workforce scheduling, ethics of OR

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Multi-day fair collaboration in demand-responsive transportation

Enrico Angelelli[1], **Valentina Morandi**[1] and Maria Grazia Speranza[1]
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Technological developments are modifying in different directions the way we move and transport goods. One of these directions aims at reducing the number of kilometers traveled by road vehicles and/or at increasing the used capacity of a vehicle through collaboration among companies providing on-demand transportation services. While the potential of collaboration initiatives to reduce the number of vehicles on the road is recognized by many, there are also several obstacles that are known to limit the number of successful collaborations (see, for example, [1]). We consider the case of companies that offer a demand-responsive transportation service and are engaged in a horizontal collaboration initiative. Collaboration initiatives may fail because larger companies benefit more than smaller companies from the collaboration, and smaller companies may lose customers or even be pushed out of the market (see [2]). One of the challenges in the design of successful collaboration schemes is to find mechanisms that make the collaboration beneficial to all the companies involved (as in [3] and [4]). We present an optimization model that controls the level of fairness in the assignment of customers to shared taxi companies engaged in a collaboration initiative. The model assigns the customers with the objective of minimizing the total routing cost while bounding the number of customers and the traveled time of each company over a pre-defined time horizon and/or in a single day. Different approaches to control the fairness are compared on a set of benchmark instances. An adaptive large neighborhood search heuristic is then presented for its solution. The computational results show the flexibility of the multi-day approach and its potential to further reduce the operational costs compared with the single-day optimization and, at the same time, to be fair to all companies, and, thus, to make the collaboration sustainable in the short and long run.

Keywords: Collaboration, Demand-responsive transportation, Fairness

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Session: OPTSM 2 – Rail Yards Evasion

Tuesday September 10th 10:00am - 11:00am

Conference Center B

Chair: Jianghai Xiang

Integrated Optimization of Train Makeup Problem and Resource Planning for Railroad Shunting Yards: A Logic-Based Benders Decomposition Approach

Peiran Han[1], Lingyun Meng[1], Nikola Bešinović[2], Jianrui Miao[1], Xiaojie Luan[1], Yihui Wang[3] and Zhengwen Liao[1]

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In the shunting yard, various complex operations occur, leading to inefficiencies in railcar connections. Therefore, designing an effective operational research methodology is essential for the shunting yard, and even for the local rail freight network. At the planning level, this paper addresses the integrated train makeup problem and resource scheduling (TMRS). Treating train makeup as an assignment problem guides all operations, while a series of hybrid flow shop scheduling tasks are established to coordinate the operations of trains, blocks, and railcars. Due to the complexity of TMRS, we reformulate the integrated problem as a hybrid mixed-integer programming and constraint programming model. Logic-based benders decomposition (LBBD) is utilized to partition TMRS, with lower bounds designed and integrated into the solving procedure to accelerate convergence. We propose feasibility cuts and optimality cuts based on the structure of subproblem, which are dynamically added to the master problem. Finally, the modelling approach and solving techniques are implemented on small artificial instances and a real-scale example, demonstrating their practical effectiveness and ability to achieve optimal solutions.

Keywords: Shunting yard, Hybrid flow shop scheduling, Freight transportation, Constraint programming, Logic-based Benders decomposition

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Solving a classification track assignment problem in railway marshalling stations

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The safe, efficient, and reliable transportation of freight by rail is crucial to the economy of many countries. The level-of-service of railway transportation is influenced not only by train performance on main routes but also by yards performance at network hubs. At railway network hubs, called marshalling stations, the railcars on inbound trains are decoupled, sorted onto tracks in the classification yard according to their destination, and then assembled into outbound trains. The scheme by which railcars are assigned to classification tracks is essential to the efficient operation of a marshalling station, as it strongly influences the connection times of each railcar and it additionally impacts the usage of other facilities and resources at the station. In this paper, we propose a novel method to real-time optimize the assignment of railcars to classification tracks in a marshalling station, by considering the disassembly and assembly operations of railcars, as well as the required block sequence for each outbound train. We formulate the problem as a binary linear programming model with the objective of minimizing the total weighted disassembly and assembly shunting costs required for all railcar sorting operations. A two-stage decomposition algorithm, which divides our model into the roll-in and pull-out subproblems, is developed to improve the solving efficiency. For the roll-in subproblem, we propose a basic model and further a group-indexed model, to determine the optimal railcar track assignment scheme according to the objective of minimizing the total weighted disassembly cost and simplified assembly cost. For the following pull-out subproblem, the objective is to determine the pull-out scheme that minimizes the total weighted assembly cost, additionally considering the block sequence requirements of outbound trains. This sub-problem can be decomposed further for each outbound train, enabling very rapid solving times using our proposed quadratic assignment model and heuristic method. Computational tests on some illustrative instances and some realistic instances are conducted to test the effectiveness and efficiency of the proposed approaches. Lastly, the influence of varying certain parameters is discussed to evaluate the generality of our approaches. This methodology enriches the existing research on the classification track assignment problem in marshalling stations, especially in China.

Keywords: Transportation; Marshalling station; Classification track assignment; Integer programming; Decomposition algorithm

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Routing and scheduling of trains and engines in a railway marshalling station yard

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This study investigates the problem of routing and scheduling trains and engines in a receiving/departure yard of railway marshalling stations, which involves simultaneously assigning routes and scheduling route-setting start times for both train and shunting operations to be conducted in the yard. This is an important practical problem of traffic management in railway marshalling stations but has received little attention in the literature. Compared to similar problems in railway passenger stations, this problem is generally more complicated because of the presence of different yard operations (i.e., train and shunting operations) and the occupation of different yard resources (i.e., yard tracks and track sections), as well as the time-space coherence between operations. We first introduce the concepts of task, activity and pattern to transform the original problem into a special assignment problem, and then propose a compact binary integer linear programming model with a linear number of constraints for the problem and an objective of minimizing the total time deviation of all involved tasks. An improved technique that relies on listing all maximal (bi)cliques in a constructed graph is designed to effectively model the time coherence and track section occupation constraints. Next, a heuristic that gradually expands the patterns for the identified key activities by adding more start time alternatives is applied to rectify the possible infeasibility of the model. We further develop a rolling horizon algorithm, in which the original problem is decomposed into consecutive smaller stages by either a time-rolling or a train-rolling rule, to efficiently solve difficult instances. Finally, numerical experiments based on a set of instances derived from a receiving yard and a departure yard of a large-size marshalling station in China are conducted to demonstrate the effectiveness and applicability of our approaches. The results show that our approaches typically find (near-)optimal solutions within a practically attractive computation time of several minutes for most of the investigated instances with a fine time granularity of 15 seconds, implying a good potential for practical applications.

Keywords: Railway transportation, Routing and scheduling, Marshalling station, Binary integer linear programming

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Session: Game Theory and Multilevel Optimization

Tuesday September 10th 10:00am - 11:00am

Room Nautilus

Chair: Marcello Sanguineti

The green-aware coalition formation problem

Maria Elena Bruni[1] and Alessandro Hill[2]

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Topics concerning coalitions and coalition formation have gained interest in the last years. The reason for this is related to the widespread presence of distributed and multiagent systems, where cooperation is required or desired. The majority of the research concentrates on the coalition formation problem, which involves partitioning the set of all agents to optimize the total value of the chosen coalitions, and on cost allocation mechanisms to ensure the stability of the coalitions.

Collaboration may also lead to negative externalities, which may even exceed the positive effects of cooperation for individual players. When this happens, the interactions among players may produce highly suboptimal outcomes. Although plenty of game-theoretical models have been developed and studied in the literature, little research focuses on this aspect, or considers the presence of players with possibly different green-awareness levels. We consider green-awareness in the broader sense as a sensitivity towards the environmental and social impacts of operations. Green-awareness might be incorporated at different and complementary levels. At a higher level, an approach would be that of evaluating coalition formation in terms of its induced environmental/social impact.

As an example, in network-creation games, the quality of a network can be evaluated taking into account the energy consumption, besides the classical infrastructural costs. At a microscopic (player) level, players might not be willing to choose costlier (green-aware) actions. When this happens, a central authority may intervene by adopting proper remedial instruments, such as subsidizing the coalition.

We focus on this combined problem of coalition formation and cost allocation under a green-aware perspective. Our discussion includes possible formulations in the realm of bilevel optimization where economical aspects, social aspects and subsidization are considered on the upper level and the minimum coalition-dependant subsidization is calculated on the lower level.

Keywords: Green-awareness, coalition formation, stability, subsidization

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A generalized framework for multilevel strong interdiction problems

Alberto Boggio Tomasaz[1], Roberto Cordone[1] and Pierre Hosteins[2]

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An interdiction problem is a zero-sum game with two agents where the follower (defender) aims to solve some optimization problem after the instance has been altered by an attack of the leader (attacker). We focus on the version of the problem where the attacker prohibits the defender to utilize some elements of the instance in order to worsen as much as possible the optimal solution of the defender. These problems have many real-life applications in public security, especially with the increasing threats posed by technological advances. We present a new framework that generalizes a state-of-the-art method, for the exact computation of an optimal solution. We exploit a sampling technique which resembles a Benders decomposition and solve the restricted master problem by finding a sequence of set covers. The sample is enlarged during the computation until an optimal solution is found. Moreover, this framework can be easily adapted to fortification problems where the defender plays a preliminary additional turn by protecting some elements of the instance so that the attacker is unable to interdict such elements.

Keywords: Interdiction, Multilevel optimisation, Covering decomposition

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Wildland fire diffusion and control: A cooperative game-theoretic model

Patrizia Bagnerini[1], Mauro Gaggero[2], Giorgio Gnecco[3] and **Marcello Sanguineti**[4,2]
[1]DIME, University of Genova
[2]INM - National Research Council of Italy (Genova)
[3]IMT Lucca
[4]DIBRIS, University of Genova

Various modelling approaches have been proposed to forecast the evolution of wildland fires over time and space [1] and to control them. Here, a methodology based on cooperative game theory is proposed to optimize the use of limited resources (e.g., firemen, Canadair, etc.) to control a fire. In particular, the Shapley value is exploited as a measure of the value of each player in a transferable-utility game [2]. Recently, it has been used to evaluate the importance of each link [3] or node [4] in a network. The wildland area is modelled as a network, in which nodes represent areas of particular interest. Some of them may become fire outbreaks, from which the fire can propagate to other nodes. The links represent possible directions of propagation and may be weighted by taking into account features related to fire evolution (e.g., elevation of the terrain, kind of vegetation, estimated rate of spread). A temperature diffusion process is considered, where the rate of diffusion is given by the second smallest eigenvalue of the Laplacian matrix of the network. A transferable-utility game is defined, where the players are a subset of the edges and the utility function is related to the decrease of the rate of diffusion of the fire when an edge is removed – i.e., a direction of propagation from a fire outbreak is controlled. The Shapley values of the players are exploited to decide the order in which the edges should be removed (i.e., how one should act with fire-extinguishing resources) in such a way to effectively reduce the fire diffusion rate.

This work was supported by the Italian Ministry of Enterprises and Made in Italy (project F/310027/02/X56 "Distributed and coordinated drone swarm for fire detection and suppression activities"), by the Italian Ministry of Research (PRIN 2022S8XSMY "Optimal robust shape control for distributed parameter systems"), and by the GNAMPA-INdAM 2023 project "Sviluppo di metodi di machine learning per la stima del valore Shapley e di sue generalizzazioni", code CUP_E53C22001930001. M. Gaggero, G. Gnecco, and M. Sanguineti are members of GNAMPA-INdAM. M. Sanguineti was partially supported by the project of the PDGP DIT.AD021.104 "Optimization and Control Techniques" of the Institute of Marine Engineering, National Research Council of Italy.

Keywords: wildland fires, transferable-utility games, Shapley value

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Session: Optimization under uncertainty 2

Tuesday September 10th 10:00am - 11:00am

Room Rocce

Chair: Ciriaco D'Ambrosio

A quantified approach to stability in interval linear programming

Milan Hladík[1]

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Uncertainty in linear programming can be modelled by different ways. We suppose that we have interval-valued coefficients, and each interval coefficient is associated either with a universal or an existential quantifier. We introduce a novel type of robustness of an optimal basis. It is called AE stability since the order of quantification (forall-exists) of the interval coefficients is that the universal quantifiers precede the existential ones. Thus, we have a very general technique to model diverse types of robustness, from the very conservative (worst case analysis) to the very optimistic (best case scenario).

We consider interval coefficients in the right-hand sides of the constraints and in the objective function, which is motivated by the transportation problem. Nevertheless, we also discuss possible extensions to the case with uncertain entries of the constraint matrix.

For the proposed AE basis stability, we provide its characterization by explicit formulae. Then, we analyze the computational complexity, and for the computationally hard cases we propose cheap sufficient conditions. Eventually, we present several applications, including the aforementioned transportation problem.

The author was supported by the Czech Science Foundation Grant P403-22-11117S.

Keywords: Linear programming, Sensitivity analysis, Interval analysis

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Several Challenges of Interval Transportation Problems

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Interval linear programming provides a mathematical tool for handling transportation problems, in which the quantities of supply, demand and the transportation costs can be affected by interval-valued uncertainty. The main tasks in solving interval transportation problems are describing the optimal solutions and computing the optimal values over all possible perturbations of the uncertain data. Although some problems associated with these tasks can be solved in polynomial time (e.g. computing the best possible optimal value only requires solving a single linear program), others are much more challenging.

In this talk, we highlight the main challenges in solving transportation problem with interval data and identify the potential approaches to handling them. First, we prove that the decision problem connected with computing the worst (finite) optimal value is NP-hard for all frequently used formulations of interval transportation problems and we present the available methods for finding the worst optimal value. Moreover, we discuss the computational complexity of the problem restricted to interesting special classes of interval transportation problems with further assumptions on the structure of the interval coefficients or properties of the cost matrix. Finally, we also address the problem of characterizing optimal solutions and checking whether a given transportation plan is optimal for some or each possible choice of the interval data (also known as the properties of weak and strong optimality of a solution). While weak optimality of a transportation plan can be easily tested by means of linear programming, testing strong optimality presents a more difficult challenge, in general.

Keywords: Transportation problem, Interval uncertainty, Optimality

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An Improved Exact Approach for the Interval Immune Transportation Problem

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The Interval Transportation Problem (ITP) represents a variant of the classic Transportation Problem (TP), characterized by supply and demand levels defined within specific intervals. Each configuration of supplies and demands within these intervals turns the problem into a potential classical TP, that is finding the minimum cost transportation plan that meets demand requirements without exceeding supplier capacities. One of the main challenges in this context is to identify the best and worst-case scenarios for the optimal cost given that ITP can be seen as a set of classical TP problems. This challenge has been faced originally in [1], in which the author proposed two mathematical models to find the best and the worst optimal values and in other works like [2], in which the authors proposed an Iterated Local Search. In this work, we focus on the Interval Immune Transportation Problem (IITP) introduced in [3], that is the ITP under the assumption that the cost matrix is immune to the more-for-less paradox. This paradox describes the counterintuitive situation where increasing the quantity of goods to be transported results in a reduction of total transportation costs [4]. A given cost matrix is defined to be immune against the more-for-less paradox, if an increase in either the demand, or the supply, or both leads to an increase of the cost of the optimal transportation plan. In [3], the authors provided theoretical properties of the problem and proposed a first heuristic algorithm for its resolution. Subsequently, [5] expanded upon this research, introducing novel problem properties and presenting an enhanced heuristic approach and a first exact algorithm for IITP. In this work, we present an improved version of the exact approach presented in [5] based on some theoretical properties of the TP. Preliminary test results show the effectiveness of the new approach with respect to the existing one.

Keywords: Transportation Problem, Interval RHS, More-for-Less Paradox

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Plenary: Giacomo Nannicini

Tuesday September 10th 11:30am - 12:30pm

Conference Center A

Chair: Roberto Wolfler Calvo

Convex optimization algorithms on quantum computers

Giacomo Nannicini[1]

[1]Daniel J. Epstein Department of In- dustrial and Systems Engineering, University of Souther California, 3551 Trousdale Parkway, Los Angeles, CA

Optimization is often mentioned as one of the main application areas for quantum computers, but is this claim backed up by theoretical evidence? In this talk we provide a gentle overview of recent and not-so-recent advances in quantum optimization, with an emphasis on algorithms and subroutines for convex optimization problems that lead to rigorous asymptotic speedups.

Session: Vehicle Routing 2

Tuesday September 10th 2:30pm - 4:30pm

Conference Center A

Chair: Sanne Wøhlk

Exact and heuristic methods for multi-compartments multi-trip multi-product petrol replenishment problem with time windows

Simone Zanda1, Massimo Di Francesco1, Samuele Ennas1, Roberto Wolfler Calvo1, 2

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2LIPN, Université Sorbonne Paris Nord Villetaneuse, France

In this study, we investigate a novel variant of the petrol replenishment problem (PRP) with multi-compartment, multi-trip and multi-product deliveries within specified time windows (MCMTM-PVRPs). Moreover, vehicles are equipped with debit meters to enable split-compartment deliveries, allowing a single compartment to serve multiple customers. We face this complex variant by a branch-and-price approach. The problem is formulated as a set partitioning problem, in which the pricing problem of the column generation is an elementary shortest path problem with resource constraints. The main contribution of this research is the development of a new pruning strategy integrated into a resource-constrained shortest path algorithm. Numerical experiments on a real-world network with five types of petroleum products and a heterogeneous fleet of vehicles demonstrate the effectiveness of this approach.

We also introduce an Adaptive Large Neighborhood Search (ALNS) metaheuristic to solve large problem instances. This algorithm leverages adaptive mechanisms to explore and exploit the solution space effectively, providing high-quality solutions within reasonable computational times.

This study was carried out within the MOST – Sustainable Mobility National Research Center and received funding from the European Union Next-GenerationEU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) – MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.4 – D.D. 1033 17/06/2022, CN00000023). This manuscript reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.

Keywords: Branch & Price, ALNS

The Impact of Fairness in Last-Mile Logistics: A Bi-Objective Vehicle Routing Problem Including K-Sum Minimization

Renata Mansini[1], **Filippo Ranza**[1] and Roberto Zanotti[2]

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In recent years, the spike in popularity of e-commerce and on-demand services has led to a significant increase in delivery services. Such services increase traffic in urban areas negatively impacting citizens by increasing pollution, noise levels, and the risk of accidents.

Conventional vehicle routing models generally prioritize travel cost minimization without considering residents well-being. This paper introduces the concept of residents fairness, defined as disturbance mitigation, in the context of last-mile logistics. We introduce a bi-objective Vehicle Routing Problem (VRP) addressing both cost minimization and resident disturbance mitigation. The problem is formulated on a multi-graph, incorporating one or more paths between the same two locations on the map. Each parallel path differs in traversal time and impact on residents. The total disturbance is quantified by the number of residents on the k most impacted streets in the selected routes. The problem is solved by optimizing the objective functions lexicographically. First, the routing cost is minimized. Then, the impact on the k most impacted streets is minimized allowing a given degradation of the first objective function. A detailed sensitivity analysis is performed of numerous real world based instances, with several k values and different degradation levels allowed. Instances are created considering different cities and information about how the population is distributed within the cities.

Keywords: Vehicle Routing Problem, Multi-graph, Fairness, K-Sum

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Vehicle Routing Problem for perishable products integrating information from on-board sensors

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In the context of managing the supply chain for perishable products, last-mile delivery is a critical phase where both efficiency and timeliness are key factors. Furthermore, timely information on the condition of perishable products is crucial to ensure that customers receive products of the desired quality. This work proposes a mathematical model to address the challenges associated with the distribution of perishable products [1] in the final stages of the supply chain. The aim is to optimize vehicle routing and ensure the effective and efficient delivery of perishable products with specific degradation characteristics; considering the temperature conditions [2] during products transport, to ensure that customers receive products that meet a certain level of quality. The complexity of the model stems from the need to balance several factors, including minimizing routing costs, maintaining high product quality during the transportation and respecting capacity and time window constraints.

