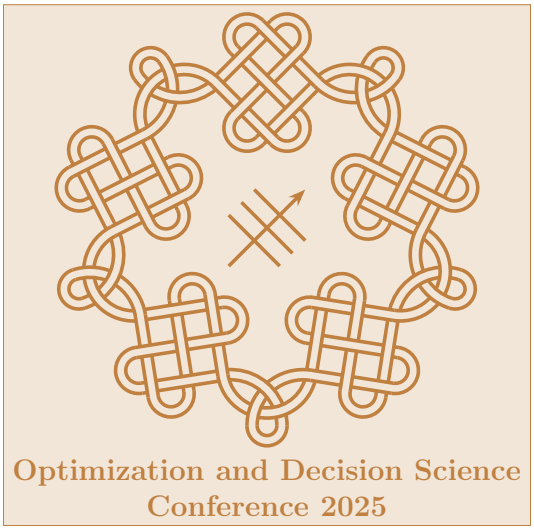


ODS2025

INTERNATIONAL CONFERENCE on
OPTIMIZATION and DECISION SCIENCE

Milano (Italy) September 1st - September 4th – 2025

Book of Abstracts

hexaly

This book contains all of the abstracts accepted for presentation at the International Conference on Optimization and Decision Science, ODS2025, held in Milano from the 1st to the 4th of September, 2025. ODS2025, organized by AIRO, the Italian Operations Research Society is entitled "Mathematics, algorithms and the art and science of decision-making". The conference scope includes operations research, optimization, problem solving, decision making and their applications. The book of abstracts contains 217 contributions, 30 of which associated to papers accepted for publication in the AIRO Springer Series volume devoted to the conference. The contributions are organized into four parallel streams and 53 sessions, 27 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. The conference hosts also satellite events; among them the UltraOptymal workshop, whose presentations are featured in this Book of Abstracts.

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We also acknowledge the contribution from the following partners:



Invited Sessions

PRIN UltraOptymal organized by Francesca Maggioni, Daniele Manerba, Enza Messina and Francesca Vocaturo

Combinatorial optimization organized by Paolo Toth

Optimization under uncertainty organized by Francesca Maggioni

Scheduling organized by Alessandro Agnetis, Gaia Nicosia and Andrea Pacifici

Packing and cutting organized by Michele Monaci

Equilibria, variational models and applications organized by Mauro Passacantando and Fabio Raciti

Math programming software (Hexaly) organized by Thierry Benoist

Healthcare organized by Giuliana Carello and Elena Tanfani

Human and algorithmic decision-making organized by Giovanni Righini

OPTSM - Railway optimization organized by Valentina Cacchiani

OPTSM - Public transport optimization organized by Valentina Cacchiani

Location organized by Serena Fugaro

Energy systems organized by Maria Teresa Vespucci

AIRO Young Dissertation Award organized by Matteo Cosmi

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PRIN WOW organized by Raffaele Cerulli

PRIN HEXAGON organized by Stefano Gualandi

Roundtables

Communicating mathematics and O.R. organized by Alice Raffaele

Sportello Matematico per l'Innovazione e le Imprese organized by Serena Fugaro and Emanuele Pizzari

Reviewing papers and responding to reviewers organized by Matteo Cosmi

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Plenary Session

Monday September 1st 9:10am - 10:10am

Room 3

Chair: Francesca Maggioni

Perspectives on Using Benders Decomposition to Solve Two-Stage Stochastic Mixed-Integer Programs

Walter Rei[1]

[1]School of Management - University of Quebec in Montreal

Benders decomposition has shown great potential as an efficient method for solving two-stage stochastic integer programs. As originally proposed, these programs are decomposed by partitioning the decision variables into two groups: the first-stage decisions, which define a master problem, and the second-stage decisions, which define a set of subproblems. An optimal solution is then obtained by successively solving the master and subproblems until the master's solution can be certified as optimal, with the subproblems used to generate violated cuts that strengthen the master's formulation. Although this decomposition strategy has produced successful results, recent studies suggest that the partitioning choices underlying the decomposition deserve to be revisited. Specifically, the Benders method can be significantly enhanced and accelerated by transferring information from the subproblems to the master, thereby strengthening the master's formulation, or by sending information in the opposite direction, from the master to the subproblems, to improve the quality of the generated cuts. In this talk, I will highlight these new strategies for partitioning decision variables and discuss how to effectively implement these enhancements within the Benders framework. These ideas will be illustrated with numerical results on stochastic network design problems, demonstrating the practical impact of these methodological advances.

Keywords: Benders decomposition, Mixed-Integer Programs

Session: Uncertain logistics problems with pickup points in urban areas

Monday September 1st 10:10am - 11:10am

Room 3

Chair: Francesca Vocaturo

Utilizing Parcel Lockers and Crowdshipping with In-Store Shoppers for Dynamic Pickup and Delivery

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This study investigates a hybrid logistics system that combines parcel lockers and crowdshipping with in-store shoppers to improve last-mile delivery efficiency. It addresses rising demand for faster, more sustainable, and cost-effective services. Physical stores act as micro-fulfillment centers, enabling the preparation of unpredictable online orders. Crowdshipping with in-store shoppers accelerates processing by picking items directly from store inventory, reducing both time and operational costs. Parcel lockers offer customers a convenient and secure pickup option, improving delivery speed and reducing transportation costs. The system faces a same-day pickup and delivery problem, where requests and the appearance of in-store crowdshippers emerge dynamically and stochastically. In-store crowdshippers complement the delivery capacity of a fixed fleet of dedicated vehicles. We model the uncertain arrival of requests and appearance as a Markov decision process (MDP), aiming to minimize total service costs (including transportation, crowdshipper compensation, and late-delivery penalties) through optimal request assignment and routing. However, identifying the optimal policy for the MDP is intractable due to the curse of dimensionality affecting state, action, and random outcomes. To address this, we propose an anticipatory policy in which requests are assigned to routes at a dispatching epoch by solving a tailored team orienteering problem. In this model, each request's profit includes the expected value of it being served by an in-store shopper. This value is estimated using a learning-based algorithm, enabling proactive and efficient decision making that balances in-store and vehicle-based resources. We perform a computational study to evaluate the performance of the proposed algorithm.

Keywords: last-mile logistics, approximate dynamic programming, Markov decision process

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A Stochastic Programming approach for combined forward and reverse logistics in hub-and-spoke e-commerce networks

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A robust strategy to managing e-commerce logistics integrates forward and reverse logistics systems, ensuring the collection of returns alongside traditional product distribution. This technique employs hub-and-spoke networks to aggregate both distribution and collection demands from several customers into a few central hubs. Within this framework, we examine a complex variant of the Vehicle Routing Problem with divisible deliveries and pickups where each hub may have mandatory delivery and return pickup demands and can be visited multiple times within the same or different routes [1]. Due to the large fluctuation of demand within the aggregating hubs, we also assume that an uncertain optional pickup quantity may arise and propose a two-stage Stochastic Programming formulation including ad-hoc recourse actions. To tackle the complexity of solving this model using numerous scenarios, we have developed a Progressive Hedging-based matheuristic approach [2]. This method exploits a scenario problem decomposition, an Augmented Lagrangian Relaxation framework, and various heuristic enhancements. Our approach overcomes state-of-the-art solvers in terms of solution quality and efficiency over a representative set of realistic instances and can be readily adapted to similar contexts.

Keywords: Hub-and-spoke networks, Two-stage stochastic programming with recourse, Progressive Hedging approach

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The Waste Collection Routing Problem with Time-Varying Stochastic Demand

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Waste collection is a fundamental service performed in urban areas, which heavily relies on vehicle routing [1]. In this field, we introduce the Waste Collection Routing Problem with Time-Varying Stochastic Demand (WCRP-TVSD), where a homogeneous fleet of vehicles must visit a set of collection points under capacity constraints. We divide the planning horizon (or day) in not-overlapping time slots. Each collection point is associated with a known initial demand. For each collection point and for each time slot, additional (uncertain) demand may arise. The demand increments are revealed upon arrival at the collection points, but an estimation of such additional demand is known in advance and depends on the nature of the collection point. For example, a restaurant is more likely to produce a higher quantity of waste in the afternoon than in the early morning, while a school probably shows the opposite pattern. The WCRP-TVSD consists of designing vehicle routes for service purposes that visit each collection point exactly once during the planning horizon. The set of planned routes has to be consistent with the number of available vehicles. The aim is to minimize the expected total cost given by net routing costs and penalties associated with uncollected waste at the end of the planning horizon. Note that the quantity of waste left over for the next day at a collection point is due to several reasons (e.g., unexpected events of "capacity saturation" or natural accumulation after the planned visit). We formulate the WCRP-TVSD as a two-stage stochastic program and propose a scenario-based approach for its resolution. In addition, we present for the WCRP-TVSD a faster machine learning procedure which encompasses several deterministic policies. Extensive computational experiments show the effectiveness of this procedure.

Keywords: Urban Logistics, Stochastic Programming, Machine Learning

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Plenary Session

Monday September 1st 11:30am - 12:30am

Room 3

Chair: Francesca Maggioni

Inbound Truck Scheduling with Estimated Times of Arrival

Ola Jabali[1]

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We address the problem of dynamically scheduling inbound trucks at a warehouse with known service times and uncertain arrival times. Truck arrival time distributions are hidden. However, we approximate them via estimated times of arrival (ETAs). The objective is to minimize the total expected waiting time. We use information relaxations and an information penalty to develop a dual bound on the cost of an optimal policy. A series of theoretical analyses establishes the dual problem and then transforms it from a stochastic dynamic program to a compact mixed integer linear program. On average, the penalized dual bound is nearly 10 percent stronger than a bound based on perfect information. We propose a lookahead policy that uses ETAs to adapt decisions to new information. When the dispatcher can fully observe truck arrival time distributions, the gap between the policy value and the dual bound is less than one percent. This result suggests that when distributions are hidden, the larger duality gap of about 10 percent we find is due primarily to partial observability and that the policy makes good decisions. Relative to industry practice, the lookahead policy decreases expected waiting time by 29 percent, on average. Further, the lookahead policy selects actions quickly enough to be used in practice.

Keywords: Scheduling, Stochastic Dynamic Programs, Mixed-Integer Programs

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Session: Combinatorial optimization 1

Monday September 1st 14:20 - 15:40

Main Room

Chair: Paolo Toth

Evaluation of the effect of data generation and asymmetry in new capacitated vehicle routing test instances

Willem Meiring, Jan van Vuuren, Paolo Toth

Developments in vehicle routing problem research rely fundamentally on the availability of robust and realistic benchmarking test instances. The impact of different data generation methods and distance matrix properties, particularly asymmetry and the method of distance measurement, on the performance of a capacitated vehicle routing problem (CVRP) model is investigated empirically in this paper. Factors such as customer distribution and depot locations are also considered. A full factorial experimental design is employed to evaluate performance variations upon adopting the standard settings in the commercial solver CPLEX. New, realistic sets of CVRP test instances are generated for this purpose and are made publicly available. In our experimental study, a maximum relative deviation of up to 194% in distance measurements was observed when comparing the symmetric Euclidean distance metric with real asymmetric road distances. As a result, the use of real asymmetric road distance is strongly recommended when testing VRP models and algorithms in the context of urban routing problems.

A Hybrid Genetic Search Algorithm with Advanced Diversity Control for The Multi-Vehicle Inventory Routing Problem with Time-Windows

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The Inventory Routing Problem (IRP) combines inventory management and delivery vehicle routing into a unified decision-making process, resulting in a complex combinatorial optimisation problem. It is an extension of the classical Vehicle Routing Problem (VRP) in which inventory replenishment decisions are incorporated, requiring the simultaneous optimisation of delivery schedules, quantities, and routes over a planning horizon. As a result of the computational complexity of solving IRP instances exactly, hybrid (meta)heuristic and matheuristic approaches have become increasingly popular for obtaining high-quality solutions within realistic time frames. Matheuristics draw from the power of commercial solvers within a metaheuristic framework to enhance solution quality and efficiency. In this paper, we introduce a new matheuristic adaption of the celebrated Hybrid Genetic Search with Adaptive Diversity Control (HGSADC) algorithm, originally proposed for solving large-scale VRP instances, tailored to address the unconstrained multi-vehicle IRP with time-windows. The algorithm's performance is evaluated with respect to a large set of adapted IRP benchmark instances, thereby demonstrating its ability to produce high-quality solutions within reasonable computational times.

Enhancing Kernel Search with Pattern Recognition: the Single-Source Capacitated Facility Location Problem

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We introduce Pattern-based Kernel Search (PaKS), a two-phase matheuristic for the solution of the Single-Source Capacitated Facility Location Problem (SSCFLP) that combines a pattern recognition technique with a Kernel Search (KS) heuristic. KS is an integer programming based heuristic framework that has been shown to produce high-quality solutions for several classes of combinatorial optimization problems, such as knapsack problems [3], general mixed integer linear programs [1], and discrete location problems [2]. We use a pattern recognition technique to identify structural patterns characterizing an optimal (or near-optimal) solution to the SSCFLP. These patterns are then exploited to improve KS. In more details, PaKS employs, in the first phase, spectral biclustering to identify an implicit spatial separation of the facilities and customers into subsets, called regions, each showing strong internal interdependencies. Or, in other words, such that across high-quality solutions customers are generally allocated to facilities within the same region, although possibly assigned to different locations in a solution from another. In the second phase, PaKS employs an enhanced KS that leverages through the interdependencies among decision variables identified beforehand. On a set of 112 benchmark instances, consisting of up to 1,000 locations and 1,000 customers, computational results show that PaKS consistently outperforms both a standard KS implementation and the current state-of-the-art heuristic for solving the SSCFLP, as well as CPLEX when run with a time limit. Experimental results conducted on a large set of new very large test problems, comprising up to 2,000 locations and 2,000 customers, demonstrate that PaKS outperforms both the conventional KS heuristic and CPLEX in terms of quality of the solution found, finding the largest number of best solutions and achieving the smallest average gap.

Keywords: Pattern recognition, Biclustering, Kernel Search, Heuristic framework

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On A Hierarchy Of Integer Quadratic Programming Polytopes

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A folklore result in integer programming is that bounded integer variables can be replaced with binary variables, using bit representation. Under certain conditions, this can be used to reformulate mixed-integer quadratic programs as mixed-integer linear programs, and thereby render them easier to solve. In fact, several reformulation strategies can be found in the literature. We conduct a systematic comparison of these strategies by focusing on integer quadratic programs with box constraints, and present a hierarchy for the associated polytopes.

Keywords: mixed-integer nonlinear programming, global optimisation, polyhedral combinatorics

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Session: Maritime transportation and port logistics

Monday September 1st 14:20 - 15:40

Room 1

Chair: Giacomo Boracchi

Analyzing Infrastructural Changes in Maritime Terminals: Insights from an Operation-Time-Space Network

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In this work, we use a variant of the Time-Space Network (TSN) known as the Operation-Time-Space Network (OTSN) to evaluate the impact of buffer areas outside a maritime terminal. Thanks to OTSN we obtain a graphical representation of the port system, with a specific focus on the maritime terminal. The nodes represent both the operations to be performed and the physical locations where these activities occur. OTSN allows us to monitor ongoing activities and resource consumption during each time slot of a given planning horizon (1).

Inspired by (2), where TSNs have been used to assess a truck appointment system (TAS) for a maritime terminal, we propose to utilize OTSN to evaluate both infrastructural and organizational changes on TAS. In particular, we analyze and evaluate the introduction of new infrastructure, such as buffer areas outside the terminal, in terms of congestion and truck service time.

We developed an OTSN and a flow model based on the proposed network. We implemented the OTSN since it enables the application of capacity constraints that can apply to a single activity, multiple activities, or the entire network, as well as more specific temporal constraints, such as exact times or time windows for the start and/or end of an activity, or maximum dwell time for trucks/containers (i.e., trucks/containers cannot remain in a specific area or node for longer than a specified limit). The system described using the OTSN is based on a port area in the Ligurian region. We utilize the OTSN and the related network flow model to evaluate different port systems, with and without buffer areas, along with various management strategies related to services provided to trucks in the buffer areas. Preliminary results related to tests conducted to validate the accuracy of the model and its capability to solve large instances optimally are presented.

Acknowledgement: This work has been partially supported by the PNRR project Ecosystem RAISE (Robotics and AI for Socio-economic Empowerment)-CUPD33C22000970006-UNIGE: SPOKE 4—Sustainable Ports.

Keywords: Operation Time space network, Truck appointment system, buffer area

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Optimizing Train Unloading Operations in a Maritime Container Terminal

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Maritime container terminals are key infrastructures in the global logistics network, facilitating the transshipment of goods between sea and inland transport modes. Terminal performance relies on the coordination of several interdependent operations. Research has shown that optimized rail-sea exchange systems can significantly reduce handling inefficiencies [1]. In this work we focus on a problem emerging in the rail process, that is, the optimization of the train unloading operations, essential for enhancing efficiency and reducing operational costs. The Train Unloading Planning Problem (TUPP), a novel complex planning problem centered on assigning each container from the train to a suitable yard block in the export area. Each container is associated with specific characteristics such as size, weight, destination and occupies a unique position on the train. The process involves a gantry crane operating the train along the rail track and reach stackers working in the yard. The goal is to create an unloading plan to reduce handling time and resource consumption, thus minimizing the unnecessary equipment movements. To the best of our knowledge, this specific planning problem has not been studied in the literature. We formulate a Mixed-Integer Linear Programming (MILP) model that determines the unloading sequence and container-to-block assignments, aiming to minimize the gantry crane's movements, spreader length adjustments, and the distances traveled by reach stackers, while respecting compatibility and capacity constraints. To improve computational performance, several valid inequalities are introduced. We present preliminary results on test instances involving up to 40 containers loaded on a train. While the MILP model can solve small instances optimally, the inclusion of valid inequalities improves the solver's performance by reducing computation time and the optimality gaps in larger instances. This work establishes a foundation for further methodological development in the context of train unloading optimization.

Keywords: Maritime Container terminal, Train unloading operations, Mixed integer linear programming

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Simulation-Optimization Approaches For Enhancing Ports Operational Efficiency

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Optimization-based decision support systems are essential in managing the complexity of modern container terminal operations, where efficient resource allocation and process coordination are critical. This study investigates the application of a simulation-optimization approach, developed in Witness Horizon, to support operational decision-making in the management of import container flows. The proposed model integrates key real-world constraints such as yard capacity, variable travel times, and stochastic arrival patterns, reflecting the dynamic nature of terminal logistics. The discrete-event simulation model is combined with an optimization module, enabling the application of meta-heuristics and optimization algorithms. This study aims to identify fleet configurations that minimize container dwell time and CO_2 emissions. The framework is designed to be adaptable to varying operating conditions through parameter-driven adjustments, ensuring scalability and contextual flexibility. Results from a case study inspired by operations at the Port of Genoa (Italy) demonstrate the applicability of the approach. The analysis confirms that hybrid fleet configurations, combining diesel and electric vehicles, offer the best trade-off. By embedding operational constraints and domain knowledge within the optimization loop, this work contributes to the development of practical, data-driven methodologies for improving terminal performance, reducing energy consumption, and informing strategic planning in container yard management.