This research is supported by the grant under the project "TECH4YOU - Technologies For Climate Change Adaptation And Quality Of Life Improvement" - CUP H23C22000370006.

Keywords: Vehicle Routing Problem, Perishable Products, Sensors

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Combined truck-drone system for delivering and monitoring tasks in urban area

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We consider the problem of delivering items to customers located in an urban area, by using truck and drone [1,2]. This urban setting includes some areas of interest, that must be monitored. The drone is involved in both the delivery and the monitoring tasks [3]. Each customer can be served by either the truck or the drone. The drone can take off from either the depot or the truck at customer locations, make a delivery to a single customer and return to the truck. During delivery, the drone may deviate from the optimal route to monitor an area of interest. The aim is to serve all customers, by either truck or drone, and to monitor the area of interest at minimum cost. We formulate the problem as a mixed-integer linear program. A computational analysis is carried out by considering instances generated by the Solomon benchmarks, properly modified in order to consider both delivery and monitoring tasks for the drone. We analyse the behaviour of the considered delivery and monitoring system, in terms of feasibility, effectiveness, and efficiency.

Francesca Guerriero and Luigi Di Puglia Pugliese were supported by a grant awarded by "European Union – Next Generation EU" under the "PRIN 2022" project: SMOTION (ID 2022EAECWJ), CUP H53D23002000006 (Francesca Guerriero), and CUP B53D23009270006 (Luigi Di Puglia Pugliese).

Keywords: Travelling Salesman Problem, Covering Tour Problem, Truck-Drone, Monitoring task

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A Hybrid Genetic Search Based Approach for Garbage Collection in the Italian Countryside

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This work introduces a novel meta-heuristic to address the garbage collection problem in the rural countryside of a municipality in Italy. We formulate this problem as a variant of the classical capacitated vehicle routing problem (CVRP) known as the generalized vehicle routing problem (GVRP). In the GVRP, nodes are organized into clusters, with the constraint that only one node from each cluster must be visited. The proposed meta-heuristic is a Hybrid Genetic Search (HGS) that leverages recent advancements in CVRP methodologies. This meta-heuristic adapts successful strategies and techniques from CVRP to the GVRP context.

To evaluate the performance of the HGS meta-heuristic, we conduct an extensive computational analysis on 498 benchmark instances, ranging from small to large sizes, obtained from the GVRP and related literature. The results demonstrate that the proposed approach is competitive with other well-known methods. In only six instances out of 498, the algorithm fails to reach or improve upon the best-known solution in the literature.

Finally, we present a case study involving garbage collection in the rural countryside of the municipality of Campobasso. This case study illustrates the effectiveness of the proposed approach in addressing real-world generalized vehicle routing challenges.

Keywords: vehicle routing problem (VRP), Hybrid Genetic Algorithm, Garbage Collection

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Is it beneficial to collect household waste based on requests?

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Waste and recyclable material are often collected from households on fixed schedules. As a consequence, the bins at some households will be less than full while other households are struggling to have enough space in the bin for the waste they generate before the next emptying. Similarly, the single household may not need the same duration between emptying at different times.

To overcome these challenges, a suburb of Copenhagen and the responsible waste collection company wanted to analyze the idea of letting the single household request emptying of their bin when needed. That way, bins will be emptied when they are full, which has the attractiveness of higher service for citizens. A natural hypnotizes is that changing the waste collection system from fixed schedule to such collection by request will lead to fewer emptyings and therefore fewer kilometers driven.

We present the results of the case study made in the suburb, where such a system was tested on a small scale and simulated for the whole municipality. The study show that, while the number of emptyings is indeed reduced when only emptying by request, the driving distance needed to perform those emptyings is significantly increased, thereby indicating that from an operational point of view, such a system is not beneficial in this setting.

Keywords: Routing, Waste collection, Simulation, Practice

Session: OPTSM 3 – Train Routing and Rescheduling

Tuesday September 10th 2:30pm - 4:30pm

Conference Center B

Chair: Valentina Cacchiani

A new model for the train routing selection problem

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Given a set of routes associated with route costs and a set of compatible route pairs associated with pairing costs, the train routing selection problem (TRSP) aims to assign a route to each train, minimizing the sum of the route and pairing costs while ensuring pairwise compatibility among the selected routes. This problem holds significant practical importance, particularly in rail traffic management, where it plays a central role. We propose a binary quadratic programming formulation for the TRSP and employ a linearization technique from the literature [1], with a linear number of additional variables and constraints, to derive a novel and effective integer linear programming (ILP) formulation. Exploiting the specific nature of the TRSP, we devise a technique to enhance the strength of the linear programming (LP) relaxation of the ILP model, resulting in a significant improvement in its computational performance. We obtained in this manner the first effective exact approach for solving the TRSP with proven optimality. Our approach is capable of solving real-world instances of the French railway network in very short computational times. These instances have typically been tackled only by heuristic algorithms in the existing literature. Furthermore, we theoretically and computationally compare the new linearization against the classical one with a quadratic number of additional variables and constraints and against the only ILP model from the literature [2]. Extensive computational results demonstrate that the new ILP model outperforms the other ones in terms of computational time, number of instances solved with proven optimality and strength of the LP relaxation. This work has been funded by CN-MOST - Spoke 4.

Keywords: Rail Traffic Management, Weighted Clique Problems, Integer Lin- ear Programming

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Stop-skipping to Reduce Delays in Train Rescheduling

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In railway systems, unexpected disturbances often make the planned train schedule infeasible. The real-time Railway Traffic Management Problem (rtRTMP) consists in applying retiming, reordering and rerouting of trains with the aim of minimizing delay propagation. In this work, we additionally consider the option of skipping stops to further reduce delays. We extend the RECIFE-MILP model, a Mixed Integer Linear Programming based heuristic for the rtRTMP with microscopic network description, by including stop-skipping. We evaluate the benefit and impact of this rescheduling measure on train and passenger delays in a suburban railway network.

Keywords: Stop-skipping, Train Rescheduling, MILP model

SINTEF Train Dispatching Competition: DispLib2025

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Real-time train rescheduling (sometimes called train dispatching) is a problem that has attracted many research groups around the world. Several different algorithms have been presented over the years, from exact methods based on mathematical programming to heuristics based on machine learning. Unfortunately, almost every one of these algorithms has been tested on specialized scenarios, with constraints and objectives tailored to a specific application, making comparisons between algorithms very difficult if not impossible. Many other research communities have benefited from working with standardized sets of benchmark instances and from holding computational competitions (e.g., CVRPLIB, PESPLIB, and the International Timetabling Competition). With this in mind, we have collected instances from academic and industrial contributors, and built a benchmark set called DispLib2025. We focused on creating a format that is easy enough to be used and understood by many, but also rich enough to represent problems from real-life applications. We are now launching a competition that starts in the fall of 2024 and ends in summer 2025. The winners will be asked to present their work at ODS 2025. Here, we officially kick off the competition and introduce its challenges.

Keywords: Train Dispatching, Scheduling, Computational Competition

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The impact of track discretisation in rescheduling models for advanced distance-to-go railway signalling

Nina D. Versluis[1], Paola Pellegrini[2], Egidio Quaglietta[1], Rob M. P. Goverde[1] and Joaquin Rodriguez[2]

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For effective railway operations, real-time railway traffic management is crucial. In case of disturbances, traffic management can apply rescheduling and rerouting measures to resolve conflicts while minimising the propagation of delay. To support human dispatchers in taking optimised decisions, conflict detection and resolution (CDR) models are developed. Predominantly based on alternative graphs or mixed integer linear programming (MILP), the existing models mostly refer to conventional signalling systems in which the track is discretised into fixed blocks. Only at block entries, trains can receive a brake indication. Hence, train separation is based on a number of blocks. With the implementation of continuous braking curve supervision in distance-to-go (DTG) signalling systems such as the European Train Control System (ETCS) [1], train separation is based on absolute braking distances. Consequently, an explicit relation between speed and train separation is required in CDR models for DTG signalling [2]. Recently, we proposed enhancements for existing CDR models to describe DTG operations. The enhancements relate to track discretisation, speed profile options and train separation. We applied these enhancements to RECIFE-MILP [3], resulting in a tailored CDR model for DTG signalling [4]. In this research, we consider the model for the more advanced DTG signalling systems of ETCS Level 3: Fixed Virtual Block and Moving Block. In these train-centric signalling systems, train position and integrity are monitored onboard – as opposed to conventional trackside train detection. We update the DTG model accordingly, and we investigate the impact of track discretisation granularity on the model performance. The impact is assessed in terms of delay recovery and rescheduling decisions. The results indicate that, depending on the track and traffic scenario, a finer granularity can lead to different rescheduling and rerouting decisions due to shorter train separation.

Keywords: Railway traffic management, conflict detection and resolution, rescheduling and rerouting, distance-to-go signalling, moving-block signalling, mixed integer linear programming

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A risk-averse two-stage stochastic programming approach for backup rolling stock allocation and metro train rescheduling under uncertain disturbances

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Disturbances occur inevitably during daily operations of the metro system, leading to train delays and low service quality. Different from common deterministic reactive train rescheduling frameworks, taking the inherent uncertain characteristic of disturbance duration into account, this paper formulates a two-stage stochastic programming model to address the integration of proactive backup rolling stock allocation and reactive train rescheduling. Specifically, the backup rolling stock allocation plan is optimized in the first stage, while the train timetable and rolling stock circulation are rescheduled under different disturbance realizations in the second stage. The objective is to achieve a balance between allocation costs and negative disturbance impacts, which is evaluated by the mean-conditional value-at-risk criterion on account of the risk-averse attitude of train dispatchers. For computational tractability, the proposed model is reformulated as an equivalent mixed-integer linear programming (MILP) model. To improve the computational efficiency, an innovative solution framework incorporating integer L-shaped and three accelerated subproblem-solving techniques is designed. The MILP is decomposed into a master problem and a series of subproblems using the classical integer L-shaped method. Given that the subproblems include integer variables, solving them remains a time-consuming task. To expedite the process, three acceleration techniques are developed to reduce the solution space. Finally, numerical experiments are carried out based on Beijing Batong Metro Line to verify the performance of the proposed mathematical model and solution framework. The results indicate that the proposed method outperforms benchmarks. Furthermore, comprehensive analysis is conducted on the effects of different parameter settings to provide some managerial insights for dispatchers.

Keywords: Disturbance management, Backup rolling stock allocation, Train timetable, Rolling stock circulation, Integer L-shaped method

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Real-time Train Rescheduling by extending RECIFE-MILP

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During railway operations, unexpected delays occur on a daily basis and may cause train conflicts and delay propagation. Consequently, real-time Train Rescheduling is needed to obtain a new feasible schedule by applying train reordering, retiming, and rerouting [2]. A well-established Mixed Integer Linear Programming (MILP) model for Train Rescheduling was proposed in [3]: it allows modelling the rail infrastructure at a very detailed level with the goal of minimizing train delay propagation. In [3], a heuristic algorithm, called RECIFE-MILP, based on the MILP model of [2] was proposed: it consists of first solving the MILP model within a given time limit by neglecting train rerouting and then solving the complete model with the computed solution as a warm-start. Several boosting methods were proposed to improve the heuristic performance.

In this work, we extend RECIFE-MILP by including additional constraints and a more complex objective function as proposed in [1]. In particular, we consider (mandatory or soft) train connections and restrictions on the access or speed to utilize the available infrastructure resources. The goal is to penalize, through a step-function, trains arriving late or early and differences from the desired travel time, the use of detours, and the violation of soft train connections. Computational experiments are executed on realistic instances to show the performance of the extended heuristic algorithm.

Keywords: Train Rescheduling, MILP, Heuristic

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Session: Scheduling 1

Tuesday September 10th 2:30pm - 4:30pm

Room Nautilus

Chair: Paolo Detti

Customer Order Scheduling with Dedicated Parallel Machines

Arianna Alfieri[1], Andrea Grosso[2], Erica Pastore[1] and **Fabio Salassa**[1]

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Most of the scheduling problems are related to job scheduling, where a job can be a single item or a batch of identical items to be allocated at the same machine. In this problems, the parameters are given to the job level (e.g., processing time or release time of the job) exactly as the computed performance measures (e.g., completion time of the job). Recently, a new type of scheduling problem appeared: the customer order scheduling problem where the elements to be scheduled are orders instead of jobs. The main difference between jobs and orders is that an order is composed by several items, and each item has to be processed on a different machine. In this context, some parameters are order-dependent (e.g., release time, due date) while others are item-dependent (e.g., processing time). The performance measures are order-dependent as all the items in the same order must be completed before the order can leave the system. This problem requires the allocation of the jobs of each order to the machines and the scheduling of the allocated items on each machine. When each job has a dedicated machine, the problem has only the scheduling component, as allocation is no longer needed. The problem setting is the following: there are n customer orders composed of all the items that can be manufactured on m machines. Each machine can produce one particular item. The processing time of order i on machine j requires p_{ij} time units. The optimization criterion is the total completion time of orders. For this problem, we developed several formulations, namely a formulation based on positional variables, a formulation based on precedence variables and a formulation based on TSP-like variables. Performances of these formulations and their relative Benders decomposition reformulations will be presented. Finally, considerations on performances addressing different objective functions will be also provided.

Keywords: Customer Order Scheduling, Dedicated Machines, Mixed Integer Formulations

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Efficiency-Fairness Tradeoff for Multi-Agent Single Machine Scheduling

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Fairness issues naturally arise in several real-world contexts, whenever two or more individuals compete for the use of a resource. In this work, we address fairness concepts in the context of classical single-machine scheduling. We consider a problem arising when two agents, each owning a set of jobs, compete to schedule their jobs on a common processing resource. Each schedule implies a certain utility for each agent and an overall system efficiency (system utility). We present our approach when both agents want to minimize the total completion time of their respective jobs. In this framework, the utility of an agent in a schedule σ is the difference between the total completion time of the agent in its worst possible schedule and in σ [1]. In other words, the utility of the agents represents the gain they have compared to their worst-case scenario, in terms of their objective function value. The system utility is then the sum of the two agents' utilities. According to the structure of the two sets of jobs, a solution that maximizes system utility can be particularly unfair to one of the agents. On the other hand, a fair solution may be inefficient in terms of system utility. For this reason, we are interested in solutions that incorporate some criterion of equity for the agents and, at the same time, are efficient from a global point of view. More precisely, we are interested in investigating the tradeoff between fairness and efficiency. To this purpose, given a measure of fairness, we model the problem as a bicriteria problem, where the objective is to maximize both the fairness and the overall utility of the agents. For this problem, we propose an efficient Branch & Bound algorithm where the upper bound computation is based on the solution of the Lagrangian Relaxation of two subproblems. Furthermore, we provide the results of an experimental study showing the viability of the combinatorial algorithm on instances up to 60 jobs.

Keywords: Multi-Agent Scheduling, System Utility, Fairness, Branch & Bound

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Crop rotation scheduling problems with sustainability constraints

Mario Benini[1], Paolo Detti[1] and **Luca Nerozzi**[1]

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In this work, we address the problem of planning the allocation of crops to arable land over a time horizon, taking into account crop rotation principles and diversification strategies promoted by sustainable agriculture initiatives. The problem consists in deciding the sequence of crops to plant over a finite number of seeding periods (i.e., the planning horizon) on each plot of a farmland, taking into account (1) that the profit and yield of a crop directly depend from the sequence of crops immediately preceding it on the same plot; (2) the incentives and requirements for sustainability defined by the PAC regulations of EU. In fact, monoculture schemes, in which the same crop is assigned to the entire farmland over the whole planning horizon, lead to a series of issues, such as loss of yield and soil fertility, increase of weed and pest diseases. In the literature, crop planning and rotation problems have received considerable attention from the operations management and agricultural economics communities, especially focusing on sustainability [1,3,4]. The problem considered in this work has been first addressed in [2], in which an ILP model is proposed and tested on real-world instances for different sets of sustainability constraints. Here, we present a novel arc-flow model able to optimally solve the crop planning problem, under different sustainability scenarios, with a substantial efficiency improvement compared to the model in [2].

For larger simulated instances, a column generation approach has been developed, in which the pricing problem is solved through dynamic programming. A computational campaign shows that the proposed approaches are viable to solve large problem instances.

Keywords: Sustainable Agriculture, Crop Rotation Planning, Column Generation

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Lower Bounds and a Constraint Programming Approach for Scheduling an Assembly Problem with Precedence and Resource Constraints

Andrea Corsini[1] and Mauro Dell'Amico[1]

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In this work, we delve into a real-life scheduling problem involving the production of off-road vehicles, subject to precedence, machines, and resource constraints. This scheduling problem shares characteristics with many others, but also comprises less investigated aspects like a specific precedence structure and a resource constraint limiting the number of simultaneously active machines. We formally present the problem and devise two lower bounds. To solve the problem, we propose a Constraint Programming model and compare it with a Mathematical Programming one. Our findings reveal the superiority of the Constraint Programming approach in both real-life and synthetic instances, and validate the quality of the proposed lower bounds.

Keywords: Scheduling, Constraint Programming, Mathematical Programming, Lower Bounds

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Robust parallel machine scheduling under short random interruptions

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Consider a parallel scheduling problem with m machines and n non-preemptive jobs with given economical values, to be completed within a given due date, say one day. Each machine may be subject to a random short interruption which, if occurs during a job, causes the failure of the job and loss of its value. The schedule of all the n jobs must be decided in advance, while the interruption time is communicated at time 0. Then, a recourse strategy can be adopted on the affected machine and its jobs rescheduled so that the least valuable job (or possibly no job at all) is lost. The more idle time on the machine, the better the chances for effective rescheduling. The resulting trade-off between job completion and idle time might also involve the activation of new machines, at some cost. We address a robust optimization problem aiming at minimizing both the economic loss caused by the failed jobs and the activation cost of additional machines. We provide an integer programming method and a computational study.

Keywords: Recoverable defects, Dynamic programming, Mixed integer programming

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Recycling Hub Demand-Driven Blind Vehicle Routing Planning for E-Waste Collection

Alessia Ciccarelli[1], Marta Flamini[2], **Maurizio Naldi**[2,3] and Elpidio Romano[1]

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E-waste collection is the first step in a circular economy approach where e-waste is recycled, refurbished or properly disposed. In some cases, the recycling process determines the amount of e-waste to be collected. We propose a blind algorithm for vehicle routing when collection must match the demand by the recycling hub, but it must proceed with no information about the availability of e-waste items at the collection stations. Through a simulation conducted on a real-world case in the city of Rome, we show that the demand satisfaction level can exceed 75% in more than 75% of the simulation instances.

Keywords: vehicle routing, e-waste, waste collection

Session: Predictive Methods

Tuesday September 10th 2:30pm - 4:30pm

Room Rocce

Chair: Caterina Fenu

Economic Fluctuations in Small Open European Union Economies during the COVID-19 Pandemics

Karol Szomolányi[1], Martin Lukáčik[1] and Adriana Lukáčiková[1]

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Our analysis explains the business cycle characteristics in the small open European Union Countries during the COVID-19 pandemic. The characteristics were identified by the statistical panel evaluation of the cyclical components of GDP and its selected items, labour, and average product of labour. The cyclical components were computed for all European countries. Data suggests that during the pandemic period from the second quarter of 2020 to the second quarter of 2021, the cyclical characteristics were similar to the pandemic cyclical characteristics observed by other world studies [1]. The economic volatility, including consumption and investments, was similar to other crises in small countries, even if the average product of labour was rather acyclical.

Our analysis used the open economy real business cycle model (MXN) presented by Uribe and Schmitt-Grohé [2] to explain the pandemic economic phenomena in small open European Union countries during the pandemic. The original theoretical model has been modified to allow applications of labour market shocks, total factor productivity shocks, and consumption shocks. Various adjustment investment costs and debt elasticity of interest spread are considered. The values and parameters adjusting the given shocks were calibrated so that the calculated theoretical moments corresponded closely to the observed cyclic characteristics. According to the results, short-term fluctuations in the model economy correspond to pandemic cyclical characteristics if shocks in terms of trade were applied in addition to the decrease in labour supply and increase in investment adjustment costs. In small countries, the model results suggest that trade shocks were more significant, investment adjustment costs were higher, and the elasticity of the interest spread increased. Financial frictions were higher in small European Union countries due to the pandemic.

Keywords: COVID-19 pandemics, European Union, small countries, business cycle, MXN model

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Generating Data of User Demands and Decision Makers using Large Language Model

Jiawei Chen[1] and Lei He[1]

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Reception and analysis of user demands are crucial for scheduling problems. Collecting and analyzing user needs is essential for profitability and better service. However, such data is often proprietary and confidential. Technology giants also face limitations in data availability for training accurate machine learning models for user demand analysis. To overcome this challenge, developers propose using artificially synthesized data, which is computer-generated or simulated data with artificial labels. By employing appropriate simulation methods, developers can obtain high-quality data with reduced noise and errors, enabling training of more accurate machine learning models. One of synthesis methods is the agent model-based method which utilize agent models simulating human behavior to generate synthetic data. Nowadays, Large Language Models (LLM) have shown capabilities in natural language processing tasks[1]. Therefore, LLMs have potentials in generating user demands and scheduling decision with a certain preference in natural language. As for user demand analysis, semantic analysis and keyword extraction are performed based on user needs. Scheduling problems involve demand generation, demand analysis, planning, scheduling, and simulation decision-making. LLM simulate demand generation and decision-making. A LLM can generate user requirements in natural language, analyse and organize them, accurately extract keywords, and generate observation task targets. Various techniques like evolutionary algorithms, heuristic algorithms, and reinforcement learning can be employed to solve such scheduling problem, resulting in different solutions. The decision-maker then selects a solution with preferences. An AI agent with LLM[2] can assist in this step. This simulation framework allows easy and effective creation of user demands and data of decision-makers for developing and training predictive and recommendation models efficiently.

Keywords: Scheduling Problems, Large Language Model, Natural Language Processing

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Probabilistic branch-and-bound for clusterwise linear regression

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Clusterwise linear regression,a supervised learning technique that aims at finding latent groups with distinct linear relationships, has numerous applications across diverse scientific and applied domains. However, it often leads to optimization challenges due to the combinatorial nature of the problem. This paper introduces pclustreg, a novel approach based on probabilistic branch-and-bound optimization that maximizes the log-likelihood of a Gaussian mixture model. We show that, under suitable conditions, pclustreg guarantees (with a user-defined probability $s < 1$) a solution with log-likelihood at least as good as the infeasible oracle estimator, which knows the true cluster assignments. Additionally, pclustreg can be used as a computationally lean heuristic, as showcased on simulated and real-world datasets.

Keywords: Clusterwise Regression,Mixed-Integer,ProbabilisticBranch- and-Bound, Maximum Likelihood Estimation, Gaussian Mixture

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On the distribution of the random risk under alternative loss functions

Fulvio De Santis[1], Stefania Gubbiotti[1] and **Francesco Mariani**[1]

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In standard statistical decision theory the average performance of a decision is quantified by the risk function, that depends on the parameter of the model. The risk function may be summarized by the Bayes risk, its average with respect to a prior distribution assigned to the parameter. However, the expected value might not be a good representative of risk's randomness. We here propose to study the whole distribution of the risk function and to report additional summaries such as the median and the mode. For the specific set up of point estimation of a normal variance, we provide closed-form expressions for expected value, cumulative distribution and density functions of the risk under quadratic loss. A simulation-based approach is proposed when closed-form expressions of the distribution and its summaries are not avalaible, for instance when alternative loss functions are considered. Finally, the problem of sample size determination is considered.

Keywords: Bayes risk; point estimation; prior distributions; sample size determination; statistical decision theory

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Infinite-dimensional moment-SOS hierarchy for nonlinear PDEs

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We present in [1] a new approach to a class of nonlinear partial differential equations (PDEs) based on a generalization of the moment-sum-of-squares hierarchy (see, e.g., [2]) to infinite-dimensional settings. We first reformulate the nonlinear PDE as a linear equation involving the moment functions of an occupation measure supported on the solution of the PDE. Then we exploit a recent result in [3] for the moment problem on the space of distributions to ensure the convergence of a hierarchy of finite-dimensional semidefinite optimization problems solving approximately the original infinite-dimensional problem. As an illustration, we present some numerical experiments for solving with our method the heat equation subject to a nonlinear perturbation.

Keywords: moment-SOS hierarchy, semidefinite programming, nonlinear PDE, polynomial optimization, moment problem

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Seriation analysis: bridging together numerical optimization and statistics

Silvia Columbu[1] and Caterina Fenu[1]

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Seriation is an ordering problem which seeks to find the best enumeration of a set of units. The solution is obtained through the minimization of a correlation function which reflects the desire of two units to be close in the sough sequence. In this talk, we will revise the existing literature focusing on the optimization, statistical and numerical analysis aspects of this problem.

Keywords: Network optimization, Seriation, Statistics

Session: Vehicle Routing 3

Wednesday September 11th 8:30am - 9:50am

Conference Center A

Chair: Renata Mansini

A Metaheuristic approach for a rich Routing and Scheduling problem in Home Healthcare

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Home healthcare (or simply homecare) refers to providing healthcare services and assistance to individuals in their homes rather than in a hospital or other healthcare facilities. Providing homecare services is an optimization problem involving scheduling and routing issues. We consider here the well-known formulation proposed by Mankowska et al [2], which comes along with a large and challenging dataset that has attracted the attention of many researchers (see e.g. [3]). Although this formulation is interesting and challenging from a computational point of view, it lacks some specific features that would make the problem more attractive in reality. For this reason, we introduce hereby an extended formulation that comprises additional real-world features, i.e., multiple departure points for caregivers, incompatibilities between patients and caregivers, and working shifts for caregivers. In addition, the objective function penalizes caregiver waiting times and overtime, and unbalanced workload distribution. For this novel formulation, we propose a new dataset and a search method based on Simulated Annealing (SA), obtained by extending our previous work on the original problem[1]. For the formulation obtained, we created a new artificial dataset by using real road distances and sampling the relevant locations, considering the area's actual population distribution. Our search method, properly tuned, has been tested on the new dataset, highlighting which are the most impactful components of the objective function. This is an ongoing work, which could be further extended by hybridizing SA with exact methods, bringing forth a matheuristic approach.

Sara Ceschia has been funded by the European Union - *NextGenerationEU*, under the project "Modeling and solving a real-world home healthcare routing and scheduling problem".

Keywords: Home Healthcare, Scheduling, Routing

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A multi-pickup and delivery problem with time windows for blood vials collection

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The problem addressed in this study involves efficiently collecting biological samples (such as blood vials) from collection centers and delivering them to associated analysis laboratories using dedicated vehicles. The problem is a challenging variant of the multi-pickup and delivery problem with time windows. Its key components include a fleet of vehicles, collection centers, and analysis laboratories. Vehicles start and end their shifts at the same depot. Each collection center has its own working hours and service times for pickups, with samples needing to be delivered to the designated laboratory within a specified time to prevent degradation. The delivery process at laboratories also has fixed service times. The degradation time imposes inter-dependent time windows. Each collection center is visited multiple times during the day, and the time window associated with a visit depends on the time at which the previous visit was performed.

In the literature, Doerner et al.[1] studied a very similar problem but considered just a single laboratory for the tests, instead of multiple laboratories as in our case. They proposed a model and different solution methods to optimize the pickup of samples with time windows dependent on dispatching policies.

In this study, we develop a mathematical model utilizing a multi-commodity formulation alongside a heuristic algorithm aimed at minimizing total routing costs. Both methodologies are then extensively computationally tested and applied to real-world instances for practical validation.

Keywords: Multi-pickup and delivery problem, Inter-dependent time windows, Mathematical model, Heuristic

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Evaluating the Fairness of the Distribution of Services: A Case Study of Green Urban Areas for Older People in Italy

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The improvement of quality of life and the evaluation of service distribution have become increasingly important topics in urban planning, particularly concerning the localization of green spaces. Green spaces offer numerous benefits, such as improved air quality, reduced heat island effect, and positive externalities, impacting the health of people, especially those with specific needs [1]. Fairness and walkability are essential for creating an age-friendly environment. In this context, we propose a general method to assess the fairness of services distribution for different age groups, paying particular attention to older individuals and their unique requirements [2]. By maximizing the positive impact achieved through the optimal placement of Nature Based Solutions, we propose a methodology to evaluate fairness, using kernel convolution and economic indices, such as the Gini coefficient [3]. We propose a detailed analysis of various aspects related to older people, and their unique needs.

Keywords: Fairness, Older People, Urban Greening

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Optimizing Attended Home Delivery: a Stochastic Multi-period Time Window Assignment Vehicle Routing Problem

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[2]Department of Information Engineering, University of Brescia

[3] Department of Mechanical, Energy and Management Engineering,

We study a multi-period stochastic variant of the Time Window Assignment Vehicle Routing Problem, as introduced in [1]. Our problem includes uncertainty in customer demands, locations, and service times. Customers are partitioned into geographical zones, each of which has to be visited a predetermined number of times over a planning period of several days. Whenever a zone is visited, a time window is assigned. Time windows are decided before knowing customers and their demands. A fleet of homogeneous vehicles is available to serve customers each day. At a tactical level, the problem looks for a time window assignment that minimizes the expected traveling costs plus the expected penalty costs for unserved customers. We propose a two-stage formulation and a solution approach, which relies on the Sample Average Approximation Method, while encompassing a perturbation method to assign time windows in the first stage and an Adaptive Large Neighborhood Search to optimize routes in the second stage. We conduct an extensive computational analysis on both synthetic and real instances from a Canadian retailer. Our method's performance is evaluated by comparing it to a lower bound derived from the exact solution of a deterministic equivalent formulation across a finite set of scenarios. Our method outperforms the manual approach used by the company.

Keywords: Time Window Assignment, Vehicle Routing Problem, Stochastic Programming, Sample Average Approximation Method

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Session: OPTSM 4 - Train Timetabling

Wednesday September 11th 8:30am - 9:50am

Conference Center B

Chair: Alessio Trivella

Analysis on the Fragility of Train Timetables

Marta Leonina Tessitore[1], Marcella Samà[1], Giorgio Sartor[2], Carlo Mannino[2] and Dario Pacciarelli[1]

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When looking at preventive approaches for disturbance management, the focus is on designing robust timetables that are able to absorb secondary delays. Following the recovery robustness approach [1,2], we use the concept of timetable fragility to analyze the resilience of a timetable, i.e., for measuring its ability to recover from primary delays with optimal corrective actions. We look at the recovery problem from the infrastructure managers' point of view. Given a timetable and suitable objective functions, the fragility defines a special class of scenarios associated with each pair train/section and use them to identify the pairs where a primary delay is more likely to generate large knock-on delays, thus allowing a more detailed analysis. In particular, the objective function should reflect real-time decision-making criteria adopted by dispatchers. Since no single, universally accepted measure exists, we explore some of the most common objective functions, e.g., the minimization of the max delay, or the minimization of the sum of consecutive train delays at the last station of their routes. Building on the concept of fragility maps, we propose additional analyses, including exploring the impact of precedence constraints in optimal dispatching and sensitivity analysis of the optimal solution. Considering real-life scenarios from a busy railway line in Norway, we discuss several potential uses of the fragility to improve decisions at different levels of the railway planning process, including dispatching, timetable design, and network design.

Keywords: Timetable Fragility, Robustness, Mixed-Integer Programming, Train Scheduling

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Passenger-oriented train timetabling and rolling stock scheduling on urban rail transit line: two-stage method vs. integrated process

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The planning process in urban rail transit is traditionally done hierarchically, following a top-down manner. This sequential process begins with network design, followed by line planning, train timetabling, and finally rolling stock scheduling and crew scheduling. However, this sequential planning method has been mentioned to be sub-optimal in the literature. To address this, integrated approaches, mainly relying on heuristics, are being explored to mitigate the gap between solutions at different stages.

This study focuses on optimizing train timetable and rolling stock schedule for urban rail transit line, embedding the time-dependent passenger demand within the mathematical model. Notably, the presence of an intermediate depot along the line and the consideration of different types of rolling stocks contribute to the increased complexity of the integration for train timetabling and rolling stock scheduling. Addressing the multifaceted challenges in the integrated problem, this study aims to optimize four sequential sub-problems: train timetabling, passenger assignment, rolling stock circulation, and rolling stock assignment. Through the numerical experiments of applying the proposed integrated formulation to real-world data from Chongqing Rail Transit, the properties of the exact formulation are discussed. Two-stage methods for different integration possibilities of sequential sub-problems are explored. Under identical computation configurations, experimental results show that the integrated solving process is not always superior to the two-stage method. By comparing the results of integrated solving and two-stage method, this study provides insights into the scenario and the size of the problem that the two methods are suitable for application.

Keywords: Urban rail transit, Train timetable, Rolling stock schedule, Integrated optimization, Sequential process

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Simulation-based optimization for energy-efficient urban rail timetables considering train movement disturbances: bridging theory and practice with real-world applications

Yongji Luo[1], **Lu Liu**[1] and Yushi Tang[1]

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Train energy consumption accounts for a significant proportion of total energy consumption in urban rail transit. Optimizing train timetables to reduce train energy consumption is one of the important ways for the sustainable development of urban rail transit. In terms of energy-efficient timetabling optimization, the main method is to adjust arrival and departure times of trains to reduce energy consumption during the section travel of the train or to increase the utilization of regenerative braking energy among adjacent trains. Although previous studies have achieved promising theoretical results, their practical applications have been limited. The main reason is the various disturbances that trains encounter during actual operations, leading to discrepancies between planned timetables and actual timetables, thus rendering the optimized energy-efficient timetables ineffective in practical scenarios. To address this issue, this paper constructs an energy-efficient timetabling optimization model considering disturbances in train operations, including fluctuations in station dwell times and speed adjustments under train delays. A simulation-based stochastic approximation algorithm is designed to solve this model. Based on the real-world data of Qingdao Metro Line 2 in China, numerical experiments are conducted and it is found that the energy consumption can theoretically be reduced by 8% to 10%. To further validate the effectiveness of our approach in practical scenarios, the practical applications were conducted on multiple lines in Qingdao, Suzhou and other cities in China. On different lines, the optimized energy-saving timetabling solutions were tested for periods ranging from one month to half a year. The application results show that without reducing service levels, the actual measured energy saving effects achieved 2%-8%. It can be seen that the actual measured result is lower than the theoretical experimental value and has a wider range of variation. To investigate the reasons, the characteristics of each line are analyzed and some interesting patterns are found. First, the energy saving rate is closely related to the degree of disturbances, with higher disturbances resulting in lower energy saving rates. Additionally, the energy saving rate is also related to energy-saving hardware devices installed along the urban rail line (e.g., regenerative braking systems, supercapacitors), with more installed hardware devices leading to lower energy savings from energy-efficient timetables. Our research not only advances theoretical understanding of energy-efficient timetabling, but also provides valuable insights for applications in practical scenarios.

Keywords: Urban rail, Energy-efficient timetabling, Simulation-based optimization, Real-world application

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Improving a railway timetable by implementing technologies for increased automation

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The capacity of many railway networks and corridors in Europe is highly utilized, but 'planning norms' such as headways and buffer times in the timetable are already optimized given the available infrastructure [1]. Thus, while maintaining high punctuality, planning norms in busy networks can only be further decreased by implementing new technologies for increased automation, such as Driver Controlled Operation (DCO), European Rail Traffic Management System (ERTMS), Automatic Train Operation (ATO), and Traffic Management System (TMS). For each of these technologies, investments are necessary, which would be too expensive to implement directly on a national level. Furthermore, since the technologies are relatively new, it is desired to first investigate the effects of the technologies on a small number of corridors before implementing them nationally. Consequently, we find the need for a tool that can assess the implementation of new technologies on different corridors and rolling stock and their effect on the timetable. To this end, we propose a novel railway timetable optimization model that extends the Periodic Event Scheduling Problem (PESP)[2, 3], by allowing the implementation of planning norm decreasing technologies under a budget constraint. Specifically, the model can choose what technologies to implement (DCO, ERTMS, ATO, TMS) on what corridors and train series such that the optimized timetable benefits the most. The model is tested on the Dutch national railway network and smaller sub-sections of it at varying input parameters. Numerical results show that the model can be solved efficiently for medium-sized instances and is able to use the available budget to implement planning norm decreasing technologies on specific corridors and train series. The proposed extended PESP-model can thus be used as a decision support tool for railway and infrastructure operators to determine which technologies should be implemented on which locations in a railway network.

Keywords: Timetabling, periodic event scheduling problem, railway technologies, railway automation

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Session: Scheduling 2

Wednesday September 11th 8:30am - 9:50am

Room Nautilus

Chair: Marcella Samà

Multi-Neighborhood Search for the Makespan Minimization Problem on Parallel Identical Machines with Conflicting Jobs

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We consider the problem of scheduling conflicting jobs on parallel identical machines, which is gaining increasing attention in the scientific literature [3,5]. Among the possible objectives, we consider the makespan minimization.

Our solution method is a Multi-Neighborhood Search approach guided by a Simulated Annealing metaheuristic, a setting that has recently shown its effectiveness on various scheduling and timetabling problems (see, e.g., [1,4]).

Our method employs an implicit solution representation based on a global ordering of the jobs, and three neighborhoods, Move, Swap, and 2-Opt, adapted from the vehicle routing literature. Neighborhood exploration is stochastic and it is based on a biased two-step random selection: first, a random neighborhood is chosen according to the relative probabilities, then, a move is uniformly drawn.

Our preliminary results show that our solver is capable to find many optimal solutions and to improve considerably the results over a constraint programming model [2], especially when the conflict graph is dense.

Keywords: Scheduling, Makespan, Conflicting Jobs, Multi-Neighborhood Search, Simulated Annealing

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Shutdown Maintenance Scheduling using Two-Stage Stochastic Programming with Endogenous Uncertainty

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We introduce the problem of maintenance scheduling across two consecutive maintenance plans which require plant shutdown. Due to budget, resource and time limitations, maintenance of some components needs to be postponed from the first shutdown to the second with the risk of costly failures in between. We minimise the total expected cost of maintenance and scheduling by developing a two-stage stochastic programming model. The first stage determines which components should be postponed, whereas the second stage determines whether these components undergo maintenance in the second shutdown based on the occurrence of a failure event. The probability of failure depends on the first-stage decision leading to a stochastic problem with endogenous uncertainty. We solve the model for randomly generated instances with a limited number of components to illustrate the complexity of the problem. We propose a strategy for the early detection of infeasible solutions and demonstrate its effectiveness through numerical results.

Keywords: maintenance scheduling, two-stage stochastic programming, endogenous uncertainty

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Solving a dynamic remote operations scheduling problem: a multi-level periodic predictive-reactive rescheduling policy

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We present an effective and efficient solution approach for addressing a dynamic scheduling problem encountered by a large international company. The company needs to assign projects to remote technicians and schedule the associated tasks over a shifting planning horizon while minimizing changes to the plans agreed upon with customers, as new projects and tasks arrive over time and need to be allocated within the existing schedule. This process must take into account technician skills, project families, task release dates, deadlines and precedence constraints, and the joint execution of common tasks requiring multiple technicians. We formulate the static problem as a mixed-integer linear program (MILP), aiming to minimize makespan in a parallel and identical machine system. Following the three-field notation by [1] we are interested in the $P_M \mid fmls, r_j, d_j, M_j, prec \mid C_{max}$ problem. To address the dynamic aspect, we propose a periodic predictive-reactive rescheduling policy [2] based on a rolling horizon approach [3], that focuses on generating a baseline schedule and then, in a periodical reactive way, "repairing" it to accommodate new incoming tasks. The rescheduling repair process involves a multi-level approach with four levels of adjustments to systematically integrate new information with increasing degrees of perturbation in the current schedule. To align with the company's goal of minimizing plan changes, we progressively attempt partial reschedules before resorting to full rescheduling. For instance, in the first level, no disruptions are permitted when integrating new arrival tasks, while in the fourth level changes in start times and assignments are admitted, but at the cost of a penalty. To assess scalability, we validate our algorithm using both real-world and synthetic instances, demonstrating its efficiency and effectiveness in reaching optimality in most cases. Additionally, we provide valuable managerial insights for the company.