Optimization Of Mobility Policies In Port-City Scenarios Through Simulation And Surrogate Models

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A port located within a city is a paradigmatic example of an area where logistic and mobility flows interact systematically, giving rise to negative phenomena like pollution and congestion. Thus, the adoption of innovative mobility policies is a key factor to mitigate the externalities and maximize the economic benefits. Here we focus on the optimization of lane-restriction policies, which is far from trivial because of the complexity of the traffic dynamics in an area shared by trucks and mobility flows. Therefore, the optimization process needs to take into account all the factors influencing the network, e.g. traffic light timings, for the new policy to be beneficial. Thus, in this paper we propose a method, based on the combination of traffic micro- simulation and deep learning models, to evaluate and optimize the impact of mobility policies acting in port-city contexts. In the paper we provide a case study focused on the port-city context of Genova, Italy, one of the most important ports of the Mediterranean Sea. Our simulation tests show how the proposed methodology can be a useful tool to evaluate a priori the possible adoption of a new policy, allowing many insights on its impact and maximizing its benefits.

Session: Traffic management

Monday September 1st 14:20 - 15:40

Room 2

Chair: Valentina Morandi

Strategic route pricing model for air traffic management for CO_2 emissions and congestion reduction

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European air traffic management faces significant challenges due to high demand, congestion, and environmental concerns. Airlines aim to minimize operational costs, often favouring shorter routes to reduce fuel consumption and route charges. However, disparities in Air Navigation Service Provider (ANSP) unit rates and congestion can incentivise longer, less efficient routes (Castelli et al., 2013), leading to increased CO_2 emissions. This study proposes a strategic approach to optimize flight trajectories (Bolić et al., 2017) and pricing mechanisms to balance cost efficiency, congestion management, and environmental impact. A multi-stage modelling framework is introduced, combining continuous linear programming for traffic redistribution, quadratic programming for trajectory pricing, and integer linear programming for daily traffic management. The results demonstrate the potential of this approach to reduce emissions and congestion while maintaining ANSP cost of service and operational feasibility. This work highlights the importance of integrated strategic planning to address the complex interplay between economic and environmental factors in air traffic management.

Keywords: Air Traffic Management, route pricing, emission reduction

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Improving Social Cost in Mixed-Autonomy Road Traffic Networks with Evolutionary Stackelberg Routing

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An Evolutionary Stackelberg framework is proposed for a two-population routing game, where a central controller with bounded rationality manages a fleet of autonomous vehicles that share road networks with human-driven cars. The objective of the central controller is to select routes for its vehicles that minimise social costs. To facilitate the operation of these autonomous vehicles, the E-Aloof strategy is employed. This is a low-information, adaptive online learning strategy, whereby the leader is only required to observe the instantaneous distribution of traffic, with no requirement for the storage of past system states. This approach can be regarded as an evolutionary adaptation of the Aloof strategy, a greedy static Stackelberg strategy. In contrast, human drivers exhibit behaviour that is both selfish and myopic, adapting their routing strategies in accordance with the Stackelberg Replicator Dynamic. This dynamic assumes that drivers make decisions by comparing their travel costs with those incurred by other vehicles they encounter. A comparison analysis between the different strategies is carried out in a nonatomic routing game on a n-parallel link network with linear cost functions. In particular, it is verified under which assumptions low-information and no-information strategies are equivalent in terms of social cost.

Keywords: Intelligent Transportation Systems, Smart Cities, Stackelberg Routing, Evolutionary Game Theory, Stackelberg Evolutionary Game Theory

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Smart Departures: A Novel Framework for Balancing Travel Inconvenience and Congestion Control

Fabio Buffoli[1], Carlo Filippi[1], Valentina Morandi[1], Maria Grazia Speranza[1]
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In densely populated, industrialized regions, highway congestion inconveniences drivers and causes economic losses and environmental degradation. This study tackles these challenges by introducing an experimental optimization framework that concurrently schedules departure times and selects travel routes to ease overall congestion while minimizing individual delays.

The proposed framework embeds an optimization model within a comprehensive system that operates on a rolling planning horizon. Rather than focusing extensively on real-time technological integrations, the approach emphasizes constructing a feasible set of alternative paths—restricting choices to those within a specified margin of the fastest route—and optimally assigning departure times to sustain balanced flows throughout the network. Initially formulated as a convex nonlinear program, the model is reformulated into a linear programming (LP) model via a modified piecewise linearization technique, thereby ensuring computational efficiency for large-scale networks.

Extensive computational experiments conducted on a realistic highway network in Northern Italy demonstrate the platform's effectiveness in harmonizing individual travel comfort with overall network performance. Future developments will be briefly discussed, outlining potential enhancements to scalability and adaptability in evolving urban traffic management systems.

Keywords: Traffic optimization, Departure time scheduling, Congestion control, Linear programming, Smart mobility

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Real-time rerouting of traffic flows to control the risk of disruptions

Valentin Morandi[1], Lorenzo Peirano[1], Maria Grazia Speranza[1]
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We present a study of a real-time system designed to ensure the safety of monitored road infrastructures (such as bridges and overpasses) while managing the congestion of the surrounding road network. To address this challenge, the system collects information about risk levels and traffic density and detects incoming vehicles directed toward these structures. We introduce an optimization model formulated as a MILP problem, known as the Time-dependent Risk-AvoidiNg System-optimum (TRANS) model. The TRANS model allows each of the detected vehicles to traverse a monitored road structure or assigns to it a new path with the goal of finding a trade-off between the risk of disruptions or damages and the congestion level in the surrounding network. The increase in travel time of a new path with respect to the preferred path through a road structure is controlled to guarantee fairness to drivers, as in Angelelli et Al.(2021). The goal of the model is to assign to each incoming vehicle a path such that the risk threshold is met and the congestion level of the surrounding network is minimized. The efficient frontier between risk and congestion is obtained by varying the value of the risk threshold. Computational experiments, run on data taken from the real case of a bypass bridge of Brescia provided in Ventura et Al.(2024), show that the proposed approach is capable of significantly reducing traffic congestion while keeping the risk of dangerous situations under control.

Keywords: Coordinated approach, real-time control, optimal path, route guidance.

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Session: Decision-making under uncertainty in network design and routing problems

Monday September 1st 14:20 - 15:40

Room 3

Chair: Daniele Manerba

A Consensus Fixing Based Heuristic for Liner Shipping Network Design with Stochastic Demands

Mikkel Lassen Johansen[1], David Pisinger[1]

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To reach the sustainability goals in maritime shipping, it is important to design a route network that ensures a good utilization of the resources while ensuring sufficient capacity to satisfy the demand. The network design is complicated by very fluctuating demand due to seasonal variation in production and demand. We consider two-stage stochastic liner shipping network design problem, where the first-stage decisions are to design the network, while the second-stage decisions are to flow the containers in the most efficient way depending on the given demand scenario. A highly parallel heuristic is presented based on consensus fixing: The first-stage decisions are solved using a ALNS framework while the flow problems are solved independently for each scenario using an fast column generation algorithm. Then, the scenarios try to reach consensus about fixing a single first-stage variable, using various score and select functions. The process of alternating between heuristic solution (first-stage), column generation (second-stage) and variable fixing is repeated until all first-stage variables have been fixed. Computational results are reported for real-life instances from LINER-LIB, showing that high-quality solutions are obtained within reasonable CPU time.

Acknowledgement: This work is funded by ERC-2022-ADG, project 101093188 DECIDE. This work is part of the UltraOptymal Workshop.

Keywords: two-stage stochastic optimization, scenario analysis, metaheuristics, consensus fixing, adaptive large neighborhood search, liner shipping network design, column generation, LINER-LIB

A Benders decomposition approach for a green bi-objective stochastic fleet size and composition vehicle routing problem

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In this study, we examine the optimization of fleet size and mix, together with vehicle routing, under uncertain demand conditions, with explicit consideration of sustainability aspects in the context of Last Mile logistics. We propose a two-stage bi-objective stochastic mixed-integer programming model that simultaneously minimizes total costs and vehicle emissions associated with delivery activities. The first-stage tactical decisions involve determining the fleet size, composition, and consistent routing, whereas the second-stage operational decisions pertain to the allocation of parcels to be delivered and the selection of customers to be served by an external delivery provider. The ε-constraint method is applied to transform the bi-objective problem into a single-objective formulation, enabling the identification of all Pareto-optimal solutions. To cope with the computational challenges posed by real-world instances, an L-shaped algorithm is designed and implemented within the ε-constraint framework. The performance of the L-shaped approach is evaluated, demonstrating that it provides cost-effective solutions in short computational time. Managerial insights are finally discussed.

Acknowledgement: This work is part of the UltraOptymal Workshop.

Keywords: Green fleet composition and routing, Multi-objective stochastic optimization, Last Mile logistics

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A Stochastic Electric Vehicle Routing Problem under Uncertain Energy Consumption

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The increasing adoption of Electric Vehicles (EVs) for service and goods distribution operations has led to the emergence of Electric Vehicle Routing Problems (EVRPs), a class of vehicle routing problems addressing the unique challenges posed by the limited driving range and recharging needs of EVs. While the majority of EVRP variants have considered deterministic energy consumption, this work focuses on the Stochastic Electric Vehicle Routing Problem with a Threshold recourse policy (SEVRP-T), where the uncertainty in energy consumption is considered, and a recourse policy is employed to ensure that EVs recharge at Charging Stations (CSs) whenever their State of Charge (SoC) falls below a specified threshold. We formulate the SEVRP-T as a two-stage stochastic mixed-integer second-order cone model, where the first stage determines the sequences of customers to be visited, and the second stage incorporates charging activities. The objective is to minimize the expected total duration of the routes, composed by travel times and recharging operations. To cope with the computational complexity of the model, we propose a heuristic based on an Iterated Local Search (ILS) procedure coupled with a Set Partitioning problem. To further speed up the heuristic, we develop two lower bounds on the corresponding first-stage customer sequences. Furthermore, to handle a large number of energy consumption scenarios, we employ a scenario reduction technique. Extensive computational experiments are conducted to validate the effectiveness of the proposed solution strategy and to assess the importance of considering the stochastic nature of the energy consumption. The research presented in this work contributes to the growing body of literature on EVRP and provides insights into managing the operational deployment of EVs in logistics activities under uncertainty.

Keywords: Routing, Electric Vehicles, Uncertain Energy Consumption, Stochastic Programming, Iterated Local Search, Scenario Reduction

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Multiple Recovery Options and Customer Availability Profiles to face Synchronization Failures in Attended Home Delivery

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In the growing sector of Attended Home Delivery, unsynchronized deliveries between couriers and recipients affect both customer satisfaction and company costs. Hence, reducing such failures improves company service quality and logistics efficiency [1]. To address this issue, we study an Attended Home Delivery Problem with Recovery Options (AHDPRO) in which customers specify their probability of being at home during different timeslots of the day [2] and their preferred recovery option in case of a synchronization failure. The options include leaving the package in a predefined safe location, bringing it to a generic collection point, or scheduling a second delivery attempt. Each alternative involves different costs and, in most cases, additional operational decisions. The AHDPRO aims to complete all customer deliveries while minimizing overall routing times as well as the overall penalty due to the recovery actions implemented and weighted by the probability of a synchronization failure to occur. We propose a branch-and-cut algorithm, including valid inequalities and heuristic procedures, to solve a Mixed-Integer Linear Programming model based on an expanded graph. Using the developed method as a tool for evaluating costs and operations, we conduct an experimental campaign on scenarios adapted from the literature involving lexicographic-based optimization procedures able to address the multiple attributes of the solutions. The results obtained allow us to assess the impact of different recovery options, timeslot lengths, perceived service quality, and other key operational factors on the optimal solutions and their values [3]. Finally, to tackle very large instances, we develop an Adaptive Large Neighborhood Search, enhanced with ad-hoc operators and exploiting parallel computing, which produces high-quality solutions outperforming state-of-the-art exact and heuristic solvers.

Keywords: Attended Home Delivery, Recovery options, Customer Availability Profiles

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Session: Non-linear optimization

Monday September 1st 16:20 - 18:00

Main Room

Chair: Vittorio Latorre

A globalization strategy for unconstrained nonlinear optimization algorithms based on curvilinear searches

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In this work, we deal with unconstrained nonlinear optimization problems. Specifically, we are interested in iterative methods that carry out updates along directions that might be not of descent, such as Polyak's heavy-ball algorithm. Instead of enforcing global convergence properties through line searches and the modification of the search direction in case suitable safeguards are not satisfied, we propose a strategy based on searches along curve paths.

In this latter approach, a curve search starting from the first tentative update indeed allows to smoothly revert towards a gradient-related direction as long as a sufficient decrease condition is not met. The resulting algorithm can be proved to possess global convergence guarantees, even in the case of a nonmonotone decrease condition.

While the presented framework is rather general, particularly of interest is the case of parabolic searches; quadratic paths can be conveniently constructed and handled by resorting to Bezier curves; in this specific case, under reasonable assumptions on the first tentative update, the resulting algorithm can be shown to possess optimal worst case complexity bounds for reaching approximate stationarity in a nonconvex setting.

Practically, we show that the proposed globalization strategy allows to consistently accept (optimal) pure heavy-ball steps in the strongly convex case, while usual globalization approaches would at times negate them before even evaluating the objective function. Preliminary computational experiments also suggest that the proposed globalization strategy might be more convenient than classical safeguard based approaches in general nonconvex problems.

Keywords: Curve search methods, Asymptotic convergence, Complexity bounds, Heavy-ball

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Sparse Approximations of the Second-Order Information for Developing Memoryless Versions of the Classic Optimization Algorithms

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It is a matter of routine in the operational research discipline to analyze the relaxed versions of the discrete decision-making models, mainly by converting the integer variables to the real variables in certain intervals. This fundamental scheme makes it possible to benefit from the continuous optimization aspects to design appropriate algorithms to address such discrete models. On the other side, a wide range of practical problems in machine learning and data mining are originally in the framework of nonlinear programming models [5]. Meanwhile, since real-world decision-making models often have high-dimensional forms, we should decrease the computational cost of their solution process to the greatest possible extent. To this aim, devising memoryless versions of the classic algorithms could be helpful [4]. Generally, the optimization algorithms are designed based on successive local searches in the framework of the line search (LS) or the trust-region (TR) approaches. In both the LS and TR algorithms, the current approximation of the optimal solution is updated iteratively [1], by solving a subproblem as a local estimation of the original model. Although there exists a wide range of techniques for approximately solving the LS and TR subproblems, in some cases their solution process may be costly or even unsuccessful. Hence, since the second-order information of the model could play a crucial role in solving both the LS and TR subproblems, it is technically meaningful to develop sparse approximations of the Hessian matrix [2]. With such plans, although we may lose accuracy in some levels, which in large-scale cases is indispensable, the solution process often turns out to be low-cost and more efficient, and we can preserve the convergence. Meanwhile, we can effectively accelerate such memoryless algorithms with heuristic strategies as well [3]. Preliminary numerical experiments show the efficiency of such algorithmic initiatives.

Keywords: Nonlinear programming, Sparse Hessian approximation, Limited-memory algorithm, Accuracy-efficiency balance, Adaptive parametric setting

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Integer programming and difference of convex (DC) optimization

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We introduce an approach to solve a mixed binary linear programming (BLP) problem via DC (differences of convex) optimization. Starting from the non-linear counterpart of BLP, we define an exact penalty version of it. The resulting linear constrained concave minimization problem can be restated by rewriting the objective as the difference of two convex functions. We propose a new DCA two-phase algorithm defined by exploiting the structural properties of our problem. The first phase only ensures the convergence to a feasible solution. Thus, we introduce a second phase heuristic escape approach which is based on the global optimality conditions in terms of epsilon-subdifferential for the convex-constrained DC problem. Some computational results comparing our algorithm with those available in the literature are also discussed.

Keywords: non linear programming, mixed integer programming, difference of convex optimization

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Speed planning by minimizing travel time and energy consumption

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We address the speed planning problem for a vehicle over an assigned path with the aim of minimizing a weighted sum of travel time and energy consumption under suitable constraints (maximum allowed speed, maximum traction or braking force, maximum power consumption). The resulting mathematical model is a non–convex optimization problem. We present a convex relaxation of this problem, which is a Second Order Cone Programming (SOCP) problem, for which efficient solvers exist. Through the numerical experiments we confirm that the convex relaxation can be solved very efficiently and, moreover, we provide the Pareto front of the trade-off between the two objectives. Moreover, we present mild conditions that guarantee that this relaxation is exact. This property guarantees that we can find the global optimum of the original problem with convex solvers. Moreover, the solution is very efficient in terms of computational time. Finally, we present a counterexample showing that, if the previous conditions are not met, the relaxed problem might not be exact.

Keywords: Speed Planning, Bi-Objective Optimization, Minimum Travel Time, Minimum Energy Consumption, Exact Convex Relaxation.

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On Implicit Concave Structures in Half-Quadratic Methods for Signal Reconstruction

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In this work, we introduce a new class of non-convex functions, called implicit concave functions, which are compositions of a concave function with a continuously differentiable mapping. We analyze the properties of their minimization by leveraging Fenchel conjugate theory to construct an augmented optimization problem. This reformulation yields a one-to-one correspondence between the stationary points and local minima of the original and augmented problems. Crucially, the augmented problem admits a natural variable splitting that reveals convexity with respect to at least one block, and, in some cases, leading to a biconvex structure that is more amenable to optimization. This enables the use of efficient block coordinate descent algorithms for solving otherwise non-convex problems. As a representative application, we show how this framework applies to half-quadratic regularization in signal reconstruction and image processing. We demonstrate that common edgepreserving regularizers fall within the proposed class, and that their corresponding augmented problems are biconvex and bounded from below. Our results offer both a theoretical foundation and a practical pathway for solving a broad class of structured non-convex problems.

Session: Last-mile delivery and drones

Monday September 1st 16:20 - 18:00

Room 1

Chair: Carmine Cerrone

Carousel Greedy: From Drone Photogrammetry To Social Network Analysis, Passing Through Logistics Problems And Wireless Sensor Networks, A Systematic Survey And The First Open-Source Python Library

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The Carousel Greedy algorithm has emerged in recent years as a simple and effective technique for solving a broad class of combinatorial optimization problems. Despite its growing adoption in fields such as logistics, graph theory, and network optimization, a systematic review of the existing literature, as well as an official and reusable software implementation, have so far been lacking. This work aims to address these gaps by (i) providing a structured survey of the main scientific contributions that have employed CG, classified by problem type and application domain, and (ii) presenting the first open-source Python library specifically designed for CG, with a focus on modularity and ease of use. The objective is to foster the dissemination and adoption of CG within the scientific community by lowering the implementation effort and supporting experimentation across diverse application settings. The library is publicly available and is intended to serve as a foundation for future developments, extensions, and collaborative research in the field of metaheuristics.