Keywords: Dynamic Scheduling, Periodic Predictive-Reactive, Parallel and Identical Machines, Mixed-Integer Programming

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Computing Values at Risk of Complex Jobshops Makespan using Machine Learning

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This work deals with complex job shop scheduling problem (with releases, setups and blocking constraints) solutions represented by temporal activity networks. In this setting activities have incomplete and uncertain releases, processing times and sequence dependent setups durations. Such uncertainties are known to be bounded within some intervals. The effect of the uncertainties is that the realized makespan would be substantially worse than the computed value of the makespan, affecting the decision maker level of confidence in the given solution and the solution approaches used to find them. In the literature, few studies have been conducted on risk prediction on the delay or worsening of makespan. Only recently, an advanced methodology has been proposed [1] to evaluate quantile-based measures of risk for the makespan, i.e., the Value-at-Risk (VaR) and Conditional-Value-at-Risk (CVaR). This is a pseudo-polynomial procedure and its complexity quadratically grows with both the size of the network and the amount of uncertainty affecting it [2]. To bridge the gap between efficiency and reliability in the amount of time required by the solving process, we propose a machine learning-assisted approach to determine a rapid and accurate estimate of these risk indices based on specific features of the given network and leveraging data records of previous risk evaluations. These models could provide insights and quantify the risk of delay, aiding in informed decision-making, facilitating a proactive risk management. Computational experiments conducted on a wide set of benchmark instances validate the proposed approach and the accuracy of our estimates, allowing us to glimpse the relationship between the activity network representing a feasible schedule and the risk indices.

Keywords: Activity Networks, Job Shop Scheduling, Uncertainty Evaluation, Machine Learning

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Session: Decision-making

Wednesday September 11th 8:30am - 9:50am

Room Rocce

Chair: Antonio Sforza

Decision making in real life : What is wrong with expected utility

Jean-Charles Pomerol[1]

[1]Sorbonne Université, emeritus professor

This paper is devoted to practical decision making. In the first part we review the reasons why maximizing subjective expected utility (SEU) is not an adequate criterion for decision making. These reasons go back to Herbert Simon (1983) and his arguments against Olympian decisions and for *satisficing* decisions. In few words we have no credible information on the probabilities of the future events, we even don't know what will be the events in the far future. But the most important weakness of SEU is that the value space is essentially multidimensional. As Simon (1997) says "*In an important sense, all decision is a matter of compromise*". It's extremely reducing to try to curb the multidimensional space of your choice criteria to an one dimensional scale on $\mathbb{R}$. This exposes to all the drawbacks related to aggregation (Pomerol, 2000).

In the second part we focus one one-shot decision making which is very generally the case in practice, and the use of any kind of expected utility which fundamentally assumes that the game is played several time because the expected utility is an average. We return on the notion of lottery with examples and we show that the decision maker's strategy depends on the probabilities as well as the sum at stake. One issue in this setting is that people have generally a very bad representation of chance.

In the third part we discuss the maximin criterion for decision, in relation with the absolute value of the probabilities and we show that there is a kind of threshold around 10^{-3}, which separates prudent behavior from paralysis. We moreover relate this threshold with the so-called precautionary principle.

Finally we develop some other issues for practical decision making (Pomerol, 2023).

Keywords: Decision making, Expected utility, Risk assessment

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Cost-Benefit Analysis and Prescriptive Decision Tree Model for Planning Flood Risk Mitigation Measures

Jacopo Napolitano[1], Giovanni Maria Sechi[1] and Massimo Di Francesco[2]

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[2]Department of Mathematics and Computer Science, University of Cagliari, Cagliari, Italy

Hydrological extremes occurrences and urbanization trends generated flood disasters worldwide and motivated the need to set up adequate flood risk management plans. In the context of flood risk, the European Commission Flood Directive 2007/60 requires preliminary damage evaluations to estimate flood impact on the territories and recommends policy-makers to decide upon flood mitigation work construction and mitigation strategies implementation via a Cost-Benefit Approach (CBA) (Nas, 1996). Costs are related to each mitigation infrastructure and its maintenance over their life cycle. Benefits can be evaluated in terms of expected damage reductions (Napolitano et al., 2022). To perform a coherent comparison, the expected damages can be evaluated both in the current scenario (actual configuration) and in future scenarios after building mitigation works. This research integrates CBA with Prescriptive Decision Trees (PTDs) to optimize planning measures for a flood-mitigation problem. PTDs (Bertsimas and Freund, 2004) are logical and systematic ways to address a variety of problems involving decision making with a single criterion in an uncertain environment. The construction of the PDT starts from the list of possible decisions and the list of possible outcomes. Each decision step is represented by a decision or event node interconnected by arcs. The procedure for solving a decision tree is called backwards induction or folding back. The prescriptive decision tree is solved after the evaluation of the root node after all other nodes. The optimal solution identifies the best value of the selected criterion (NPV of benefit). By applying the proposed approach, we can detect among all the different scenarios the optimal decision strategy according to the chosen economical criterion. This methodology has been tested on a real case study located in the north Sardinia (Italy).

Keywords: Cost-Benefit Analysis; Prescriptive Decision Trees; Decision Analysis under Uncertainty

References

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A two-stage approach for the multiple suppliers purchase planning problem under uncertainty

Claudio Gentile[1], **Francesca Giancola**[1,2] and Sara Mattia[1]

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One of the most important topics in supply chain and logistics management is the optimization problem of purchase planning and supplier selection. This problem involves the optimal selection of suppliers and purchase planning to minimize overall costs while maintaining quality standards and meeting delivery requirements. One of the main issues when addressing this type of problem is the presence of uncertainty in the processes. In particular, in this work, we consider the case where suppliers' lead times are variable and subject to uncertainty. We define a two-stage robust model of the problem also describing an uncertainty set that is of interest in real-life applications. We propose an efficient algorithm based on Benders' decomposition method, with the development of a dedicated branch-and-cut technique.

Keywords: Supply chain, data uncertainty, robust optimization

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Teaching Mathematics from problems and phenomena with the modelling approach of the Operations Research

Andrea Mancuso[1], Adriano Masone[1], Claudio Sterle[1] and **Antonio Sforza**[2]

[1]DIETI - Dept of Information Technology and Electric Engineering/University Federico II of Naples
[2]OPSLab - Optimization and Problem Solving Laboratory/DIETI

The teaching of Mathematics plays a fundamental role in the teaching of STEM subjects in schools and universities. Its teaching must be placed in the general context of student education. It can be said that teaching is a chain that starts from the content of each discipline and develops through teaching strategies and forms of learning up to assessment. Based on this, the Operations Research group of the Department of Information Technology at the University Federico II of Naples has successfully experimented a teaching strategy addressed to teachers and high school students introducing curriculum topics in mathematics in a simple and engaging way, starting from problems and phenomena, and using the modelling approach typical of Operations Research. It is possible to build the different components of mathematical relationships (equations, inequalities, and functions) starting from data and variables, with their units of measurement. An equation or an inequality can indeed be assumed as a model, especially when they represent a simplified mathematical representation of a real-world phenomenon. Equations and inequalities serve as mathematical models when they describe relationships between data and variables, to predict, or simulate how different factors interact in a particular system. It is necessary to state that the numbers in relationships are the known and available data, and the variables are associated with the object of decision-making and the analysis of a phenomenon. Problem modeling is a valuable teaching approach in mathematics that involves presenting real-world problems or situations to help students understand and apply mathematical concepts and skills. This method not only enhances students' problem-solving abilities but also demonstrates the practical relevance of mathematics in everyday life. The proposed teaching strategy is based on some keywords. Among others: Reversal (from phenomena and problems to the definition of curricular topics) and Integration (among the various components of Mathematics, especially between Algebra and Geometry). This strategy has been experimented with commendable results in the school year 2022/23 in fifteen schools in the Campania Region as part of the OPS4Math project funded by the Ministry of University and Research (MUR) within the Call for the Diffusion of Scientific Culture, and in the school year 2023/24 in nine schools in the province of Naples as part of the Orientalife project of the Regional School Office of Campania Region.

Keywords: Problem Modelling and Solving, Teaching, Mathematics, Operations Research

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Session: Warehouse Optimization

Wednesday September 11th 10:00am - 11:00am

Conference Center A

Chair: Paola Festa

Branch-Price-and-Cut for Order Batching Problems in 2-Block Warehouses

Julia Wahlen[1]

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Given a set of customer orders, each comprising a list of items to be picked, the order batching problem (OBP) consists of grouping all orders into batches such that the total distance traveled to pick all items is minimized while respecting the pickers capacity and assigning each order to exactly one batch. We consider a rectangular warehouse with parallel aisles of equal length and width and three cross-aisles that divide the warehouse into two blocks. In this talk, the first branch-price-and-cut (BPC) approach for the OBP in warehouses with two blocks will be presented. The storage locations of the items and the routing strategy used by the pickers to traverse the warehouse are assumed to be fixed a priori. We consider exact [1] as well as heuristic [2] picker routing strategies. Starting from a set partitioning formulation of the OBP, the column generation pricing subproblem is modeled as a shortest path problem with resource constraints on a linear digraph and is solved with a dynamic programming labeling algorithm where bounding is used as an acceleration technique [3]. Strong valid inequalities are used to strengthen the formulation and dedicated separation heuristics are employed. Ryan and Foster branching is applied to finally ensure integer solutions. Preliminary computational results of our BPC on benchmark instances from the literature [4] are promising.

Keywords: Order Batching, Picker Routing, Branch-Price-and-Cut

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Enhancing the Order Picking Process through Simulation and Optimization

Francesca Guerriero[1], Pasquale Legato[1], Giusy Macrina[1] and **Rina Mary Mazza**[1]
[1]University of Calabria, Italy

Order picking is the most labour, time-consuming and cost-intensive process in warehousing [1]. Besides its very own policies and practices, it is also affected both upstream from space allocation decisions and downstream by order reception and organization. As a result, the problems connected to planning and carrying out order picking operations can be dealt with by adopting a holistic-based approach offered by a proper decision support system. We propose a simulation-based optimization framework that benefits from mathematical programming models for the storage location assignment problem (SLAP) and the order picking problem, modelled as a variant of the Traveling Salesman Problem, i.e., the Picker Routing Problem (PRP) [2]. Then, simulation is used to mimic the overall order picking process occurring in a real distribution center. Preliminary numerical experiments are presented for different storage configurations and order picking strategies. Useful managerial insight follows scenario analysis in a rack-based warehouse featuring man-abroad vehicles that travel horizontally across the aisles according to an S-shape routing policy.

Keywords: simulation-optimization, order picking, warehousing

References

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Good suboptimal solutions for the optimization of automated warehouses

Daniele Ferone[1] and **Paola Festa**[1]

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The attention of this work is enhancing the efficiency of automated warehouses within the cosmetic industry [1]. The automate warehouses are responsible for storing items like colors, pigments, and bulk products, all contained in identical boxes. When processing a production order, the corresponding bill of materials is transmitted to the weighing unit, situated in close proximity to the warehouse. Subsequently, the required components are retrieved by transporting the respective boxes to the weighing unit using a conveyor and an Automated Guided Vehicle system. The same means are employed to return the used boxes to their designated locations within the warehouse. The storage arrangement involves boxes positioned on both sides of a rail, which supports a crane. Along the rail, there are H available locations. The crane moves to access these locations during a trip, defined as the sequence of movements between two consecutive visits to the origin.

The crane must perform pickups to supply the required boxes and deliveries to return the used boxes to their designated locations. Pickup operations can occur in any order, as there is no precedence constraint among components in a bill of materials. Conversely, the order of returning used boxes is determined by the weighing unit and cannot be chosen in the warehouse; the crane processes incoming boxes in the order they arrive.

Consequently, the optimization algorithm takes into account a set of pickup orders, a sequence of deliveries, or a combination of both in its input. We propose a GRASP [2] to address the $q/1/\mathrm{PD/F}$ problem, with $q \geq 2$. In this version, both pickups and deliveries must be performed, the crane has a capacity of q, and the locations are fixed. The objective function is to minimize the total distance required to fulfill all pickups and deliveries.

Keywords: Scheduling, GRASP

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Session: OPTSM 5 – Passenger-oriented Public Transport

Wednesday September 11th 10:00am - 11:00am

Conference Center B

Chair: Bianca Pascariu

Passenger-centered Disruption Management of Multimodal Networks

Christopher Szymula[1] and Nikola Besinovic [1]

[1] "Friedrich List" Faculty of Transport and Traffic Sciences, Chair of Railway Operations, Technische Universität Dresden

The behaviour and performance of long-distance transportation networks prove crucial, as long-distance traffic volumes continue to increase all over Europe (s. EC2023). This does apply for regular operations but also under the impact of disruptions. The disrupted network performance becomes even more important with regards to recent ambitions of multimodal integration (s. EU2020), as the resulting interconnectedness can provide chances of additional counter measures but also adds the risk on propagating disruption effects across multiple modes and networks. To assess the impact of multimodality in the disruption context, we propose the passenger-centered multimodal disruption management model (MDMM), which adjusts the services of multiple modes for a given disruption scenario to minimize the adverse effects on travelling passengers. To tackle this challenging task, we leverage the power of mixed integer programming to model passenger flows, service adaptations of different modes and the corresponding infrastructure constraints. By combining the model with column- and row generation into the iterative multimodal disruption management framework (MDMF), we provide optimal service adjustments, the corresponding timetables and the resulting passenger flows to encounter the given disruptions. The performance of the framework is demonstrated on a real-life case study, which combines aircrafts and long-distance railways. The results show, that multimodality has a clear impact on the networks capabilities to encounter disruptions and also to the spread of the corresponding effects. However, we also show that mode-specific properties remain important for the performance of disrupted networks.

Keywords: Network, Disruption Management, Multimodal

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Designing an optimized fueling infrastructure for a hydrogen-powered railway system

Alessio Trivella[1], **Amina Balha**[1] and Daniela Guericke[1]

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Motivated by a collaboration with a governmental institution in the Netherlands, we study the upgrade of a diesel-powered railway network to a hydrogen-powered network [1,2]. Specifically, we consider the problem of designing an efficient hydrogen fueling infrastructure, which involves choosing: (i) what rail yards in the network to use for fueling operations, (ii) how to allocate trains to these yards, (iii) where to locate hydrogen storage and (iv) fueling stations (which can be of different type), and (v) how to connect the latter two sets of facilities via pipelines. This problem is key in the deployment of hydrogen railway systems, and requires careful planning to avoid oversizing costly fueling infrastructure while accounting for track availability at yards and operational costs due to fueling operations [3,4]. To tackle this novel problem, which has the structure of a nested facility location problem, we provide a mixed-integer linear programming formulation to minimize the total annualized investment and operational costs. Our model can solve to optimality small instances but is intractable for our real case study. Thus, we devise a two-phase decomposition approach: A first phase decides on the yards to use for hydrogen fueling and train allocation, and a second phase optimizes, independently for each rail yard, the location of hydrogen storage, fueling stations, and pipelines. Both phases can be solved optimally with a commercial solver and iterated via a feedback loop. Numerical experiments on a real case study in the Netherlands show the effectiveness of the developed approach and provide insight on the optimal infrastructure design.

Keywords: Railway system, hydrogen trains, fueling infrastructure, mixed-integer programming, decomposition

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Integrated demand and supply simulation for realistic assessment of rail traffic management optimization

Bianca Pascariu[1], Grégory Marlière[1], Georges Sfeir[2], Johan Victor Flensburg[3], Federico Naldini[1], Filipe Rodrigues[2], Paola Pellegrini[1] and Carlos Lima Azevedo[2]

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Several algorithms have been proposed for optimizing rail traffic management in case of perturbation. However, their assessment often overlooks modeling assumptions. Realistic evaluations are essential to ensure theoretical solutions match practical feasibility and performance.

Our research introduces a modular framework for evaluating the performance of rail traffic management algorithms in a realistic context. It integrates the demand with passenger simulation and behavioral models, and the supply with rail traffic simulation and control models.

We propose the integration of passenger simulation in the rail traffic simulator OpenTrack [3] via an Application Programming Interface (API). The passenger simulation includes a random utility route choice model, where passengers select paths through Monte Carlo simulations and the utility of each path alternative, previously estimated using observed choices. Trains are realistically simulated in OpenTrack, and historical distributions of traffic perturbations are applied via the API. When train delays increase, the API triggers passenger rerouting: depending on the current and planned traffic evolution, passengers decide whether to stick to their original plan or choose a different option. This mimics realistic decisions, where passengers react to updated traffic information. We then propose the periodic exchange between the simulation and the traffic control optimization algorithm to be assessed in close-loop [1]. The latter receives information on the current status of traffic and passengers and provides train routing and scheduling decisions to implement.

We validate the proposed framework using different passenger and traffic scenarios in a suburban sub-network of Copenhagen. We consider different variants of an optimization algorithm [2], with train delay minimization as sole objective, and including passenger delays, where the optimization is augmented with a passenger demand prediction module.

To our knowledge, this is the first proposal of such a realistic framework involving a complex and realistic rail traffic simulator.

Keywords: Real-time rail traffic management, Passenger railway optimization, Train and passenger simulation

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Session: Decomposition Methods

Wednesday September 11th 10:00am - 11:00am

Room Nautilus

Chair: Enrico Gorgone

Benders Decomposition for the Discrete Ordered Median Problem

Ivana Ljubić[1], Miguel A. Pozo[2,3], Justo Puerto[2,3] and Alberto Torrejón[2,3]

[1]ESSEC Business School of Paris, France

[2]Department of Statistics and Operational Research. Faculty of Mathematics, University of Seville, Spain

[3]Institute of Mathematics of the University of Seville, Spain

The Discrete Ordered Median Problem (DOMP) is a well-known facility location problem where p-facilities are to be located so that customers are first ranked according to their allocation cost to the nearest open facility, and then these costs are multiplied by a suitable weight vector λ. The goal is to decide which p facilities to open, so that the sum of "λ-weighted" allocation costs is minimized. That way, DOMP generalizes many well-known discrete location problems including p-median, p-center or centdian. In this article, we also allow negative entries of λ, allowing us to derive models for better addressing equity and fairness in facility location, for modeling obnoxious facility location problems or for including other client preference models.

We present new mixed integer programming models for DOMP along with algorithmic enhancements for solving the DOMP to optimality using mixed integer programming techniques. Specifically, starting from state-of-the-art formulations from the literature (see Labbé et al., 2017 and Marín et al., 2020), we present several Benders decomposition reformulations applied to them. Using these approaches, new state-of-the-art results have been obtained for different ordered weighting vectors.

Keywords: Discrete location; Ordered median optimization; Benders decomposition, Branch-and-Benders-cut

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PathWyse 1.0: a software library for the Resource Constrained Shortest Path

Matteo Salani[1] and Saverio Basso[1]

[1]Dalle Molle Institute for Artificial Intelligence (IDSIA), USI-SUPSI, Lugano, Switzerland

In this work, we present the release 1.0 of *PathWyse*, a flexible, dual-licensed library dedicated to the Resource Constrained Shortest Path Problem (RCSPP), a fundamental and hard combinatorial problem.

PathWyse is capable of modeling and solving a variety of standard RCSPPs with an off-the-shelf implementation of state-of-the-art algorithms. The library provides C++ and Python interfaces, streamlining the process of modeling custom problems with minimal coding effort.

From an algorithmic standpoint, the current release introduces parallel implementations of both exact and heuristic algorithms. Notably, heuristic algorithms are orchestrated within a competitive ensemble framework, enhancing their efficacy. Additionally, this release showcases an upgraded bi-directional dynamic programming approach in which the join procedure, typically a time-consuming component of the algorithm, now leverages binary search and Pareto frontier exploration, contributing to significant performance enhancements.

We conducted computational experiments using instances drawn from existing literature, encompassing scenarios featuring a singular resource constraint across cyclic networks and large acyclic networks. We also present findings related to instances with multiple resource constraints within cyclic networks. Our framework's adaptable parametrization demonstrates the ease with which users can efficiently model and resolve multi-constrained problems. To facilitate understanding and implementation, we offer a tutorial on integrating a column generation algorithm, employing PathWyse as the solver for the pricing problem. Finally, we introduce a novel benchmark dataset composed of large acyclic networks with multiple resources.

Keywords: Resource Constrained Shortest Path, Software Library

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Lagrangian Relaxation for the Intermediate Facilities Location problem

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[2]Dipartimento di Ingegneria dell'Energia Elettrica e dell'Informazione "Guglielmo Marconi", Università di Bologna

For transportation companies the consolidation of freight and merging operations is crucial in order to reduce costs and keep the level of service provided to customers, especially when trucks travel with a half load. These kinds of operations take place in intermediate facilities or terminals located between the origins and the destinations of freight. We consider the problem to locate the intermediate facilities in a transportation network, which gives rise to a combinatorial problem.

We address the problem through the Lagrangian decomposition. The Lagrangian dual is solved by efficient non-differentiable optimization methods and the sub-problem (the Lagrangian relaxation) is reduced to a binary knapsack problem. The proposed method is tested on randomly generated instances obtaining a tight lower bound. In addition, we develop a Lagrangian-based heuristic to attain an integer feasible solution. Preliminary numerical results are reported, compared with those of the state-of-the-art Branch & Bound algorithm.

This study was carried out within the MOST – Sustainable Mobility National Research Center and received funding from the European Union Next-GenerationEU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) – MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.4 – D.D. 1033 17/06/2022, CN00000023). This manuscript reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.

Keywords: Lagrangian relaxation, Non-differentiable optimization

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Session: Timetabling

Wednesday September 11th 10:00am - 11:00am

Room Rocce

Chair: Andrea Bettinelli

Enhancing Time Slot Efficiency in Scientific Conferences by Employing Latent Dirichlet Allocation

Luca Frigau[1]

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Organizing a scientific conference is challenging, especially in defining the scientific program. Despite generally the members of the program committee have experience in that task, it is expected that unforeseen problems come to light. In medium-large conference, the scientific program requires the inclusion of parallel sessions both to limit of the conference's duration and to offer specialized talks at each time. On the other hand, to run more sessions in parallel may cause potential topic overlapping, forcing the participants to choose what attend between more sessions of interest.

Usually, organizing conference sessions and assigning them to specific time slots is a task carried out by the members of the program committee, and consequently it is quite a manual, time-consuming, and subjective process. Since human beings are involved, several mistakes can happen because of the many possible solutions and various constraints, like room availability and scheduling conflicts for participants with multiple roles.

To overcome these problems, we have proposed an automated and flexible strategy for planning scientific meetings. This approach uses Latent Dirichlet allocation and optimal scheduling to minimize topic overlapping between parallel sessions in order to make the organization more efficient and reduce errors caused by manual intervention.

We tested our efficient allocation approach using real data concerning conferences of different dimensions demonstrating its effectiveness.

Keywords: Conference, Topic modeling, Optimization, Parallel sessions

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A Stochastic Programming Approach for the University Examination Timetabling Problem with Uncertain Time Slot Capacity

Sara Ceschia[1], Daniele Manerba[2], Andrea Schaerf[1], Eugenia Zanazzo[1] and **Roberto Zanotti**[3]

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[3]Department of Clinical and Experimental Sciences, University of Brescia, Brescia, Italy

The Examination Timetabling (ETT) problem [1] has long been the subject of extensive research, with the primary goal of efficiently assigning university exams to time slots while preventing overlaps for students with common exams. The objective is to maximize the spreading of the exams over the time horizon to obtain a more sustainable timetable for the students. This work starts with the original uncapacitated version [2] and departs from it by introducing capacity constraints that limit the number of exams per time slot. To enhance the realism of the model, we consider the capacity in each time slot as a random variable. This stochastic variant is first formulated as a two-stage Stochastic Programming problem where recourse actions consist in rescheduling exams in successive time slots or moving students to spot-market rooms. Then, we conduct an in-depth analysis of the impact of uncertainty on solutions using a deterministic equivalent Mixed-Integer Programming formulation. Additionally, we propose a Progressive Hedging (PH) approach, leveraging a specialized optimizer [3] to address the computational challenges posed by the stochastic nature of the problem. Preliminary results on real-sized instances are promising, underscoring the significance of accounting for stochasticity in the problem formulation.

Keywords: University Examination Timetabling, Stochastic Programming, uncertain capacity

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A Mixed-integer Linear Program to create the shifts in a supermarket

Nicolò Gusmeroli[1] and **Andrea Bettinelli**[1]

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The shift design and the personnel scheduling problem is known to be a difficult problem. It is a real-world problem which has lots of applications in the organization of companies. Solutions are usually found by dividing the problem in two steps: first the shifts are created, then the employees are assigned to them by respecting a bunch of constraints. The assignment of different tasks increases the complexity, since we have to consider the skills of the single employee necessary to perform any activity. In this paper we present a mixed-integer linear programming formulation which models together the shift creation and the construction of rosters for employees, with the objective of minimizing the amount of uncovered demand. Finally we provide the results for three real-world instances, confirming that this approach is promising.

Keywords: Scheduling, Combinatorial optimization, Mixed-integer Linear Programming

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Plenary: Antonio Frangioni

Wednesday September 11th 11:30am - 12:30pm

Conference Center A

Chair: Massimo Di Francesco

Improving collaboration in optimization: an imperfect proposal

Antonio Frangioni[1]

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Our task as developers of optimization-based solutions is arduous. Powerful general-purpose solvers allow to solve hard problems with unprecedented efficiency by harmoniously coordinating several different algorithmic concepts, harnessing decades of developments in mathematics, algorithms and computer science. Yet, applications demand the solution of problems of ever increasing size and complexity, which—barring unexpected breakthroughs—will always be out of reach of systems that do not exploit all the available forms of structure, as it is most often the case with general-purpose ones. This has always motivated a vast amount of research in approaches that harness "the main properties" of one's problem at hand, using a myriad of classical and innovative techniques (QC and AI coming to mind for the latter), often with excellent results. However, too few of these improvements, the results of years of effort by talented researchers, ever become widely available for the solution of other problems that share the given structure, but only as one among the many. One of the factors motivating this shortcoming is the lack of optimization software systems that really embrace the concept that solution methods to very difficult problems require the rather complex arrangement of several different individual components (parts of the problem and corresponding solution approaches), each of which being the nontrivial software implementation of sophisticated algorithms, possibly recursively. I describe an ongoing attempt at designing and implementing such a system, providing a few examples of its successful application to very demanding problems. This is as much a community building effort as it is a software project, in that the usefulness of the system would only be fully realised if it actually succeeded in significantly improving the collaboration between optimization software developers across academia and industry. There are many barriers to be overcome for this to have a chance at happening, which I will point out in the hope of spurring the debate on what software systems for optimization we would like to have and how we could eventually succeed in producing them.

Session: Clustering, Knapsack & Packing

Wednesday September 11th 2:30pm - 4:10pm

Conference Center A

Chair: Stefan Irnich

Complexity results on the Bi-level Interdiction Knapsack Problem with unit costs

Alberto Boggio Tomasaz[1], Margarida Carvalho [2], Roberto Cordone[1] and **Pierre Hosteins**[3]

[1] Università degli Studi di Milano, Milan, Italy

[2] Universitè de Montréal, Montréal, QC, Canada

[3] Università degli Studi di Torino, Turin, Italy

In this contribution we pursue the study of the Bi-level Interdiction Knapsack Problem, where a leader interdicts some knapsack items subject to a budget constraint in order to maximally reduce the total profit of the Knapsack Problem that the follower solves on the remaining items. We study the computational complexity of the problem when the leader's interdiction costs are unitary and prove that the problem remains Σ_2^p-complete using a reduction from the bi-level 3-SAT problem. Additionally, we prove that the version with unitary lower level weights but arbitrary interdiction costs is NP-complete.

Keywords: Bi-levelKnapsack, Polynomial hierarchy, Interdiction, Stackelberg game

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On mines, flows and investments: a new algorithm for the precedence constrained continuous knapsack problem

Valerio Dose[1], Fabio Furini[1] and Marco Locatelli[2]

[1]Sapienza - Università di Roma
[2]Università di Parma

Imagine a student who must obtain a certain amount of credits to graduate and needs to choose which courses to take. Naturally, they would like some of them more than others, but it may be the case that to attend a course they are required to complete also some of the less preferred ones. Thus, what is the best plan to employ?

This is an example of a precedence constrained knapsack problem in combinatorial optimization. In this talk we will introduce some continuous relaxations of this problem which have applications in the mining industry, and can be suitably used to model other investment planning problems.

We will present a new algorithm to compute a solution, which is devised studying the behavior of the classical primal simplex algorithm when applied to the LP formulation. This reveals one of the very few examples of a simplex algorithm with an underlying combinatorial structure.

Keywords: knapsack, precedence, maxflow, mining

An adaptive exact algorithm for the hyper-rectangular clustering problem with axis-parallel clusters

Diego Delle Donne[1] and Javier Marenco[2]

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[2]Escuela de Negocios, Universidad Torcuato Di Tella, Buenos Aires, Argentina

Given a set of points in the space of an arbitrary (but fixed) dimension, the hyper-rectangular clustering problem with axis-parallel clusters (HRC-AP) consists in grouping the points into clusters, in such a way that each cluster is determined by a hyper-rectangle in the corresponding space. HRC-AP has been proposed as a model for explainable clustering [1], as it is straightforward to describe the obtained clusters by the bounds defining each hyper-rectangle. In this context, if each coordinate corresponds to a relevant parameter in the application generating the given points, then clusters are specified by a lower and an upper bound on each parameter, and this is easier to communicate than a distance-based clustering. Previous works from the literature have taken advantage of this feature of axis-parallel hyper-rectangular clustering [3,5,6].

A variant of HRC-AP considering the existence of outliers (called HRC-APO), allows a certain number of points to be discarded and not included in any cluster. In previous works [2,4], we explored integer programming techniques for HRC-APO proposing several formulations and algorithms. We showed that extended formulations (solved via branch-and-price) outperformed classical compact formulations. Nevertheless, these techniques fall short as soon as the number of points to be clustered is increased to medium-sized real-life instances.

In this work we propose an adaptive exact strategy which takes advantage of the capacity to solve small instances to optimality of our previous approaches. Our algorithm starts by solving an instance with a small subset of points and iteratively adds more points if these are not covered by the obtained solution. We prove that as soon as a solution covers the minimum number of points needed for the instance, then the solution is actually an optimal solution for the original problem. We compare the efficiency of the new method against the existing ones with an exhaustive computational experimentation.

Keywords: hyper-rectangular clustering, axis-parallel, outliers, adaptive exact algorithms

References

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Two-dimensional irregular knapsack problem with defects from a dynamic textile environment

Thiago Alves de Queiroz[1,2], Layane Rodrigues de Souza Queiroz[1,2], Manuel Iori[2] and Dario Vezzali[2]

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The production of clothing, garments, footwear, and other related goods involves cutting fabric and leather rolls. High-quality goods must be free of defects, and the cutting process must be optimized to improve all stages. The problem emerges from a dynamic textile production environment in which a large object is first scanned for defective areas and then cut into smaller irregular items free of defects. The time to define the cutting pattern is short and depends on knowing the defects first. This paper proposes an iterated local search-based heuristic as a solution method to the two-dimensional irregular knapsack problem, which is an NP-hard problem. The algorithm starts by generating an initial random solution, which is then improved using perturbation and local search operators based on swap and insertion moves. Items are positioned in the large object with the bottom-left positioning rule. Experiments are conducted on instances from the literature, evaluating the solution quality for different time limits. The algorithm achieves satisfactory solutions from as early as a 30-second time limit, occupying an average of 75.63% of the object area. The occupied area increases as the time limit increases, reaching 77.78% on average for a time limit of 120 seconds.

Keywords: Two-dimensional knapsack problem, irregular items, defective area, iterated local search

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Exact and Heuristic Solution of Irregular Packing Problems

Stefan Irnich[1], Laura Lüke[1] and Jeanette Schmidt[1]

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We consider two-dimensional irregular packing problems where a set of irregular pieces (a.k.a. items) must be packed into larger rectangular or irregular containers (a.k.a. bins or boards) minimizing the number of bins used or minimizing the material waste. A recent survey [3] highlights that nesting problems, i.e., finding a feasible placement of a set of pieces in a single bin have been widely studied. Solution methods use concepts such as raster points, direct trigonometry, no-fit polygons, and (quasi) phi-functions. However, the integrated problem of clustering pieces and nesting each cluster has not been studied intensively.

We use a column-generation-based algorithm to solve the irregular packing problem. The master program is a (set) covering problem of Gilmore and Gomory type [2]. The subproblem (a.k.a. column generation or pricing problem) is the problem of finding a nesting/packing with maximum profit. The novel solution approach that we propose is to first relax the (practically) hard subproblem into an easier *bounded knapsack problem* (BKP). Using a Benders decomposition approach, each BKP solution gives the set of items and their multiplicity, and requires solving a nesting problem to test whether it is feasible or not. In case of infeasibility, no-good cuts are added to the Benders master, which becomes an extended BKP. Depending on the type of nesting algorithm, being either exact or heuristic, the linear relaxation of the master problem can be solved exactly or heuristically. By reapplying the no-good cuts in subsequent pricing iterations, the consistency of the overall column-generation approach can be ensured. In addition, exhaustive tree search and diving heuristics can make the entire branch-and-price an exact algorithm or a matheuristic. We present computational results for irregular packing problems using a representation with raster points.

Keywords: Packing, irregular shape, branch-price-and-cut

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Session: OPTSM 7 - Railway Transportation

Wednesday September 11th 2:30pm - 4:10pm

Conference Center B

Chair: Paolo Ventura

Multi-period railway timetabling to match time-dependent demand

Renate J. H. van der Knaap[1], Niels van Oort[1] and Rob M. P. Goverde[1]

[1]Delft University of Technology, Department of Transport and Planning

The demand for passenger railway services varies throughout the day. Usually there is a peak period at the beginning and end of the workday in which many people go to or return from work or school. Outside these peak periods the passenger volumes are much lower, and more people travel for leisure purposes. Nevertheless, in many European countries a fixed line plan and cyclic railway timetable is used, which is the same for every hour of the day. Benefits of such a timetable are that they are easy to remember for passengers and that people travelling outside the peak hours still have many options for their trip. However, one disadvantage is that these line plans and timetables are usually based on peak hour demand. Since people who travel outside the peak hours usually have different travel purposes and therefore destinations, this service plan is not optimal for passengers in the off-peak. In previous work of the authors, a mixed-integer linear programming (MILP) model was proposed to create a multi-period line plan, where an optimal line plan was created for each predefined period with homogeneous demand [1]. Here, we extend this work by presenting a MILP model for creating a timetable for the multi-period line plan. In multi-period timetabling, a cyclic timetable is constructed for each period with homogeneous demand and its own line plan. In addition to the regular constraints for cyclic timetabling, multi-period timetabling should consider two additional requirements. First, special attention is needed for planning the transition between two periods. Second, we want to maintain as much regularity during the day as possible. So, if there is a line that is contained in the line plans of several periods, we want to deviate the departure and arrival times as little as possible. We will present the prosed model and some preliminary results of a case study based on real data of part of the Dutch railway network.

Keywords: timetabling, time-dependent demand, railway, mixed-integer linear programming

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Continuous-time Conflict Based Search for Real-time Train Dispatching

Bjørnar Luteberget[1], Carlo Mannino[1] and Paolo Ventura[2]
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Deviations from pre-planned timetables happen often in railway operations, and it is a computationally challenging task to make real-time scheduling and routing adjustments that minimize the overall delays in the railway network. Most of the successful exact optimization approaches for real-time train dispatching are based on Big-M or time-indexed MILP formulations, and typically assume either limited routing choices or small-scale networks. We show how to adapt Conflict Based Search[1] from the path-finding literature to real-world train dispatching problems to handle dispatching in larger networks with comprehensive routing choices. This is a decomposition approach where each train is scheduled as a shortest path problem, and a tree search algorithm handles conflict resolution between trains. The advantage of this tree search is that moving from a tree node to one of its child nodes only requires solving a shortest path problem for a single train. We present computational results on problem instances from Oslo Central Station and from freight railways in the US.

Keywords: train dispatching, branch and bound, shortest path, conflict based search

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A Continuous Rolling Horizon approach for real-time train dispatching

Luca Annese[1] Maurizio Boccia[2] **Veronica Dal Sasso**[1], Leonardo Lamorgese[1], Carlo Mannino[3] and Paolo Ventura[1]

[1]Siemens Mobility, Roma
[2]University of Naples Federico II, Napoli
[3]Sintef and Siemens Mobility, Oslo, Norway

In recent years Automatic Traffic Management Systems (A-TMSs) are gaining more and more importance in the railways context. One of the main attractions of an A-TMS is the capability to embed a software which produces, in real-time, an optimized plan for the trains on a railroad. In this context, we developed an algorithm that provides routing and scheduling choices to minimize the delay of trains at their destination. The proposed algorithm takes inspiration from the Rolling Horizon approach (see, for example, [2]) and is based on a branching tree exploration, where at each branching node a decision needs to be taken, either a routing choice or a way to resolve a conflict between a pair of trains (a conflict is identified whenever two trains try to occupy the same resource at the same time). The current solution at a node is represented by a dispatching graph. Each routing choice taken in a child node extends the path assigned to a train in the parent node, up to the next routing choice that will be found. Each conflict, instead, is modeled with disjuncive arcs (see [1]) and it is translated into the selection of one arc to be added to the dispatching graph. The schedule is then computed as the longest path tree on the dispatching graph.

As the solution space increases exponentially with the increase of the instance size, both in terms of number of trains and number of routing choices, it is not possible to explore all the branching tree in a small amount of time, which is instead a crucial point for real-time applications. Hence we developed a smart way of exploring the tree, so that we are able to obtain a good solution after just a few seconds. Computational results are shown on a set of realistic instances.

Keywords: Real-time train dispatching, Branching Tree, Continuous Rolling Horizon

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Detecting Deadlocks on a Railway Line

Gianpaolo Oriolo[1], **Anna Russo Russo**[2] and Paolo Ventura[3]

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In the context of rail transportation, deadlocks occur when two or more trains are stalled because their placement prevents each of them from moving forward [3, 4]. Given a line, that is a sequence of parallel tracks, and a placement of trains moving in both directions on the tracks, we focus on the problem of deciding whether it is possible to free the line or, vice versa, any possible sequence of train movements will eventually result in a deadlock. It is known from the context of packet-switching networks that the problem is NP-hard for more general network layouts [1].

Besides some polynomial algorithms working under special assumptions [3, 4], it follows from [2] that the problem can be solved in polynomial time on a line when the number of parallel tracks for each segment is *at least 2*. We side the latter result with the a combinatorial algorithm that solves the case where the number is *at most* 2. Our algorithm requires new tools and we indeed conjecture that it can be extended for solving, still in polynomial time, the general problem, i.e., for any number of parallel tracks.

Keywords: rail transportation, combinatorial algorithms, deadlock detection

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A new solution method for the Railroad Blocking Problem

Valerio Agasucci[4], Veronica Dal Sasso[1], Giuseppe Matera[1] , Leonardo Lamorgese[1] ,Carlo Mannino[3] , Andrea Onofri[1] , Gianpaolo Oriolo[2] , Anna Russo Russo[2] and **Paolo Ventura**[1]

[1]Siemens Mobility, Rome, Italy
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[3]Sintef and Siemens Mobility, Oslo, Norway
[4]Banca d'Italia, Rome, Italy

The *Railroad Blocking problem* consists in optimizing the movements of shipments, that in the following are called *commodities*, over an underlying railroad network by defining a suitable *blocking plan* ([1], [2]). Constructing optimized blocking planes is a major issue for a class 1 US railroad company, that ships millions of cars over its network annually.