Green Two-Echelon Location-Routing for Sustainable Last-Mile Delivery: A Case Study of a Portuguese Logistics Provider

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We propose a novel two-echelon location-routing framework for sustainable last-mile delivery that explicitly integrates heterogeneous customer behaviors and eco-conscious travel choices. Recognizing that end-consumers may elect to pick up parcels at urban satellites[1] or receive home delivery, each with distinct carbon footprints, we develop a MILP model that minimizes total CO_2 emissions across three components: heavy-truck transits between central depots and satellites, mixed-fleet deliveries within urban areas, and customer trips to pickup points. To capture realistic variability in customer willingness to travel and zero-emission transport thresholds, each customer is characterized with individualized distance limits [2]. We also embed a piecewise satellite-stop emission function to account for urban driving inefficiencies. Given the intractability of large instances, we introduce a cluster-based decomposition matheuristic. In addition, we analyze alternative objective functions calibrated on real-world operations of CTT, Portugal's national postal service in Lisbon, to illustrate how different carbon-cost trade-offs influence network design. Computational experiments on benchmark instances solved to optimality are presented. Our study offers actionable insights into trade-offs among satellite density, fleet composition, and customer travel modes, and provides a practical decision-support tool for logistics planners aiming to decarbonize urban delivery networks.

Keywords: Location-Routing, Last-mile delivery, Environmental impact

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Sustainable delivery modes in a two-echelon last-mile delivery setting

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The growing demand for online shopping has led to a rise in deliveries, which in turn has resulted in an increase in pollution, emissions, congestion, and noise. The societal and political concern is rising, as witnessed, for example, by the European Green Deal aimed at reducing greenhouse gas emissions, in which the "Sustainable and Smart mobility Strategy" is a key objective (European Commission, 2020).

We propose a two-echelon last-mile delivery with the purpose of minimizing routing costs by employing low-emission transportation modes in a urban context. We consider cargo bikes and walking couriers in combination with diverse customer areas. The transition points between different types of vehicles, also known as satellites, are regarded as micro-hubs and rendezvous points. Experimental and real-world data has been sourced from existent literature and adapted to align with the proposed problem.

As solution methods, we propose a mathematical formulation that can solve small instances to optimality, and a large neighborhood search (LNS) that is capable to tackle larger instances. The LNS uses four destroy operators, namely random removal, worst removal, path removal and related removal, and two repair operators, namely greedy insertion, and regret insertion. Operators are selected stochastically during the search, and we consider both a static and an adaptive setting for the operators weights.

The study contributes to the planning of delivery routes in urban areas, while supporting the development of policies that encourage the adoption of sustainable transportation means.

Keywords: Vehicle routing problem, sustainable logistic, large neighborhood search

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Drone-Assisted Last-Mile Parcel Delivery in Time-Dependent Networks

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The exponential growth of e-commerce is driving the search for innovative and sustainable last-mile parcel delivery solutions in urban areas. Among these, the integration of aerial drones launched from strategically located microdepots emerges as a promising alternative to traditional truck-only delivery, particularly in traffic-congested environments.

In this work, we investigate a last-mile parcel delivery system in which a logistics service provider operates a heterogeneous fleet of traditional trucks and drones. While trucks travel on a time-dependent road network, drones are launched from microdepots to reach customers avoiding traffic congestion. The objective is to jointly determine the optimal fleet composition as well as the location of drone-launching microdepots, and customer assignments, while minimizing overall delivery costs.

We formulate the problem as a Mixed-Integer Linear Program on a time-expanded network that captures the temporal variability of road traversal times due to congestion. The proposed model accounts for drone endurance limits, truck load capacities, and customer delivery time windows. In order to address large-scale instances, we design a tailored Adaptive Large Neighborhood Search that leverages problem-specific destroy and repair operators for drone allocation and microdepot-based routing in a time-dependent setting.

A preliminary computational campaign on realistic delivery scenarios demonstrates the effectiveness of our approach. Compared to truck-only delivery, the hybrid system achieves significant cost reductions, emphasizing the value of drone integration via microdepots in enhancing service quality and reducing operational costs in traffic-sensitive urban areas.

Keywords: time-dependent vehicle routing, last-mile delivery, aerial drones.

Heuristic Approach for Last-Mile Logistics with Truck and Multiple Drone Delivery

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The integration of drones into last-mile delivery operations has recently attracted growing interest due to their potential for reducing delivery times and environmental impact. Nevertheless, the limited flight range of drones, primarily caused by battery constraints, presents significant challenges. To overcome this limitation, hybrid delivery systems combining trucks and drones have been proposed, enabling drones to be launched and retrieved by a supporting vehicle. In this work, we address the Truck-and-Multiple-Drones Delivery Problem (TSP-mD), in which a single truck collaborates with multiple drones to serve a set of customers. While drones can be deployed simultaneously, the truck must wait for their return before proceeding. Due to the combinatorial nature and complexity of the problem, we propose a tailored heuristic solution designed to optimize the hybrid truck multi-drone problem. Computational experiments conducted on realistic instances demonstrate the effectiveness of the proposed method, showing substantial improvements in overall delivery time. Moreover, the heuristic results are compared with the optimal solutions obtained through a Mixed Integer Programming (MIP) model. Our results highlight the potential of heuristic methods in addressing complex coordination problems in hybrid delivery systems. Numerical experiments performed on real-world data from Amazon's delivery service.

Session: Multi-level programming

Monday September 1st 16:20 - 18:00

Room 2

Chair: Pierre Hosteins

Solution of a bilevel scheduling problem on parallel machines

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This research investigates a scheduling problem with applications in Industry 4.0. A Cyber-Physical System (CPS) called the "follower" schedules parallel uniform machines, while another agent, the "leader," decides which jobs to schedule for each period.

The leader's goal is to minimize the weighted number of tardy jobs, while the follower seeks to reduce total completion time. The problem falls into the category of bilevel optimization. To solve this problem, we proposed a dynamic programming recursion and a MIP model in [1,2]. Computational experiments showed that the MIP can solve instances with up to 40 jobs and 4 machines in a reasonable amount of time.

We will also focus on solving the bilevel problem exactly using column generation and a branch-and-bound algorithm based on properties from the follower and incorporate dominance rules to reduce the number of nodes. These algorithms will be presented in more detail at the conference.

Keywords: Scheduling, bilevel optimization, parallel machines

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Bilevel optimization with sustainability perspective: a survey on applications

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Bilevel optimization models hierarchical decision-making problems where a leader makes an initial decision and a follower responds by solving a nested optimization problem. Originating from the *Stackelberg game* concept [1], bilevel optimization has grown since the 1970s into a prominent field within mathematical programming (see, e.g., [2] and [3]). This work provides a structured overview of the main concepts related to the nature of bilevel optimization problems (i.e., players, decisions, goals), along with some general models and current methodologies spanning reformulations, exact methods, and metaheuristics. Then, it focuses specifically on real-world applications to derive a picture of notable bilevel problems from the sustainability perspective across different sectors. The survey gives a classification based on the application domains and their association with well-known operations research problems, while discussing the proposed solution methodologies. The proposed taxonomy covers five major sectors (transportation and logistics; production planning and manufacturing; water, waste, and agriculture management; supply chains; disaster prevention and response) and is based on the integration of bilevel optimization models into the multidimensional concept of *sustainable development*, as framed by the United Nations Sustainable Development Goals and the Triple Bottom Line concept [4]. Our analysis explores the hierarchical nature of these problems, identifying how sustainability dimensions are embedded within leaders' and followers' objectives. Typically, upper-level actors often incorporate environmental and social concerns (e.g., emissions reduction, equity), while lower-level actors typically pursue purely economic ones. Finally, open questions and opportunities for future research in this domain are outlined.

Keywords: Bilevel optimization, Mathematical modeling, Sustainability, Applications

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A Bi-Level Stochastic approach for On-Demand Warehousing

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On-Demand Warehousing (ODW) is an emerging concept in storage capacity management. It involves an online platform acting as a central mechanism for matching the unused storage capacity offered by the suppliers to customers. The platform receives temporal capacity availability profiles from suppliers and storage requests from customers and aims at providing a matching that maximizes the total profit of the system. Existent modeling approaches consider a single decision maker, the platform, that provides assignments that are assumed to be automatically accepted by customers. Although this assumption allows us to simplify the decision process, it does not correctly represent the reality, in which customers may choose to reject the proposed matching and quit the system, yielding to potential profit losses. In this work, we model the decision problem as a bi-level stochastic optimization problem in which the platform proposes to each customer a short list of matching options among which the customer selects the preferred one, according to a rationale which is based on the combination of two parameters, cost and distance whose weights may vary among customers and are considered stochastic. After customers made their selection, the platform decides which assignments to confirm, earning the related profit, and which requests to withdraw due to lack of capacity, paying a penalty to unsatisfied customers. The offering decision plays a crucial role in the success of the system. In fact, overexposure of attractive suppliers could yield to an excess of customers selecting them and, consequently, to rejections. We provide a linearization of the resulting bi-level stochastic model, which transforms it into a single-level Stochastic Programming model (SP) and an effective Scenario Sampling based approach (SSA) which performances are compared with several deterministic policies.

Keywords: Warehousing, Bi-level optimization, Stochastic Optimization

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A tri-level Network Protection Problem with weight control

Pierre Hosteins[1]
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Network Interdiction Problems (NIPs) are problems where an attacker tries to disable some network elements (usually edges or vertices) submitted to an attack budget, while a defender reacts to such an attack in order to optimise some kind of connectivity on the network. Classic examples are, among many others, the Maximum Flow Interdiction or Shortest Path Interdiction problems, where an attacker disables edges to minimise the maximum flow or maximise the length of the shortest path between two nodes. Though the focus is often on finding the most critical set of elements to disable from an attacker's point of view, a few works exist in the literature that instead focus on how to protect the network from the malign intervention of an attacker. These problems very often take the form of a *fortification* of a subset of graph elements, i.e. rendering some graph elements impervious to attacks, see e.g. Lozano and Smith (2017). To our knowledge, no approach has been studied to act instead on the relative attack costs of the different graph elements. We propose to study this Network Protection Problem with weight control where we can allocate the attack cost of each graph element subject to an overall budget. We provide a general cutting plane approach and solve it for a couple of classic interdiction problems (Critical Node Problem, Shortest Path Interdiction Problem). We also study the computational complexity of several examples of this class of problems and show that these tri-level problems are typically Σ_2^p-hard when the lower-level is polynomial.