In this context, each commodity is made up of a set of *cars* that need to be dispatched from an *origin* yard to a *destination* yard over the railroad network. While travelling from origin to destination, commodities will pass through several *classification yards*, i.e., yards where they will be handled for *classification* purposes, being sorted and grouped in order to be placed on different outgoing trains.

The classification process is labor and capital intensive and delays the movement of commodities. To prevent commodities from being classified at every yard through which they pass and reduce intermediate handling of commodities, operators make use of *blocks*. A block is made of a set of commodities departing from a certain classification yard and running straight to another classification yard, without marshalling, transhipping or any (de-)coupling of cars. A *classification plan* provides for each commodity in the railroad network a route from its origin to its destination that is made of a sequence of blocks, each moving from one classification yard to another classification yard.

Here we present a two-stage solution approach for the problem. In the first phase, we identify the subset of yards that will be used as classification yards. In the second stage, we define the routes for the given commodities so to minimize a weighted sum of classification and route costs. Computational results on a dataset of realistic instances are presented.

Finally, we discuss how to properly use an optimized blocking plan as input for defining an optimized set of train routes to ship the commodities over the rail network.

Keywords: Railroad Blocking Problem, Blocking Plans

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Session: Nonlinear Optimization

Wednesday September 11th 2:30pm - 4:10pm

Room Nautilus

Chair: Benedetto Manca

Solving global minimization with an approach using Peano space-filling curves

Daniela Lera[1]

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Many decision-making problems arising in various fields of human activity (technological processes, economic models, etc.) can be stated as global optimization problems. Objective functions describing real-life applications are very often multiextremal, nondifferentiable, and hard to evaluate. In this talk, the Lipschitz global optimization problem is considered.

Mathematically, the global optimization problem considered in the paper can be formulated as minimization of a multidimensional multiextremal "black-box" function that satisfies the Lipschitz condition over a domain in N dimension with an unknown constant L (see [1] for a detailed discussion on the importance of this kind of problems). To attack the problem we consider an approach that uses numerical approximations of space-filling curves to reduce the original Lipschitz multi-dimensional problem to a univariate one satisfying the Hölder condition. In particular, two different approximations of Peano-Hilbert curve are discussed: the most used and known Piecewise-Linear Approximation and the less known Non-Univalent Approximation (see [1,2]). Moreover, we apply Peano curves for solving systems of nonlinear inequalities coming from practical applications, in particular in order to find the working area of some parallel robots [3].

Keywords: Deterministic global optimization, Lipschitz and Hölder conditions, space-filling curves approximations

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On ellipsoidal approximations of Minkowski sums of polytopes

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Given a full-dimensional convex polytope $P \subset \mathbb{R}^d$, consider its inner and outer ellipsoidal approximation by ellipsoids E and αE such that $E \subset P \subset \alpha E$, where ellipsoid αE is the copy of E scaled by the *approximation factor* α, which determines the *tightness* of approximation. It is guaranteed that a pair such ellipsoids exist for $\alpha = d$. If P is centrally symmetric, a pair of ellipsoids exists even for $\alpha = \sqrt{d}$. Pairs of ellipsoids E and αE for $\alpha = d$ (or $\alpha = \sqrt{d}$, respectively) are referred to as *Löwner–John* ellipsoids. The approximation factor of d (for general polytopes) and $\sqrt{d}$ (for symmetric polytopes) cannot be improved in general, this is justified by the best possible approximations for a simplex and for a hypercube.

The complexity of finding (an approximation of) Löwner–John ellipsoids depends on the representation of the input polytope. The cases when an H-polytope (the intersection of a finite number of halfspaces) or a V-polytope (the convex hull of a finite set of points) is the input are well studied and it is tractable to find at least a precise approximation of Löwner–John ellipsoids. This is different when H- or V-representation is not available. For less explicit representations of polytopes, only looser approximations can usually be obtained efficiently, as there can be a superpolynomial number of vertices and facets. This talk extends the polynomial-time algorithm for finding a pair of ellipsoids with approximation factor $\alpha = (1+\varepsilon)d$ for an arbitrarily small $\varepsilon > 0$ for the input polytope given as Minkowski sum of a finite set of line segments (*a zonotope*). The extension allows to process the input polytope given as Minkowski sum of finite set of H- and V-polytopes. The talk also deals with ways to improve the factor of $\alpha = (1+\varepsilon)d$ for the case of zonotopes.

Keywords: Ellipsoidal approximation, Zonotope, Löwner–John ellipsoid

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Spatial branching techniques for Quadratic MIPs

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In the branch-and-bound (BB) algorithm, branching is the key step to deal with the nonconvexity of the problem. For Mixed Integer Linear Optimization (MILO) problems, branching is performed on integer and binary variables, whereas Mixed Integer Nonlinear Optimization (MINLO) solver use *spatial branching* as it is necessary to apply it to continuous variables. Spatial branching would seem pointless in MILO as fixing all integer variables yields a Linear Optimization (LO) problem. In this talk we show that if the branching point is carefully chosen, spatial branching can be more effective than its integer counterpart for a special class of MILO problems arising from Support Vector Machines with Ramp Loss (SVMRL) [2]. Similar to other MINLP algorithms that can benefit MIP solvers [1], we present a *strong* spatial branching approach for SVMRL coupled with a procedure to strengthen the LO relaxation, then report on computational tests on known instances from the literature where our approach yields a significant improvement in solve time.

Keywords: Spatial Branching, Mixed Integer Optimization, Support Vector Machines

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Unassigned distance geometry and the Buckminsterfullerene

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The Buckminsterfullerene is an inorganic molecule consisting of 60 car- bon atoms in the shape of a soccer ball. It was used in [1] to showcase algorithms that find the correct shape of a protein from limited data (length of inter-atomic distances) without any further chemical experiment: in that case, by means of a complicated constructive heuristic based on genetic algorithms. In this paper we show that we can reconstruct the Buckminsterfullerene structure by means of mathematical programming, standard solver software, and little else.

Keywords: mathematical programming, molecule, diagonal dominance, matrix cones

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The Ellipsoidal Separation Machine

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We build on the general proposal of Grzybowski et al. that defines the concept of separation of two finite point sets X and Y by means of a convex set S. We chose S as, roughly speaking, the minimum volume ellipsoid that intersects the convex combinations of all pairs of points of different class. The corresponding fitting problem is non-convex, hence we solve it heuristically via an iterative algorithm of the block-Gauss-Seidel type solving alternatively an SDP program and a quadratically constrained (convex) program. The thusly computed separating ellipsoid is used to classify new points by means of a newly defined score based on the relative fraction of the original points that are properly separated from them. This necessarily leads to being unable to classify points inside the ellipsoid, making ours inherently a classifier with reject, as opposed with most proposals in the literature where a reject function is bolted upon a standard classifier. This feature can be relevant in cases where an incorrect classification may be more damaging than explicitly refusing to assign a label, indicating uncertainty. We will provide numerical experiments comparing the quality of the ellipsoidal classifier with that of standard approaches endowed with a rejection function.

Keywords: Supervised classification with rejection; SDP programming; Block Gauss-Seidel Algorithm

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Session: Energy and Environment

Wednesday September 11th 2:30pm - 4:10pm

Room Rocce

Chair: Mauro Gaggero

Mathematical Programming for a Vehicle Replacement Problem Minimizing Costs and CO_2 Emissions

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The vehicle replacement problem has been studied since the 50s [1,2] and extended to model various real-world applications, including environmental considerations [3,4]. In this work, we address a vehicle replacement problem in which a keep-or-replace decision must be made for every asset of the fleet in every time period while meeting budget constraints. Multiple options for replacement are given for every family of assets (e.g., electrification of the fleet). The aim is to minimize total discounted costs and CO_2 emissions. The problem is inspired by a real-world industrial application in Italy and, because of its generality, can be used to model a large variety of further applications. First, we present a dynamic programming model for small-size instances of the problem. Then, we propose an effective ϵ-constraint algorithm based on different Integer Linear Programming models. We assess the effectiveness of the proposed algorithms on both randomly generated instances and realistic instances from the case study.

Keywords: Replacement Problem, Combinatorial Optimization, Bi-objective, Dynamic Programming, Integer Linear Programming, Real-world Application

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The profitability-sustainability trade-off in complex chemical value chains under product-specific carbon footprint constraints

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One of the primary goals set by the international community for the next decades is to mitigate the impacts of global warming and climate change. Consequently, numerous countries have enacted laws that legally bind them to achieve net-zero targets within the next 25-30 years. Since indirect emissions are also considered, there is a growing focus on emissions generated by externally sourced products. The most straightforward way to reduce such emissions is to require suppliers to adhere to specific standards regarding the maximum acceptable emissions per unit (or weight) of their products. As a result, companies may request their suppliers to provide products that do not exceed predefined emissions targets. This essentially introduces a form of horizontal differentiation among products, solely based on their carbon footprint. This study introduces the Product-Specific Carbon Footprint Optimization (PSCFO) problem as a deterministic multi-objective value-chain problem with the objective of minimizing CO_2 emissions and maximizing a company's total contribution margin. The aim is to achieve these objectives while meeting external customer demands for the maximum acceptable product-specific carbon footprint. To address the PSCFO problem, we propose a bilinear programming model based on a "flow-like" formulation. We validate the model with a real-world dataset provided by a multinational chemical company to assess the efficiency and practical applicability of the proposed approach. The suggested model serves as a valuable tool to account for emissions associated with each product type, estimate costs linked to introducing a more sustainable product version, and optimize operations accordingly.

Keywords: Sustainable value chain, multi-objective optimization

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Assessing Eco-Innovation Dynamics in European Union Member States Using A Novel Window Value-Based Data Envelopment Analysis

Maria Gouveia[1] and Carla Henriques[1]

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In contemporary academic discourse, eco-innovation has emerged as a crucial concept, blending efforts to address environmental issues with socio-economic progress. The European Commission defines eco-innovation as innovative endeavors advancing sustainable development by reducing environmental impact, enhancing resilience to environmental pressures, or optimizing natural resource use. It focuses on achieving environmental goals through inventive strategies, prioritizing efficient resource use and eco-friendly production/consumption. The Organization for Economic Co-operation and Development underscores two key features of eco-innovation: creating innovations to mitigate environmental harm and transcending organizational boundaries, potentially requiring shifts in societal norms and institutional frameworks. Eco-innovation has gained attention from researchers and policymakers, with the EU integrating it into policy frameworks, notably through funding programs like the Competitiveness and Innovation Framework Programme and Horizon 2020 under the Next Generation EU. Understanding how Member States implement eco-innovation strategies is crucial. Our contribution involves evaluating eco-innovation dynamics across EU countries using Window Value-Based Measure Data Envelopment Analysis, treating each region as a distinct entity. This method employs a moving average to establish reference sets for assessing relative efficiency, capturing the evolving eco-innovation landscape over time. By analyzing eco-innovation scores across five thematic areas (inputs, activities, outputs, resource efficiency, and socio-economic outcomes), our aim is to identify convergence patterns in both overall and specific facets of the eco-innovation index. This analysis will enhance understanding and aid in formulating potential policy recommendations in eco-innovation.

Keywords: Eco-innovation, European Union, Value-Based DEA

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Assessing Energy Poverty in the European Union: Insights from Value Based Data Envelopment Analysis

Carla Henriques[1], Maria Gouveia2[1]

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Energy Poverty (EP) presents a significant global challenge, affecting millions in the European Union (EU), as noted in the 2021 European Commission (EC) State of the EU report. Ongoing conflicts and rising energy prices are expected to exacerbate Energy Poverty. EP also hinders sustainable development efforts by impeding citizens' participation in the energy transition aligned with Sustainable Development Goal (SDG) 7 and efforts to eradicate poverty (SDG 1) and promote well-being (SDG 3) as per the United Nations goals. The term "Energy Poverty" gained official recognition in EU legislation in 2009, leading to ongoing measures and initiatives to combat it. However, accurate assessment methods are crucial for effective policy development and implementation within the EU. Various methods have been used to assess EP, ranging from unidimensional indicators to multidimensional approaches. Common methods include the counting approach, composite index approach, and more complex techniques like TOPSIS and AHP. This study contributes to existing literature by evaluating EP in the EU in 2020 using, for the first time, the Value-Based Data Envelopment Analysis (VBDEA) method, considering nine criteria. The VBDEA approach combines Data Envelopment Analysis (DEA) with Multiple Criteria Decision Aiding (MCDA), providing a structure that considers essential criteria in efficiency evaluation. Unlike conventional DEA models, VBDEA translates inputs and outputs into criteria assessed on value scales, enabling the explicit inclusion of decision-makers' preferences via value functions. This method also adeptly manages negative or null data. Our research findings reveal a clear trend: Eastern and Southern European countries display significantly elevated levels of EP. Conversely, Scandinavian nations and Central Europe exhibit minimal EP levels, whereas Western Europe and the Baltic countries are categorized under moderate EP.

Keywords: Energy Poverty, European Union, Value-Based DEA

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Scheduling carbon dioxide transfers between two ports via mixed-integer linear programming and heuristic approaches

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The optimization of CO2 transfers via ships between two ports is addressed by means of a scheduling approach based on the solution of a mixed-integer linear programming problem. The goal is to keep the temporary storage buffers at the ports as empty as possible while satisfying suitable constraints. Since the solution of the optimization problem may be time consuming in the presence of a large number of vessels, a greedy heuristic based on a threshold mechanism is also presented. Preliminary simulation results are showcased to assess the effectiveness of the two approaches.

Keywords: Scheduling, CO2 transfer with ships, mixed-integer linear programming, greedy heuristic

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Session: Healthcare

Thursday September 12th 9:00am - 11:00am

Conference Center A

Chair: Roberto Aringhieri

Intervention Planning for a Home Health-and-Social-Care Institute in Switzerland

Roxanne Tison[1] and Nicolas Zufferey[2]

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We consider an intervention planning problem proposed by AVASAD, a home health-and-social-care institute in Switzerland. The main decisions are to assign interventions to caregivers, decide the start time of each intervention, and determine the caregiver routes. Various constraints are considered, including skills, working hours, patient availabilities, travel times, and imposed start times for some interventions. Six objective functions are ranked according to a strict priority imposed by AVASAD (e.g., maximize the care continuity and the number of interventions assigned to caregivers with the recommended skills, minimize the travel and idle times, maximize the assignment of interventions at the patient preferred times). Various insertion algorithms are proposed and combined, and their results are favorably compared to the schedules employed by AVASAD

Keywords: Intervention planning, Homecare scheduling, Insertion heuristics, Lexicographic optimization

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A discrete event simulation model for ambulance deployment within a regional Emergency Medical Service: a case study

Maria Paola Corradi[1], Alberto De Santis[2], Domenico Antonio Ientile[1], Stefano Lucidi[2], Massimo Maurici[3], Mauro Messedaglia[4], Alessandra Pancaldi[3], **Giulia Riccardi**[2] and Massimo Roma[2]

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We consider Emergency Medical Services provided by the Azienda Regionale Emergenza Sanitaria (ARES) 118 in the Lazio region of Italy. The mission is to timely respond to citizen calls for providing first aid care and to transfer patients to an appropriate Emergency Department by ambulance, if needed.

The aim of our work is to improve the services provided through Discrete Event Simulation. In particular, we have conducted a case study focusing on the province of Rieti, adopting a static ambulance dispatch strategy. Our objectives are to reduce the response time and, possibly, the number of employed ambulances. We performed some scenario analyses enabling to assess potential effects of specific changes in the ambulance deployment and relocation.

Keywords: Emergency medical services, Discrete event simulation, Ambulance deployment

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Optimization of nutrition for I.C.U. patients

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Nutrition of patients in Intensive Care Units (ICU) is a critical treatment that needs to be optimized according to the specific needs of each patient. This study concerns the problem of optimally mixing commercially available formulas for enteral nutrition to achieve any desired mix of nutrients. The mathematical model has been discussed and improved according to feedback received from physicians in ICUs; it is solved in negligible computing time by a free integer linear programming solver. A software tool has been developed with a user-friendly interface, to allow extending the testing phase to several hospitals; it allows studying the trade-off between different objective functions

Keywords: Integer linear programming, multi-objective optimization, personalized medicine, enteral nutrition, ICU

Solving the Integrated Patient-to-Room and Nurse-to-Patient Assignment by Simulated Annealing

Eugenia Zanazzo[1], Sara Ceschia[1] and **Andrea Schaerf**[1]

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We consider a recently-proposed integrated healthcare problem [1] that deals with the assignment of patients to suitable rooms in wards (Patient-to-Room) and the assignment of nurses to patients to balance their workload (Nurse-to-Patient), in one single stage. The problem comprises objectives coming from both single problems as well as objectives that are expressed and evaluated at the level of the integrated problem.

For this problem, we propose a local search approach that uses the union of two distinct neighborhoods and it is guided by a Simulated Annealing metaheuristic. We tuned our search method, ran it on the available dataset, and validated the experiments using the available solution checker.

This is an ongoing work and preliminary results show that we have been able to solve all instances of all sizes, with different levels of quality depending on the running time.

This work has been funded by the project "Models and algorithms for the optimization of integrated healthcare management" (no. 2020LNEZYC) supported by the Italian Ministry of University and Research (MUR) under the PRIN-2020 program.

Keywords: Healthcare, Problem integration, Simulated Annealing

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Model-based Optimal Scheduling of Antiviral Treatments Against Mpox Infections

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Mpox, a double-stranded DNA virus affecting humans and some animals, traditionally confined to African tropical regions, exhibited outbreaks in non-endemic regions in Europe and America in 2022. Symptoms include skin lesions and respiratory problems; severe complications and death can occur. The virus proliferates by infecting host cells and inducing them to produce and shed new virus. The antiviral drugs cidofovir and tecovirimat [1] have been shown to hinder mpox proliferation by inhibiting viral production and viral shedding, respectively.

Mathematical models have been successfully adopted to describe the in-host evolution of infectious diseases and plan the optimal treatment of viral infections such as HIV [2] and COVID-19 [3]. In our work [4], we propose a new mpox infection model that – differently from the classic target-cell limited model [5] – separately captures the rates of viral production (p) and shedding (η), and thus allows us to explore the distinct effects of cidofovir, which reduces p, and tecovirimat, which reduces η, depending on the concentration of each drug. Our model considers five populations (uninfected cells, latent infected cells, virus-producing infected cells, internal virus and external virus); it is thoroughly analysed, assessing the disease-free equilibrium set and its stability, the reproduction number, the transient and asymptotic behaviour.

Considering mpox dynamics along with the specific effects of cidofovir and tecovirimat infusion, with parameter values derived from the medical literature, in [4] we formulate and solve an optimal control problem aimed at maximising the number of surviving healthy cells, while minimising the viral load and the drug side effects, over a finite treatment period. Model-based optimal combined treatments can thus be scheduled in different scenarios, showcasing the potential of our approach in planning antiviral therapies that combine both drugs efficiently.

Keywords: Antiviral therapies, Drug scheduling, Optimal control

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Online algorithms with foresight for radiotherapy patient scheduling

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A radiotherapy treatment consists in a given number of radiation sessions, which should start before a given due date and have a certain duration depending on the patient category. Patients are usually classified into classes of urgency having different deadlines and number of sessions.

Waiting time is the main critical issue: the time elapsed between the first consultation and the first treatment is typically rather long and delays have the potential to damage the health status of the patients [1]. Then, an efficient use of available linacs is crucial to ensure the success of the treatment.

We deal with a Radiotherapy Patient Scheduling (RPS) problem at the pure-online level under the blocking policy, which divides the work shifts in time slots of same duration [2]. We propose online algorithms that enable the scheduling of a sequence of appointments for each patient, all at the same time slot of the day, whenever a patient needs to commence a series of radiotherapy sessions. Considering a realistic and patient-centred operational context, the problem becomes very complex from a combinatorial perspective.