Keywords: Tri-level optimisation, network protection, network interdiction, weight control

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Session: Interfaces between solution methods for Optimization under Uncertainty and Artificial Intelligence

Monday September 1st 16:20 - 18:00

Room 3

Chair: Enza Messina

Wasserstein Distributionally Robust Optimization for chance constrained facility location under uncertain demand

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This paper addresses optimal facility location with chance-constraints under uncertain demand. Traditional methods, especially from Stochastic Programming and Robust Optimization, usually assume that the probability distribution underlying demand scenarios is known in advance or can be estimated. However, this assumption results impractical in many real-life settings. Indeed, Distributionally Robust Optimization (DRO) emerged as a powerful method to deal with uncertainty, given a limited set of data, and, more recently, Wasserstein DRO (WDRO) proved to be the most effective and principled technique to define plausible ambiguity sets from historical data to optimize decision under uncertainty. The Wasserstein distance is rooted in the Optimal Transport theory and provides a rigorous but flexible metric to compare probability distributions. This makes Wasserstein distance well-suited to generate new plausible data – from a limited available set – while preserving the properties of the probability distribution underlying the real data generation process. Indeed, Wasserstein is at the core of many recent Generative-AI models. In our case, the historical data about customers' demand are seen as empirical distributions (aka point clouds). Solving the facility location problem requires to identify the worst-case demand distribution for both penalizing the value of the candidate solution and evaluating the chance-constraint. This leads to solve two optimization problems over the possible demand point clouds within a Wasserstein neighbourhood of the historical data. A constrained-JKO scheme is used to identify them through an approximate Wasserstein Gradient Flow. Computational experiments demonstrate that the proposed approach effectively balances feasibility and cost efficiency under demand uncertainty, depending on the radius of the Wasserstein neighbourhood. The main achievement is a novel and more efficient WDRO method for facility location under uncertain demand.

Keywords: Optimal facility location under uncertainty, Wasserstein distributionally robust optimization, Wasserstein Gradient Flow

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Optimization-Driven and Benders Refinement Chains for Efficient Bounds in Stochastic Programming

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This talk presents a unified framework for computing tight lower bounds in stochastic optimization problems. The core idea is the use of refinement chains—structured partitions of the scenario space that guide the progressive aggregation of scenarios across multiple levels. To select the best possible refinement chain, we first introduce a mixed-integer optimization model by maximizing the expected improvement of the bounds at each level [1]. This eliminates the arbitrariness of heuristic groupings and guarantees a monotonic sequence of bounds converging to the optimal value. In the two-stage setting, we embed these refinement chains into the classical L-shaped (Benders) decomposition method. To reduce the computational burden of generating a cut for each individual scenario, we propose the Benders refinement-chain cuts method, where scenario subsets—possibly overlapping or disjoint—are used to generate group-wise optimality cuts. This aggregation significantly lowers the number of cuts required, while preserving valid lower bounds. Theoretical relationships between cuts generated at different refinement levels are also established [2]. The framework naturally extends to multi-horizon stochastic programs, involving decision-making across strategic (long-term) and operational (short-term) time scales [3]. Numerical experiments on a mean-risk multicommodity network design problem demonstrate that the proposed approach achieves strong bounds with substantial computational advantages.

Keywords: Stochastic Programming, Benders Decomposition, Scenario grouping, bounds, network design

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AI Generative Models for Realistic Urban Mobility Scenario Generation

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Traffic scenarios generation is a fundamental component for supporting complex decision-making processes in urban mobility planning, traffic management, and infrastructure resilience analysis. In particular, generating realistic traffic scenarios is crucial for optimization under uncertainty to address sustainable urban mobility challenges. By offering representative samples of potential future traffic conditions, scenario generation facilitates the development of robust data-driven strategies that can effectively adapt to the inherent variability and complexity of urban transportation systems. Traditional statistical models for scenarios generation often require extensive prior knowledge about data distributions and come with high computational costs, limiting their applicability to complex road networks. In state-of-art, generative architectures combining Variational AutoEncoders (VAE)[1] with Graph Convolutional Networks (GCN)[2] have been presented with the aim to capture the spatial correlations inherent in road network topologies and to generate realistic road speed forecasting models[3]. However, when making decisions with lasting implications over a medium to long time-frame, it is essential to consider not only the most probable scenario, possibly obtained through a forecasting model, but also a range of potential outcomes. In this talk, we will give an overview of different scenario generation models we have developed based on VAE[4] and GCN. In particular, the Beta-VAE architecture[5] allows explicit control over the trade-off between reconstruction fidelity and latent space disentanglement. The integration of GCN layers ensures that the spatial dependencies across a road network are preserved, enabling the generation of more coherent and realistic traffic patterns. The experimental evaluations on a real-world traffic dataset demonstrate the effectiveness of the proposed model in replicating empirical distributions, achieving superior results compared to conventional approaches.

Keywords: Scenarios Generation, Generative models, Urban Mobility

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Neural Network Surrogates for Efficient and Generalizable Stochastic Programming Solutions

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Stochastic programming (SP) addresses decision-making problems under uncertainty but often faces significant computational challenges due to the problem size and the number of scenarios considered. To control computational costs, a limited number of scenarios are typically used [1], however, the quality of the solution remains highly sensitive to the selected set of scenarios. Recent advancements in surrogate models based on neural networks offer a promising solution to these challenges [2,3]. In this work, we focus on employing surrogate models to approximate the recourse function value, allowing the SP model to overcome its traditional dependence on an extensive set of scenarios. By learning the structure of the recourse function, these neural surrogates enable the optimization model to generalize more effectively across a wide range of unseen scenarios, thus improving both solution quality and flexibility by overcoming the scenario count limitation. The approach has been validated on several two-stage SP problems, including facility location, multi-path traveling salesman, and closed-loop supply chain design, demonstrating substantial improvements in computational efficiency and solution flexibility. Ongoing research explores the extension of this framework to multi-stage problems [4] and the development of instance-dependent neural architectures tailored to specific SP instances. These findings suggest that surrogate neural networks is a promising direction for achieving scalable and adaptive solutions.

Keywords: Stochastic Programming, Neural Networks, Surrogate Models

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Session: Combinatorial optimization 2

Tuesday September 2nd 08:00am - 09:20am

Main Room

Chair: Federico Della Croce

A Hybrid Population-Based Local Search with Graph-based Acceptance Criteria for Solving Quadratic Assignment Problem

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Quadratic Assignment Problem (QAP) involves allocating a set of facilities to a set of locations through one-to-one assignment with minimum cost. In solving QAP, local search is an effective algorithm initiated with one candidate solution and the solution is upgraded over time benefited from local exploitation. Nevertheless, its convergence and exploration are very restrained. The population-based algorithm, on the other hand, combines both local and global exploitation which requires an equilibrium for a powerful search algorithm. This requires good acceptance criteria to balance the exploration and exploitation of a search landscape with a suitable setup. Hence, this study proposes a hybrid population-based local search (HPLS) with new acceptance criteria for solving QAP. First, a cost-oriented neighborhood strategy is implemented. Then, it is hybridized with Tabu Search to prevent going back to the earlier solutions. To strike a compromise between exploration and exploitation, new acceptance criteria built on graphing mathematical function is presented. QAP instances from the QAPLIB were used to evaluate both algorithms with a preliminary experiment. The findings show that the HPLS outperforms the PLS with a lower percentage error and standard deviation and is comparable with other well-known methods offered in the literature.

Keywords: Quadratic Assignment Problem, Acceptance Criterion; Population-based Metaheuristics, Local Search, Exploration and Exploitation

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Advancing Kernel Search for Multidimensional Multiple-Choice Knapsack Problems via Resource Relaxation

Enrico Brambilla[1], Renata Mansini[1], Roberto Zanotti[2]

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We propose a novel adaptation of the Kernel Search (KS) framework to the Multidimensional Multiple-Choice Knapsack Problem (MMKP), inspired by the original work by Angelelli, Mansini, and Speranza [1] and its recent two-phase variant applied to the same problem by Lamanna, Mansini, and Zanotti [2].

The key idea behind the new method is to exploit the insights obtained by incrementally relaxing the multidimensional knapsack constraints, slightly increasing their resource availability, to discover new high-quality (possibly infeasible for the original problem) integer solutions. More precisely, we use the information provided by each resource relaxation (represented by the solution to the corresponding continuous relaxation, reduced-cost coefficients, and integer solutions) to identify promising variables likely to be positive in the optimal solution of the original problem. Such knowledge allows us to construct an informative kernel set and a series of buckets on which KS iteratively solves reduced MILPs. Whenever a new best integer solution is found, variable fixing is applied to set the variables to their optimal values. This possibly reduces the search space and creates a new restricted problem, allowing the process to be restarted iteratively.

This approach demonstrates great potential in narrowing the relevant subset of variables for the MILP solution while preserving quality. Our preliminary computational results confirm that the method is able to find near-optimal solutions while significantly reducing solution times on benchmark MMKP instances [3]. This adaptation opens up new directions in the development of matheuristic frameworks in combinatorial optimization.