We address this complexity introducing the concept of online optimisation with foresight, which is the common framework of the proposed approaches. The rationale of foresight is to take real-time decisions under uncertainty from exploiting the partial knowledge of the optimal solution structure. Starting from such a knowledge, online algorithms with foresight are designed with the aim of avoiding the assignment of slots that could make the future patient scheduling inefficient.

A quantitative analysis shows that the proposed algorithms outperform two competitor algorithms inspired by the literature. Furthermore, the exploiting of a pattern observed in the offline solutions of the problem (implicit foresight) results to be more flexible and effective than using a solution structure given by integer linear programs on the most likely scenario (explicit foresight).

Keywords: radiotherapy patient scheduling, online optimisation, online algorithms

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Session: OPTSM 6 - Optimization in Public Transportation systems

Thursday September 12th 9:00am - 11:00am

Conference Center B

Chair: Alberto Santini

The modernization of traffic control efficiency in the service of urban mobility development

Siniša Vilke[1] and Davor Mance[2]

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The scientific research project Connected Traffic was carried out to establish quality solutions in the traffic management system of the city of Rijeka and therefore to implement intelligent transport systems in urban mobility. The aim of this paper is to show the Connected Traffic project re-search results related to the possibilities of applying the improvement of urban traffic control efficiency and traffic management. The emphasis of measuring traffic, meteorological and environmental parameters is aimed to reduce primary energy consumption and emis-sions of carbon dioxide and other harmful gases, ensuring the sustain-ability of urban transport. The methodological approach of the paper consists of the set traffic model that is used for the implementation of traffic simulations according to adequate transport scenarios or inci-dental situations. Considering the research subject, this paper sets a hypothesis which states the following: for testing the appropriate transport scenarios it is optimal to apply the simulation tools thus improving the urban traffic control efficiency and innovative methods for urban mobility devel-opment.

The paper is the result of research activities of the scientific project Connected Traffic implemented within CEKOM for smart cities (CEKOM – Center of Competence for smart cities, the city of Rijeka), funded by the EU ESIF fund, started in March 2020. and ended in March 2023.

Keywords: intelligent transport systems, urban mobility, traffic management, traffic control efficiency

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Modular Bus Assignment Optimization

Carlo Filippi[1], Gianfranco Guastaroba[1], **Lorenzo Peirano**[1] and Maria Grazia Speranza[1]
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Public transport systems are known to usually operate according to fixed route and fixed schedule schemes. As a norm, vehicles have fixed capacity that does not change over time. However, transport demand does not follow a uniform distribution in neither time nor space, leading to operational issues such as overcrowded vehicles in central areas and in peak demand periods, while on peripheral areas and in less crowded period of the day vehicles travel near-empty. As a result, the system is neither efficient nor effective. In this study, we address these issues by investigating the use of modular bus, a new emerging technology in which vehicles of smaller capacity can be dynamically combined together to form high capacity vehicles, allowing a new degree of flexibility related to the size of vehicles. A novel ILP optimization problem is formulated to minimize the size of the fleet required to satisfy the transport demand in its entirety. Exploiting two properties of modular bus, sharing and rebalancing, we prove that the potential reduction of the fleet size required to serve the transport demand are theoretically unbounded. Computational experiments shows that the better adaptation of the capacity to the demand yields the potential for significant increase in the efficiency of urban transport systems.

Keywords: Modular Bus, Public Transport, Flexible Assignment

Two-stage XGBoost for short-term bike-sharing demand forecasting

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Demand uncertainty poses crucial challenges to shared mobility services. Accurate and computationally efficient short-term demand forecasting can enable proactive demand and supply rebalancing operations in real-time. There is however limited knowledge on demand forecasting with a prediction horizon shorter than an hour, which is crucial for understanding real-time demand fluctuations triggered by unforeseen and sudden events [1]. In this study, we introduce a non-linear two-stage forecasting approach using eXtreme Gradient Boosting (XGBoost) to predict the next 15-minute demand for each service point within a bike-sharing network. The first stage model incorporates contextual variables, including seasonality, weather, and public transit utilization information, to capture the complexity of realized demand patterns [2]. To address the demand variations due to unforeseen events, a residual time series is generated by measuring recent discrepancies between actual demand and stage 1 predictions. These residuals are fed as input to the second stage to predict the upcoming demand variations. The final demand forecast combines the predicted variations with the initial estimates to offer a refined demand prediction for the next 15-minute interval. We assess the performance of our two-stage forecasting method using 3-month historical trip data from 330 service points operated by Capital Bikeshare in Washington D.C. Using the first stage model as a baseline, results show that the mean absolute error has been reduced by an average of 5.6% per service point with our proposed two-stage method. At least 10% accuracy improvement is achieved for 22.7% of the service points. Furthermore, for a 5-day period with continuous demand anomalies, our two-stage model achieves an average of 12.3% reduction in prediction errors per service point.

Keywords: Short-term demand forecasting, Shared mobility, Machine Learning

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Integrated Schedule Planning for Regional Airlines Using Column Generation

Alberto Santini[1] and Vikrant Vaze[2]

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[2]College of Engineering, Dartmouth University, Hanover, NH, United States

Medium-term airline schedule planning is traditionally tackled in a sequence of steps, including route selection, frequency planning, timetable design, fleet assignment, aircraft routing, crew scheduling, and tail assignment. Optimising each step separately is globally sub-optimal, but is often the only viable strategy because of the computational difficulty of solving the joint problem. This paper focuses on simultaneously optimising medium-term strategic decisions related to frequency planning, timetable design, and fleet assignment, as well as dealing with limited changes to the route selection process. Two conditions make this joint optimisation possible. First, we focus on the special case of regional airlines that work as feeder for larger mainline carriers. Second, we exploit a tight exponential-size formulation; we solve its continuous relaxation via column generation and obtain integer solutions via a restricted master heuristics. In this way, we optain gaps consistently under 0.2%. An important characteristic of our approach is that it incorporates explicit passenger preferences via discrete choice modelling. Preliminary results on the network of Mesa Airlines and Republic Airways show a significant potential for increased profits and load factors. The main reason for such increase is a better synchronisation of feeder flights allowing for more connections and, thus, capturing a larger share of passengers whose itinerary involve two flights with a layover at the hub.

Keywords: airline optimisation, discrete choice models, airline timetabling

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Session: AIRO Dissertation Award

Thursday September 12th 9:00am - 11:00am

Room Nautilus

Chair: AIROYoung Board

Location problems with covering constraints: models and solution approaches for the telecommunications

Alice Calamita

Facility location problems are pivotal in both academic research and practical applications across various sectors. This thesis underscores the importance of such problems within the telecommunications (TLC) sector, given the crucial role TLC plays in modern society. The advent of 5G technology has posed new challenges in meeting network quality standards, demanding sophisticated mathematical optimization techniques. Indeed, a growing demand for service and an increasing signal interference leading to service degradation are expected. Traditional network design formulations suffer from numerical issues and are limited in their applicability to large-scale practical scenarios due to slow resolution processes and unreliable solutions. In the more general context of service and coverage networks, similar urgencies exist: there is a requirement for high-quality service alongside an increasing demand for service. Hence, there is a need to address system congestion to meet service requirements. However, this topic is poorly explored in the literature, and data uncertainty is not taken into account, resulting in unreliable deterministic solutions. Driven by these complexities, this thesis makes two significant contributions addressing two distinct network design problems: one specific to the telecommunications sector and the other broadly applicable to service and communications networks, with the aim of developing solution approaches that are both theoretically robust and practically viable. The first contribution focuses on the location of transmitters, which are the facilities enabling wireless connections, to meet service coverage requirements. We addressed the drawbacks of traditional formulations from a modeling point of view, improving the modeling of service quality constraints, proposing valid cutting planes, constraints aggregation, and various presolve operations. Our proposals prove effective, allowing us to achieve optimality in large-scale scenarios within solution times aligning well with planning windows. The second contribution concerns the introduction of a novel location problem allowing for partial coverage that considers both the minimization of congestion and the protection from uncertainty in customer demand. We provide mathematical formulations to this problem and propose Benders decomposition approaches to solve it, also introducing a cut-strengthening technique to efficiently deal with the degeneracy of the Benders subproblem. Our tailored approach outperforms Gurobi on adapted instances from the literature.

Pareto Front Reconstruction of Multi-Objective Optimization Problems

Pierluigi Mansueto

The thesis is concerned with multi-objective optimization (MOO) problems under various constraint types. In particular, we consider the unconstrained, the box constrained, the general convex constrained and the cardinality constrained settings. As mathematical tool, MOO has received much attention over the years, being suitable both in operation research applications and in many real-world problems where contrasting goals have to be taken into account. In the dissertation, a general overview of the main MOO concepts is given, focusing on the notions typically employed in the gradient-based MOO approaches. In particular, we present a general formulation for the search direction problem and a general framework for single-point methodologies, i.e., approaches designed to generate a single solution to the problem at hand. The features of each of the two concepts are discussed and analyzed; finally, we show how they can be reduced to well-know schemes from the MOO literature. Then, we propose novel gradient-based methodologies aimed to reconstruct the Pareto front for the considered problem classes. In some of the mentioned settings it is the first attempt to define this type of approaches generating multiple solutions rather than one, while in the others the topic has been almost unexplored yet. However, in the MOO context, returning an approximation of the Pareto front rather than a single solution can be much more useful for the final user, so as they can choose among multiple tradeoffs of the objectives the one that is the most suitable for themselves. For each methodology, detailed descriptions of the algorithmic scheme and characteristic features are reported; moreover, each methodology is theoretically analyzed and its convergence properties are stated and proved. Finally, the proposed methods are numerically tested with wide benchmarks of test problems, comparing each of them with state-of-the-art approaches from the MOO literature. The results show the efficiency and the effectiveness of the proposals w.r.t. the competitors in diverse experimental settings.

Keywords:

Single Machine Rescheduling for New Orders. Properties, complexity and solution algorithms

Elena Rener

Rescheduling problems are understood as strategies for updating existing schedules to deal with unexpected changes in the available data. Each disruptive event also creates an opportunity to improve an initial schedule made under different conditions. It is therefore well worth optimizing processes even following a change of scenario. When the change is given by the arrival of a new set of orders (jobs) that are unknown at the time of scheduling, we speak of rescheduling for new orders. In these problems, we consider two sets of jobs, namely the old and the new, that must be scheduled together on a single machine. The goal is to optimize the execution of all jobs with respect to some objective function, but also to avoid excessive deviations from the original schedule on which other work may rely. Many rescheduling methods involve consideration of an objective function to be minimized and a disruption constraint that limits the deviation from the original solution. The dissertation studies, from both a theoretical and algorithmic perspectives, single-machine rescheduling problems to minimize classical scheduling objective functions given a disruption constraint measured as a function of the absolute deviation of the completion times. To fill the gap in the literature, where rescheduling for new orders has only been studied in a fragmented and case-by-case basis, we provide an analysis of a whole class of rescheduling problems. With an overview of structural and complexity results, we first provide some insights into the nature of these problems from a theoretical perspective. Then, with a list of algorithms, we show several ways to exploit the theoretical results to obtain exact and approximate solutions.

Keywords:

Multi-Neighborhood Search for Combinatorial Optimization

Roberto Maria Rosati

The composition of multiple local search neighborhoods provides a better connectivity in the search space and gives access to a wider set of search trajectories, in comparison to a single neighborhood, while also reducing the risk of getting stuck in a particular region of the search space. In this thesis we propose, under the name of Multi-Neighborhood Search, a methodological approach that embraces how neighborhoods are designed and composed together, as well as their behavior and interaction with each other and with the search space, their relation with the cost function, and their integration inside a metaheuristic. In our approach, neighborhoods are balanced through probabilities and internal biases, which can be fixed or adapted during the search. Moves are accepted according to the Metropolis criterion from the Simulated Annealing metaheuristic, which is employed to guide the search. We validate our approach on four challenging combinatorial problems spanning various domains: the Minimum Interefence Frequency Assignment Problem, the Sports Timetabling Problem, the Healthcare Routing and Scheduling Problem, and the Capacitated Dispersion Problem. We design Multi-Neighborhood Search methods that use from three to six distinct neighborhoods each, some of them originally conceived. Our results outperform quite consistently the state-of-the-art methods from the literature on instances from benchmark datasets. Furthermore, we demonstrate through experimental results on the Sports Timetabling Problem and the Examination Timetabling Problem that the method's robustness can be enhanced with reinforcement learning. Finally, we replicate the schemes from Multi-Neighborhood Search to the matheuristic Construct, Merge, Solve and Adapt (CMSA), to shape the Multi-Constructor CMSA, that we apply to the Maximum Disjoint Dominating Sets Problem. Moreover, we also employ CMSA to solve a real-world Bus Driver Scheduling Problem with complex break constraints.

Keywords:

Session: Recent Advances in Variational Inequalities and Equilibrium Problems

Thursday September 12th 9:00am - 11:00am

Room Rocce

Chair: Patrizia Daniele

A Variational Formulation for a Trust and Reputation System

Gabriella Colajanni[1], Patrizia Daniele[1], **Sofia Giuffrè**[2] and Attilio Marcianò[2]

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[2] Department of Information Engineering, Infrastructure and Sustainable Energy (DIIES), Mediterranean University of Reggio Calabria

Trust and reputation systems play a pivotal role in modern digital environments, fostering cooperation and mitigating risks in various online interactions.

In this talk we present a variational formulation approach to model and analyze trust and reputation systems. Leveraging variational methods allows for a comprehensive representation of user behaviors, product evaluations, and network interactions within a unified mathematical framework.

In particular, first, we compute the reputation in terms of the values of the trust, weighted by means of the reliability of the agents. The proposed definition of reputation takes also into account, if the object is not new in the system, an initial reputation. Then, we provide the definition of equilibrium in terms of the weighted trust and the Lagrange multipliers associated with the constraints of the weighted trust. In the model each trustee aims at optimizing its gain, namely the utility minus the costs. We demonstrate that the equilibrium conditions can be formulated as a variational inequality problem and we provide a novel alternative formulation. We then perform an experimental campaign of mathematical simulations, focusing on the optimal values of the Lagrange multiplier and of the optimal values of the weighted trust. Moreover, a sensitivity analysis on the weights associated with each user and on the initial reputation of the agents is performed.

Keywords: Weighted trust, Equilibrium conditions, Variational inequalities, Reputation

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On Multiple Agents Dealing with Multiple Criteria via the Hypervolume Approach

Lorenzo Lampariello[1], Simone Sagratella[2] and Valerio Giuseppe Sasso[2]

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To deal with multi-agent problems where each agent wishes to optimize selfishly multiple criteria, given the choices of the other decision makers, we resort to the hypervolume approach and identify properties making it appealing also in this context.

Keywords: multi-objective optimization, Nash equilibrium problems, variational inequalities

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On the approximation of the Shapley value via machine learning in transportation network cooperative games

Giorgio Gnecco[1], Yuval Hadas[2], Mauro Passacantando[3] and **Marcello Sanguineti**[4,5]

[1] IMT Alti Studi Lucca, Italy
[2] Bar-Ilan University, Israel
[3] University of Milano-Bicocca, Italy
[4] University of Genoa, Italy
[5] National Research Council of Italy, Genova, Italy

The Shapley value, a well-established concept in cooperative game theory, serves as a metric for assessing the significance of each player in a transferable utility game. Recently, it has found application in gauging the importance of individual arcs or nodes within a network. However, the exact computation of the Shapley value is often computationally expensive, particularly in the context of extensive networks. This study delves into the challenge of approximating the Shapley value in a transferable utility game defined on a net- work, wherein the network's characteristics are parameterized by a variable of interest (e.g., the traffic demand). We examine the smoothness of the Shapley value concerning this parameter and leverage this insight to theoretically justify the utilization of machine-learning techniques for its approximate computation. Additionally, we present potential extensions for further research in this area.

This work was supported by the Italian Ministry of Research (PRIN 2022S8XSMY "Optimal robust shape control for distributed parameter systems"), and by the GNAMPA-INdAM 2023 project "Sviluppo di metodi di machine learning per la stima del valore Shapley e di sue generalizzazioni", code CUP E53C22001930001. M. Gaggero, G. Gnecco, and M. Sanguineti are members of GNAMPAINdAM. M. Sanguineti was partially supported by the project of the PDGP DIT.AD021.104 "Optimization and Control Techniques" of the Institute of Marine Engineering, National Research Council of Italy.

Keywords: Transferable-Utility Games, Shapley Value, Approximate Computation, Machine Learning

Existence and approximation results for Quasi Variational Inequalities with linear coupling constraints

Lorenzo Lampariello[1], **Simone Sagratella**[2] and Valerio Giuseppe Sasso[2]

[1] Department of Business Studies, Roma Tre University, Rome, Italy,

[2] Department of Computer, Control and Management Engineering Antonio Ruberti, Sapienza University of Rome, Rome, Italy

We consider quasi variational inequality problems in which the feasible point-to-set mapping is defined by linear coupling constraints. We provide existence conditions easy to verify in practice. We analyze inexact solutions for different reformulations based on gap functions to obtain approximate solutions for the quasi variational inequality.

Keywords: quasi variational inequality, existence results, approximate solutions

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Decision-Making Mechanism of Livestreaming E-commerce Supply Chain: A tripartite Evolutionary Game Model

Laura R.M. Scrimali[1] and Georgia Fargetta[1]

[1]University of Catania, Department of Mathematics and Computer Science, Viale Andrea Doria 6, 95125 Catania, Italy

This paper investigates the decision-making strategies in a supply chain composed of manufacturers, social media influencers, and consumers under the live-streaming e-commerce mechanism. We analyze the three-party game using evolutionary game theory to study the dynamic evolution process of the strategies of each participant in the supply chain. We construct the replicator dynamics equations for the members of each player group and provide the evolutionary stable strategies for the entire system. Finally, we present some numerical simulations.

Keywords: Live-streaming e-commerce, Evolutionary game theory, Replicator dynamics equations

References

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Session: Vehicle Routing 4

Thursday September 12th 11:30am - 12:30am

Conference Center A

Chair: Laurent Alfandari

Graph Convolutional Neural Network Assisted Monte Carlo Tree Search for the Capacitated Vehicle Routing Problem with Time Windows

Jorin Dornemann[1] and Tobias Klein[2]

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[2] Institute for Operations Research and Information Systems, Hamburg University of Technology, 21073 Hamburg, Germany

The Capacitated Vehicle Routing Problem with Time Windows (CVRPTW) is a well-known combinatorial optimization problem that extends the classical Vehicle Routing Problem to account for additional real-world constraints such as truck capacity and customer time windows. Recent studies have explored the use of deep graph convolutional networks (GCNs) to predict the arcs that are part of the optimal tour for the Travelling Salesman Problem and related routing problems. We propose a novel context complemented graph convolutional network (CCGCN) which is integrated into a Monte Carlo Tree Search (MCTS) to solve the CVRPTW sequentially. The deep convolutional part of the proposed neural network builds efficient CVRPTW graph representations, whereas the context part processes information of partially built tours to output probabilities on which vertex to add next to the tour, which are used during the expansion of the search tree. For simulating final solution values within the Monte Carlo search tree, we conducted experiments using two different heuristics: LKH and a beam search. By leveraging the probabilities provided by our CCGCN and employing a variation of Upper Confidence Bound applied to trees, we effectively manage the tradeoff between exploration and exploitation, thus reducing the optimality gap compared to solutions generated solely by LKH. Evaluations of the proposed heuristic are performed on benchmark instances of the CVRPTW with up to 100 customers; these show promising results.