Keywords: Knapsack Problem, Matheuristic, Kernel Search

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A New Relaxation for Tree-Based Problems and Its Application to the Capacitated Minimum Spanning Tree Problem

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Dynamic programming algorithms for constrained shortest path problems are often used in Lagrangian relaxation algorithms and algorithms based on column generation for variants of the vehicle routing problem. In the q-route relaxation, paths must satisfy a capacity constraint while the elementarity constraint is relaxed, i.e., paths may contain cycles. The ng-path relaxations are defined by a family of neighborhoods, one for each vertex of the underlying network, that restrict cycling [1]. These relaxations lead to practically solvable sub-problems that are otherwise too difficult, since they have to be solved several times with different (reduced) costs. An analogue of q-routes for tree optimization problems are q-arbs, a structure that relaxes elementarity for arborescences [2]. We introduce ng-arb relaxations for (constrained) arborescences, applicable to a broad class of constrained tree-based problems. As an example, we consider the capacitated minimum spanning tree problem (CMST), which is the problem of covering a set of nodes with demands by a set of capacitated sub-trees, each rooted at a given source (analoguous to the well-known capacitated vehicle routing problem, where routes are replaced by rooted sub-trees). We integrate the new dynamic programming approach into a branch-and-price algorithm for the CMST, where ng-arb relaxations are solved in the column-generation process. Computational results for standard CMST benchmark problems show that the resulting relaxations are often very tight, leading to small branch-and-bound search trees and small overall computation times.

Keywords: Tree, Arborescence, ng-Path Relaxation, Capacitated Minimum Spanning Tree Problem

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A new combinatorial algorithm for the assignment problem

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We consider the assignment problem (AP), one of most well known graph optimization problems in the mathematical programming and operations research communities. In its more general version, the assignment problem consists of a set of n origins, a set of n destinations where the matching of origin i with destination j has a cost $c_{i,j}$ and the objective is to match each origin with a different destination in such a way that the total matching cost is minimized.

The assignment problem has plenty of practical applications. For instance, it is well known that the scheduling problem of minimizing the sum of completion times of a set of jobs on a set of unrelated parallel machines can be modeled as an assignment problem. Also, AP appears as a subproblem of a vast number of combinatorial optimization problems, e.g. it provides a standard lower bound for the traveling salesperson problem.

The assignment problem is also a special case of the well known transportation problem (TP). Correspondingly, any algorithm for TP can be used for solving AP. We remark that a recent algorithm [2] has been shown to practically outperforms the relevant exact algorithms available in the literature for TP. Among the exact approaches available in literature, we mention here the pioneering Hungarian algorithm [5], the Auction algorithm [3] and the Cost Scaling algorithm [4]. The work in [1] compares the practical performances of these three algorithms on a wide set of instances indicating best performances of the algorithm in [3]. In this work, we discuss the behavior on AP of a tailored adaptation of the algorithm in [2] and compare its performances with the approaches in [3,4,5] and with a new combinatorial algorithm specific for AP. Computational results will be presented at the Conference.

Keywords: Assignment problem, exact approach, combinatorial algorithm.

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Session: Scheduling 1

Tuesday September 2nd 08:00am - 09:20am

Room 1

Chair: Andrea Pacifici

Addressing health inequalities in waiting lists through a biobjective single-machine scheduling problem and network design

Matteo Avolio[1], Antonio Fuduli[1]

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A report of the King's Fund, an independent charitable organization dedicated to improving health and care in England, highlights that individuals living in the most deprived areas of England are more than twice as likely to wait over a year for elective treatment compared to those living in the most affluent areas.

We model this social problem as a single-machine biobjective scheduling problem, where different population groups are represented as distinct job classes based on their economic and social status or geographic location.

Specifically, in the simplest case of two job classes, our goal is twofold: first, to balance the average weighted waiting times between the classes, and second, to minimize the maximum of them. To address this problem, we propose a mixed integer programming formulation based on a network design model, which we tackle by using a Lagrangian relaxation approach. Each iteration requires solving a linear assignment problem as well as a kind of minimum cost uncapacitated flow problem. We present numerical experiments conducted on a set of randomly generated instances to evaluate the effectiveness of our approach.

Keywords: Scheduling; Biobjective optimization; Network design

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MILP Formulations for Single Batch-Processing with Non-Identical Jobs, Compatible Families, and Sequence-Dependent Setups

Annalisa Castelletti[1], Renata Mansini[1], Lorenzo Moreschini[2]
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Motivated by heat treatment in metalworking, this study investigates a new scheduling problem involving a single batch-processing machine (industrial oven) with limited capacity, where jobs are semi-finished products to be treated. The non-identical jobs must be partitioned into batches for simultaneous processing, minimizing the overall makespan. All jobs in a batch start and end their processing together, with the processing time of the batch being determined by the longest job. Moreover, jobs are grouped into compatible families, each with a specific minimum processing temperature. Within a batch, the dominant family is the one with the highest temperature requirement. An innovative aspect of our work is the inclusion of sequence-dependent setup times between consecutive batches, determined by the dominant families of each batch. Following Graham et al. (1979) classification, we address the $1 \mid s_j, p-batch, SU^k_{fg} \mid C_{max}$ problem. We call it the Single Batch-Processing Machine problem with Non-identical job sizes, Compatible families, and Sequence-dependent setup times.
We develop two mixed-integer linear programming models for the problem, and enforce them with different valid inequalities and lower bounds on both the number of non-empty batches and the makespan. The first model extends the mathematical formulations of the problem proposed by Melouk et al. (2004) and Trindade et al. (2018), incorporating new constraints to capture family dominance and family sequence-dependent setup times. The second adopts a different set of decision variables, providing an alternative representation of the scheduling decisions. Computational experiments validate the effectiveness of both formulations and provide a performance comparison between them.
Keywords: Batch-Scheduling, Sequence-Dependent Setups, Non-identical jobs, Mixed Integer Linear Programming

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Scheduling Models for Resource-Constrained Pharmaceutical Production

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This work tackles a real-world scheduling problem in pharmaceutical production, where multiple limited resources must be coordinated to mix and process active substances. The problem is formulated as a multi-resource job-shop scheduling problem, with each job representing a production order. Beyond standard precedence and capacity constraints, additional complexities such as release dates, no-wait conditions, and time window restrictions must be accounted for. Each task requires a dedicated machine—temporarily installed in a specialized cleanroom—and the simultaneous availability of a specific number of operators. These stringent operational requirements reflect the highly regulated nature of pharmaceutical manufacturing. To address this complex problem, we propose and compare two distinct modeling approaches. The first is based on an innovative generalized disjunctive graph, which captures the temporal and resource constraints through a rich graph-based structure. The second is a mixed-integer linear programming (MILP) model, offering a detailed mathematical formulation suitable for exact optimization. Our computational study reveals that while the disjunctive graph model provides valuable structural insights, it is not suitable for solving realistic, large-scale instances. In contrast, the MILP model proves capable of efficiently solving real-world instances, handling a full month of production planning with satisfactory performance and solution quality.

Keywords: Job-Shop Scheduling, Pharmaceutical Production Planning, Mixed-Integer Linear Programming, Decision Support System

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A MILP Approach to a Generalized Open Shop Maintenance Scheduling Problem in Industrial Production

Lucio Cifariello, Marta Flamini, Gaia Nicosia

This paper addresses a real-world maintenance scheduling problem arising from the production line machinery of a frozen baked goods plant. The problem is modeled as a generalized Open Shop Scheduling Problem (OSSP) and a Mixed Integer Linear Programming (MILP) formulation is proposed and validated. In the considered setting, maintenance tasks must be executed by specialized workers, with the objective of maximizing the total value of completed tasks while minimizing worker idle time and optimizing movement within the plant. The model extends the classical OSSP by incorporating additional practical constraints, including time windows, precedence relations, and concurrency requirements. Preliminary computational experiments, conducted on realistic instances generated from operational data provided by the industrial plant, demonstrate the potential of the proposed approach to effectively handle the complexity of real-world scenarios.

Session: PRIN SMACROS + SMOTION 1

Tuesday September 2nd 08:00am - 09:20am

Room 2

Chair: Giusy Macrina

On the covering tour problem with resource consumption limitation

Luigi Di Puglia Pugliese[1], Giusy Macrina[2], Marcello Sammarra[1] Martina Luzzi[2], Francesca Guerriero[2]

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We address a variant of the well-known covering tour problem [1] in which the resource consumption is considered. The problem is characterized by a set of nodes N that can be visited and a set of nodes V that must be covered. The set N contains two particular nodes, i.e., 0 and its copy, namely $n+1$, representing the nodes at which the tour starts and ends, respectively. For each node $i \in N \setminus \{0, n+1\}$, it is possible to define a subset $W(i)$ which contains all the nodes belonging to V that can be covered by visiting i. A resource consumption t_u is associated with each node $u \in N \cup V \setminus \{0, n+1\}$. A set of edges $E = \{(i,j) : i,j \in N\}$ is also defined. Each edge $(i,j) \in E$ is characterized by a distance d_{ij} and a resource consumption t_{ij}. The problem consists of 1) selecting the nodes $i \in N$ to be visited; 2) deciding the order in which such nodes are visited; and 3) the nodes $v \in W(i)$ to be covered when node $i \in N$ is visited such that the total traveled distance is minimized, all nodes belonging to V are covered, and the overall resource consumption is below a given threshold T. We analyze the impact of resource limitation on the optimal solution, exploiting the bi-objective nature of the problem. We also investigate the possibility of defining new optimality cuts derived from a Lagrangean relaxation based on the resource consumption limitation. An extensive computational phase is carried out on instances derived from benchmarks for the covering tour problem.

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Keywords: Covering Problem, Travelling Salesman Problem, Resource Consumption, Lagrangean Cuts.