Keywords: Monte Carlo tree search, graph convolutional network, vehicle routing

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Optimal road transport planning

Luca Abatello[1], Daniela Ambrosino[2,3], **Veronica Asta**[1,3] and Costanza Chiesa[1]

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As global commerce continues to expand, the strategic coordination of intermodal freight movement has emerged as a pivotal endeavour in mitigating the adverse ramifications of transportation. One of the main aims is to increase the efficiency of last and first-mile truck operations, typically managed by Multimodal Transport Operators (MTOs) in door-to-door services. These operations encompass the conveyance of empty container movements that can be avoided by combining a last mile with a first-mile operation. Thanks to this combination, the emptied container can be redirected to another customer for its loading, instead of going empty to an intermodal depot. In a previous study, both optimization and heuristic methodologies were proposed to minimize the transportation of empty containers, while considering various constraints such as time window limitations imposed by both customers and intermodal depots, cargo and container types, vehicle characteristics, and capacities. Our present study aims to extend our previous research by integrating last and first-mile operations with pure road transport services. Although this extension poses inherent challenges, it also reflects a practical scenario for carriers who regularly manage both multimodal and dedicated road trips. This expansion permits to minimize, in addition to the transportation of empty containers, the empty trucks voyages too. It not only enables the application of our model to intricate logistical frameworks but also deepens our understanding of optimizing comprehensive freight transportation networks. Ultimately, it commits to enhancing the efficiency of logistics operations holistically. The expanded problem will be introduced alongside an outline of the new solution approach. Preliminary results are given, focusing on efficiency gains.

Supported by European Union - NextGenerationEU / Ministry of University and Research (MUR) - RAISE (Robotics and AI for Socio-economic Empowerment) Spoke 4 - Smart and Sustainable Ports National Recovery and Resilience Plan (NRRP): Mission 4, Component 2, Project code: ECS00000035

Keywords: road transport planning, intermodal networks, heuristics

References

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Branch-Price-and-Cut for the Production Routing Problem with Time Windows

Eric Faußß[1] and Timo Gschwind[1]

[1]Chair of Logistics, Department of Business Studies and Economics, University Kaiserslautern-Landau, 67663 Kaiserslautern, Germany

The production routing problem (PRP) is an integrated planning problem that combines vehicle routing and lot-sizing decisions. It extends the inventory routing problem (IRP) in which the production quantities are fixed. Given a set of customers and a discrete finite time horizon, the PRP consists of deciding for each period if and how much to produce, the inventories at the depot and the customers, and the vehicle routes. The latter includes the decisions on which customers to serve and the quantities delivered. The objective is to minimize the total costs over the planning horizon consisting of production, inventory and routing cost. One prominent application of the PRP is the vendor managed inventory approach where a vendor produces a product, delivers it to customers, and is also in charge of the inventory management of the customers (see e.g. [1]). While customer time windows are an important feature of practical applications, the literature on the production routing problem with time windows (PRPTW) is rather scarce (see [2]). In this talk, we propose a path-based formulation for the PRPTW and a branch-price-and-cut (BPC) algorithm for its solution extending previous work from the literature (see [3] for the IRP). Valid inequalities are used to strengthen the mathematical formulation and a labeling algorithm for solving the pricing subproblems is employed. Computational tests are conducted on derived and established benchmark instances to evaluate the performance of the proposed BPC algorithm.

Keywords: Production Routing, Branch-Price-and-Cut, Time Windows

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A branch-and-price method for the Multi-Commodity Ring Vehicle Routing Problem

Laurent Alfandari[1] and Paolo Gianessi[2]

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In the Multi-commodity Ring Vehicle Routing Problem (MRVRP), goods are collected from virtual gates outside the city, then transit through one or several depots called Urban Distribution Centers (UDCs) before being delivered to customers in either open or closed delivery routes. The reverse pick-up trip from customers to gates via UDCs is also considered in the same model. The UDCs are located around the city and connected by a ring using transportation modes with low per-unit emission costs, such as high-capacity trucks or railway shuttles. Such a ring sytem circulation, together with a fleet of electric vans to perform the routing inside the city, matches increasing urban traffic restrictions that prevent large trucks from getting into the city center. This way, not only transshipment or cross-docking operations are performed outside the city center, but also the delivery routing may start closer to the final customers when using the ring for transportation around the city, with the assumption on per-unit emission costs that the ring is less costly to reach the other side of the city. In [1], the so-called Multicommodity Ring Location Routing Problem (MRLRP) is defined which includes strategic location and network design decisions about where to locate the UDCs and how to connect them in a ring. The City Logistics problem that is the closest to the MRVRP is the Two-Echelon Vehicle Routing Problem (2E-VRP) [1,2], but has different features and no ring structure. In this paper, we consider repositionning constraints at UDCs and design an efficient Branch-and-Price algorithm to solve the problem. The decompositon keeps the ring-transportation part at the master level and assigns the routing part to the pricing subproblem. This pricing problem is an elementary shortest path problem with resource constraints solved with Dynamic Programming, accelerated with q-routes and ng-paths. We use a two-level branching strategy based on ordering the different binary variables and tailored priority functions. The numerical results show the performance of the Branch-and-Price approach on instances of various sizes.

Keywords: Vehicle Routing, Multi-commodity flow, Transportation, Integer Programming, Column generation, Branch-and-Price, Dynamic Programming

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Session: Economics & Logistics

Thursday September 12th 11:30am - 12:30am

Conference Center B

Chair: Giulia Dotti

Strategic Re-Optimization of a Large-Scale Supply Chain Network

Selene Silvestri[1], Juan C. Pina-Pardo[1] and Matthias Winkenbach[1]

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This study introduces novel inventory and demand risk-pooling strategies and a stochastic optimization model [2] to enhance the supply chain operations of a pharmaceutical company. The aim is to address shifts in demand patterns and increased competitive pressures that the company has been experiencing since the COVID-19 pandemic, while respecting various real-world side constraints. The pandemic has triggered significant changes in demand dynamics across the industry, affecting both product mix and volume. To effectively respond, the company had to diversify its global supply sources, reroute product flows, implement alternative shipment methods, and direct customers towards alternative product options. This work outlines the encountered challenges and presents a stochastic modeling approach developed to leverage the benefits of inventory and demand risk-pooling strategies. By explicitly accounting for customer demand uncertainties [1], we demonstrate that significant cost reduction, improved resource allocation, and increased supply chain resilience are attainable through network-level horizontal prepositioning strategies. We conduct extensive numerical analyses using data from the company and present practical insights for implementation. The study concludes with several recommendations for implementing these strategies in diverse industrial and geographical contexts, underscoring the versatility of the proposed strategy and mathematical model beyond the specific case study.

Keywords: Network design, Inventory risk-pooling, Demand risk-pooling

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Channel Switching in Omni-Channel Retailing

Bahriye Cesaret[1] and Armagan Bayram[2]

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The evolution of technology has changed the ways customers engage with retailers. Customers now utilize various sales channels, including traditional in-store visits and websites, in their buying processes. Consequently, retailers are challenged with customers who tend to switch between various sales channels. Ideally, omni-channel retailing, defined as a retailer's efforts to offer customers a consistent and coordinated shopping experience across all available channels, should facilitate seamless shopping experience. While the existing practices fall short of this ideal, firms must carefully assess the impact of customer switching behavior on their profits. Omni-channel retailing allows customers to buy products from anywhere and return them anywhere, while allowing retailers to fulfill orders from anywhere. This flexibility enhances the customer experience by integrating all channels, allows retailers to achieve more availability and boosts the sales and traffic of the retailers. However, it also places significant pressure on retailers to streamline their operations efficiently and expedite product delivery to customers.

In this study, we explore two omni-channel implementations, namely, ship-from-store and home delivery. Store customers can opt for in-store fulfillment or request home delivery, whereas online orders can be shipped from the fulfillment center or any other store location that maximizes the retailer's overall profit. We further consider that both store and online customers can switch across channels. We construct a dynamic programming framework to examine optimal fulfillment decisions for both online and store orders, accounting for uncertainties in both demand and the cost of shipment to individual customers. We present our results through optimal fulfillment strategies and numerical experiments.

Keywords: Retail operations, Omni-channel retailing, Channel switching

Inventory Policy for Perishable Products with Diminishing Freshness

Matan Shnaiderman[1], Yael Lahav[1,2], Elad Harison[2] and Jacob Kobi Harush[1,2]

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The main characteristics of perishable products is a predetermined expiration date, after which the economic value of the products diminishes and they cannot be used post expiration. Two types of perishable products exist: First, products that can be consumed prior to the expiration date, but cannot be used after it due to use hazards (e.g., medical products). Second, products whose degree of freshness deteriorates over time until they cannot be used after their shelf-life period (e.g., agricultural products). These two types of products may be perceived as a single type, given the limited shelf-life duration, which may affect their salability. The study presents a model in which a retailer addresses demand for a perishable product that is divisible into multiplicative components according to the freshness level of the product and its selling price. The study also analyzes how quantity optimization vs. profit maximization decisions determine the order quantity. Additionally, the model enables retailers to determine the level of inventory that maximizes their profits.

Keywords: Global Optimization, Logistics, Supply Chain Management.

Improving Order Fulfillment Efficiency in Industrial Environments: A Decision Support System

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This study aims to improve the efficiency of order fulfillment in an industrial environment where goods are transferred from peripheral warehouses to a central facility for order consolidation and shipment.

In this scenario, the decision-making process integrates multiple factors which previously have mostly been considered individually. These include (i) the management of warehouses with specific travel times, (ii) the selection of different stock unit configurations, (iii) the choice of transportation modes with diverse costs and capacities, and (iv) the assignment of specific product features to each order to ensure homogeneity. These decisions must be coordinated to meet customer demand while minimizing transport and retrieval costs. In addition, many companies currently rely on manual information flow, resulting in costly and time-consuming operations.

To address these challenges, we propose a Decision Support System (DSS) that integrates material flow optimization and information flow digitalization. Optimization is reached by means of an integer linear programming model that considers all the different decisions. Digitalization is reached by relying on a software infrastructure that periodically reads orders, ensures stock availability, runs the optimization model, and integrates the decisions into the enterprise resource planning system. The DSS is designed to ensure scalability and portability and includes an intuitive user interface for order monitoring.

The DSS was tested over a real-world case study conducted in collaboration with an international ceramic tile company headquartered in Italy. Comparative analysis against manual solutions revealed a significant reduction in transportation costs, ranging from 24% to 40%, along with a reduction of non-added-value activities of approximately 120 hours per month. Consequently, the implementation of the DSS offers substantial cost savings by both optimizing stock transfers and maximizing valuable working hours.

Keywords: Decision Support System, Optimization, Digitalization, Transportation Plan, Peripheral Warehouses

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Session: Networks 4

Thursday September 12th 11:30am - 12:30am

Room Nautilus

Chair: Francesco Carrabs

Anonymizing networks via mathematical programming

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Social network data sets are often published and used for analysis purposes in many application domains. This may raise privacy issues, as simply hiding the identity of the users does not prevent an adversary from tracing back to the real-world entities associated with certain nodes of the network having sufficiently distinguishable features from others [1]. To protect individuals' privacy, networks are commonly anonymized before publication. In this context, the k-degree anonymization problem, originally introduced by Liu and Terzi [2], aims to identify the smallest set of modifications of the edge set of a network needed to make it k-degree anonymous, meaning that each user of the anonymized network will have the same number of connections as at least other $k-1$ users. In such a definition, different k values reflect different privacy requirements w.r.t. the vertex degree feature. This work addresses different settings of the problem allowing edge insertions and/or deletions. We compare different families of integer linear programming formulations of the problem on benchmark social network instances and additionally derive some properties and valid inequalities that we exploit in the solution process.

Keywords: social networks, k-degree anonymity, mathematical programming

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Heuristic approaches for the Anchored k-Core Problem

Raffaele Cerulli[1], Elvira Plenzich[1], Carmine Sorgente[1] and **Roberto Tufano**[1]
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The Anchored k-Core (AKC) problem, introduced by Bhawalkar et al. [1], poses a crucial challenge in preserving the cohesion of social networks. Individual actions of the users in a social network significantly influence the interaction of their connections, occasionally leading to their disengagement as an adverse effect. This indicates the importance of identifying the most influential users, whose incentivization to remain engaged by the network provider is essential to uphold the cohesion of the whole network.

Formally, given a graph $G = (V, E)$, an integer k, and a budget b, the problem aims to select b nodes, named *anchors*, in such a way that the number of nodes in the resulting AKC is maximized, where the AKC is the maximal induced subgraph of G where each vertex has a degree at least k, except for the selected anchors, which may have a lower degree.

The AKC problem is solvable in polynomial time for $k \leq 2$, while it becomes NP-hard and inapproximable for $k > 2$ [1]. Both heuristics [2,3] and exact formulations [4] have been proposed in the literature. The focus of this work is solving the AKC problem with a fixed budget through heuristic approaches. The performances of the developed algorithms are systematically compared with those of the state-of-the-art approaches, using benchmark instances available in the literature dedicated to social network analysis.

Keywords: Combinatorial optimization, Anchored k-Core, Heuristics

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The bi-objective minimum spanning tree problem: a parallel approach

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Multi-objective combinatorial programs, optimization problems characterized by the simultaneous optimization of multiple objectives over a discrete feasible set, are often NP-hard and the generation of their complete Pareto frontier is time consuming. This talk presents a preliminary work on a parallel two-phase algorithm for the bi-objective minimum spanning tree (BMST) problem designed to speed up the search for efficient solutions. In the first phase, the extreme supported efficient solutions are computed by resorting to an algorithmic approach (Prim embedded in a dichotomic search); in the second phase, the non-extreme supported and non-supported efficient solutions are determined. In this latter phase, a parallel approach for the generation of all spanning trees of a connected graph through edge interchanges based on increasing evaluation of reduced costs of associated weighted linear programs is adopted. The results of preliminary computational experiments will be presented.

This work has been supported by University of Rome La Sapienza grant number RM1221816BB0FEE3 and by Unione europea - Next Generation EU grant number 20223MHHA8

Keywords: multiple objective programming; combinatorial optimization; minimum spanning tree; two-phase methods; parallel computing

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Kernel Search approach to solve the Minimum Spanning Tree Problem with conflicting edge pairs

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In this talk, we deal with the Minimum Spanning Tree Problem with Conflicting Edge Pairs (MSTC)[2-5], a variant of the classical Minimum Spanning Tree where, given a list of conflicting edges, the goal is to find the cheapest spanning tree with no edges in conflict.

We face the problem using a tailored Kernel Search (KS) heuristic method [1] whose aim is to identify the most promising variables of a MILP model and construct and solve restricted subproblems based on them. The promising variables are the ones having a high probability to take a value greater than zero in the optimal solution. The set of promising variables is named *kernel set* and it is updated during the computation. The remaining variables are partitioned into *buckets* used to build the subproblems. In order to improve the effectiveness of the algorithm, through a better partitioning of the variables into the kernel set and the buckets, we use the independent sets of proper subgraphs of the conflict graph because the set of edges of any feasible solution of MSTC corresponds to an independent set in the conflict graph. We believe that the use of the independent set to improve the effectiveness of KS can be extended to other optimization problems with conflicts, whenever the conflict graph is used.

The computational results, carried out on benchmark instances, show that our approach provides competitive results with respect to the other heuristics proposed in the literature.

Keywords: Spanning Tree, Conflict Edges, Kernel Search

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Session: ACHILLES PRIN and CN MOST PNRR Projects – on ecosustainable and innovative last-mile logistics solutions

Thursday September 12th 11:30am - 12:30am

Room Rocce

Chair: Claudio Sterle

Optimization of green vehicles and crowdsorcing in the last mile deliveries

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Last mile deliveries represent a critical component of modern supply chains, accounting for a significant portion of logistics costs and environmental impact. In this talk, we propose an optimization framework that integrates the use of green vehicles and crowdsourcing to enhance the efficiency and sustainability of last mile deliveries. The optimization model considers various factors such as vehicle routing, vehicle selection, and crowd participation to minimize delivery costs and carbon emissions while meeting customer demands and delivery constraints. Furthermore, we develop a mathematical formulation to solve the proposed optimization problem, taking into account dynamic factors such as traffic conditions and delivery demands. Through numerical experiments, we demonstrate the effectiveness and practical applicability of the proposed framework in real-world scenarios. Our results indicate significant cost savings and environmental benefits achievable through the integration of green vehicles and crowdsourcing in last mile deliveries. This research contributes to advancing sustainable logistics practices and provides valuable insights for decision-makers in the transportation and logistics industry.

Keywords: Parcel delivery, Supply chains, Networks, Nonlinear Optimization

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The Covering Tour Problem with Arc Upgrade

Marta Baldomero-Naranjo[1], Maurizio Boccia[2], **Andrea Mancuso**[2],Adriano Masone[2], Antonio M. Rodríguez-Chía[1] and Claudio Sterle[2,3]

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In this study, we introduce the *Covering Tour Problem with Arc Upgrade* (*CTPAU*), an extension of the *Covering Tour Problem* (*CTP*) that exploits the possibility of enhancing the network by upgrading arcs. The *CTP* is defined on a graph consisting of three sets of nodes: those requiring coverage, those eligible to provide coverage, and a subset of the latter which must be visited. The objective is to determine the minimum cost tour that complies with both visiting and covering requirements. We introduce a further layer of complexity by exploring the possibility of arc upgrades. Such upgrades decrease the length of an arc, usually within specific limits, incurring a cost directly proportional to the degree of reduction. Thus, the *CTPAU* aims to determine the minimum cost tour that meets the *CTP* requirements and incorporates the possibility of upgrading arcs, while adhering to budget constraints. In this context, we present three *MILP* formulations for the *CTPAU* differing in the way subtours are tackled. The proposed formulations have been experienced and compared on benchmark instances from *TSPLIB* to assess our approach.

Keywords: Covering Tour Problem, Arc Upgrade, *MILP* formulations, Branch & Cut

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A classification-based heuristic approach for truck-and-drone routing problems

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The growing interest in innovative delivery systems to lower the costs of last-mile logistics has led the definition of new and complex vehicle routing problems. Within this context, problems involving the use of autonomous vehicles (e.g., drones) and/or service points (e.g., parcel lockers) as alternatives to traditional home deliveries by truck have received significant attention from the Operations Research Community. In recent years, several variants of truck-and-drone routing problems have emerged, differing in operating conditions and the structure of the hybrid delivery system. Given the complexity of these problems, exact solution methods typically can solve only small-size instances. As a result, heuristic solution methods must be developed to find good solutions with an acceptable computational burden. This work proposes a novel heuristic approach that integrates data science and machine learning techniques with combinatorial optimization methods. The aim is to determine a good/optimal customer-to-vehicle assignment a priori to reduce the solution space of the truck-and-drone routing problem. The assignment is determined by classifying customers based on a subset of features specifically defined for the problem. This information is then utilized to construct the route of the delivery system. An extensive computational campaign on benchmark instances has been carried out with a twofold objective. Firstly, we aim to evaluate the impact of features on customer classification. Secondly, we intend to demonstrate the benefits of combining classification with combinatorial optimization methods.

Keywords: Heuristic, Truck-and-drone, Routing

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Exact and Matheuristic approaches for the Truck-Drone Team Logistics Problem

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Truck-and-drone routing problems are a topic of increasing interest due to advancements in drone technology. Initially, drones were thought to serve only one customer per flight; however, recent improvements in drone technology have led to the definition of multi-visit truck-and-drone routing problems, where a drone can serve multiple customers in each flight. These routing problems, which require a careful synchronization between the truck and the drone, are challenging to solve, even with a small number of customers. In this work, we address a multi-visit, single-truck, single-drone routing problem also known in the literature as the Truck-Drone Team Logistics Problem (*TDTLP*). In particular, we study two versions of the *TDTLP* arising from the possibility for the drone to land or hover at the recollection points. Our study proposes a novel mixed-integer linear programming formulation for the *TDTLP*, solved by a Branch-and-Cut (*B&C*) algorithm. Then, we introduce a matheuristic approach that incorporates our *B&C* algorithm to solve medium- and large-size instances. Computational results on benchmark instances demonstrate the robustness and efficacy of the proposed methods.

Keywords: truck-and-drone delivery, MILP, mathheuristic

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