References

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Route Optimization using GPU for Autonomous Agricultural Vehicles

Francesco Paolo Saccomanno[1], Giovanni Giallombardo[2], Francesca Guerriero[1]

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This research investigates an efficient collaborative approach for precision agriculture tasks, utilizing autonomous drones (UAVs) for monitoring and ground vehicles (UGVs) for targeted treatment (irrigation or fertilization). The drone employs a Close Enough Traveling Salesperson Problem (CE-TSP) strategy for its monitoring flights, ensuring comprehensive data acquisition (imagery) of all target plants by visiting locations sufficiently close to each ([1]). Upon completion of the drone's monitoring, the collected data informs the calculation of an optimized treatment route for a fleet of UGVs using the Capacitated Vehicle Routing Problem (CVRP). The UGVs then execute the planned treatments. While the UGVs are operating and during their subsequent return to the depot for recharging, the drone undertakes a new monitoring cycle. This continuous data acquisition enables dynamic updates of plant needs. Consequently, upon the UGVs' return and during their recharge period, a new CVRP is rapidly calculated based on the latest drone-acquired data, preparing them for their next treatment cycle. Notably, the UGV routing, while currently formulated as a CVRP, could potentially be extended to a Capacitated Close Enough Traveling Salesperson Problem if the treatment operation (e.g., spraying) does not necessitate pinpoint accuracy on each individual plant. The primary challenge addressed in this research remains the need for extremely fast computation of the routing problem for the UGVs at each depot return. To achieve this, we propose a heuristic methodology based on GPU that efficiently processes the drone-captured data to define treatment requirements and rapidly generates near-optimal routes for the UGVs. This collaborative drone-UGV system aims to significantly enhance the efficiency and responsiveness of precision agriculture practices through timely and targeted interventions based on the most recent field information.

Acknowledgement: This work was supported by a grant awarded by "European Union – Next Generation EU" under the "PRIN 2022" project: Smart agriculture by collaborative robots swarm (P2022E38SJ)

Keywords: Precision Agriculture, CE-TSP, CVRP, Drones, GPUs

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A heuristic algorithm for the Resource Constrained Covering Tour Problem

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The Resource Constrained Covering Tour Problem (RCCTP) [1] is a network optimization problem arising in wireless communications. It is defined on an undirected graph, where nodes represent sensors deployed within a geographic area, to monitor environmental parameters like air and noise pollution, traffic congestion, and others. Some nodes (ground nodes) are directly accessible by an unmanned vehicle (agent) that can physically recharge sensor batteries. By contrast, other nodes (air nodes) are not directly accessible. In the latter case, battery recharging is performed via wireless power transmission technologies. Specifically, while the agent recharges the batteries of the ground nodes directly, it can also recharge the batteries of the air nodes lying within a predefined covering radius. Travelling between ground nodes and performing recharging tasks consume limited resources. The RCCTP aims to find a minimum distance Hamiltonian tour visiting possibly a subset of ground nodes, while ensuring that all air nodes are covered and the resource consumed does not exceed a given threshold. We propose a heuristic decomposition scheme and discuss some preliminary computational results, carried out on instances adapted from standard benchmarks for the Covering Tour Problem [2].

Acknowledgement: This work was supported by grants awarded by "European Union – Next Generation EU" under the "PRIN 2022" project: SMOTION (ID 2022EAECWJ), CUP B53D23009270006 (Luigi Di Puglia Pugliese and Marcello Sammarra), CUP H53D23002000006 (Francesca Guerriero); and under the "PRIN 2022 - PNRR" project: COSMO, CUP H53D23008850001 (Giusy Macrina).
Keywords: Covering Problem, Unmanned Vehicle, Hamiltonian Tour, Decomposition Approach.

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A novel framework for the last-mile delivery using AGVs and Public Lines

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This study explores the potential for integrating passenger and freight transportation into last-mile delivery networks, using autonomous ground vehicles (AGVs). Specifically, it investigates the possibility of using the spare capacity of existing public transport lines, such as subways, trams, and buses, during the off-peak hours, to distribute goods ([1],[2]). In our framework, customers are divided into two main categories: daytime and night-time customers, characterised by different delivery requirements. night-time customers may be served during the off-peak hours. Daytime customers will be assigned to some available service points (drop-off points) that could be activated. Both night-time customers and drop-off points are served by the AGVs. The proposed framework is modelled as a variant of the Location and Routing Problem, whose goal is to ensure the coordination of all network resources while meeting customer expectations, minimising the overall costs. A preliminary computational study is carried out to attest to the behaviour of the proposed framework.

Acknowledgement: 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 Giovanna Miglionico); and under the "PRIN 2022" project: SMOTION (ID 2022EAECWJ), CUP H53D23002000006 (Francesca Guerriero), and CUP B53D23009270006 (Luigi Di Puglia Pugliese).

Keywords: Vehicle Routing Problem, Location, Last-mile, Public Lines, Autonomous Ground Vehicles.

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Session: Optimization under uncertainty 1

Tuesday September 2nd 08:00am - 09:20am

Room 3

Chair: Francesca Maggioni

Approximate Dynamic Programming Approaches for a Multiperiod Stochastic VRP with Irregularly Clustered Customers

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[2]Xinjiang Academy of Transportation Sciences Co. Ltd., Urumqi, China

We consider a dynamic and stochastic VRP, motivated by the case of a company delivering furniture. There is a stochastic stream of customer requests, which are associated with volume, service time, and due date. Volume is relevant, due to the kind of delivered items, which may require assembly. The sum of service and traveling times for each route cannot exceed a maximum tour duration. Customers are clustered into a high-density cluster close to the deposit and low-density clusters that are less convenient to serve. We may delay service to inconvenient customers, waiting for more requests from the same cluster. There are multiple objectives: traveled distance and service quality (on-time delivery and waiting time). The problem can be decomposed into a *dispatching* decision (selection the requests to serve during the current day) and a daily *routing* decision.

We consider the application of approximate dynamic programming. Since a value function approximation approach is problematic, we experiment with cost function and policy function approximations, complemented by some degree of lookahead. Decision rules are tuned by simulation-based optimization. We analyze performance in the simpler setting of a capacitated TSP (single vehicle). Then we consider the introduction of a lookahead by rollout of the base decision policy. Finally, we investigate the generalization to multiple vehicles.

Keywords: approximate dynamic programming, stochastic VRP, decision rules

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Simheuristics for Optimization Problems under Uncertainty Scenarios

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Uncertainty is a fundamental characteristic of many real-world systems, affecting fields such as transportation, healthcare, logistics, finance, manufacturing, and smart cities. To analyze these complex and unpredictable environments, simulation techniques are widely used. They allow researchers and practitioners to model stochastic behaviors using probability distributions and assess system performance across different scenarios.

Yet, simulation by itself does not solve optimization problems, especially those involving large and combinatorial search spaces. These are common in real-life tasks like vehicle routing with uncertain demands or job scheduling with random processing times. Such problems are often NP-hard, making exact methods impractical for large instances. This is where metaheuristics become useful since they are flexible and can produce high-quality solutions within a reasonable amount of computational time. However, most metaheuristics are designed for deterministic settings. When uncertainty is introduced, their performance becomes less reliable.

Simheuristics combine simulation with metaheuristics to address optimization problems that include stochastic elements, such as random objective functions or probabilistic constraints. This hybrid approach benefits from the strengths of both components: the explorative power of metaheuristics and the uncertainty-handling capacity of simulation. As a result, simheuristics improve solution quality under uncertainty while maintaining scalability and efficiency.

Keywords: Simheuristics, Metaheuristics, Simulation, Stochastic Optimization

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The Vehicle Routing Problem with Stochastic Service

Behnam Gavili Kilaneh, Maximiliano Cubillos, Fausto Errico

We introduce the dynamic vehicle routing problem with stochastic service times (DVRP-SST), which finds application in the context of home appliance repair services. We consider the setting where, at the beginning of the day, the service provider receives a set of service requests that must be completed on that day. The service times are stochastic and follow given probability distributions. A fleet of homogeneous technicians is available to serve customers. Each technician is paid for a fixed shift duration, exceeding which entails an overtime cost. All technicians begin and end their routes at the depot and are dynamically assigned to customers. Once a technician arrives at a customer location, the service duration is revealed, and she must perform it. The objective is to minimize the expected total travel and technician overtime costs. We model the DVRP-SST as a Markov decision process. To solve the DVRP-SST, we develop a lookahead algorithm. At each decision epoch, we select the action with the least cost contribution plus the estimated cost-to-go. The latter is coupled with a variant of the multiple traveling salesman problem. We demonstrate the effectiveness of our method through a series of computational experiments.

A Stochastic Programming Model for Anticipative Planning of Integrated Electricity and Gas Systems with Bidirectional Energy Flows under Fuel and CO2 Price Uncertainty

Maria Teresa Vespucci[1], Giovanni Micheli[1], Alessia Cortazzi[2], Cinzia Puglisi[2]

[1] University of Bergamo, Italy
[2] CESI, Milano, Italy

A two-stage multi-period mixed-integer linear stochastic programming model is proposed to assist qualified operators in long-term generation and transmission expansion planning of electricity and gas systems to meet policy objectives. The first-stage decisions concern investments in new plants, new connections in the electricity and gas sectors, and the decommissioning of existing thermal power plants; the second-stage variables represent operational decisions, with uncertainty about future fuel and CO2 prices represented by scenarios. The main features of the model are: (i) the bidirectional conversion between electricity and gas enabled by Power-to-Gas and thermal power plants, (ii) a detailed representation of short-term operations, crucial for addressing challenges associated with integrating large shares of renewables in the energy mix, and (iii) an integrated planning framework to evaluate the operation of flexibility resources, their ability to manage non-programmable generation, and their economic viability. A case study on the decarbonisation of the Italian integrated energy system demonstrates the effectiveness of the model. The numerical results show: (i) the importance of including a detailed system representation for obtaining reliable results, and (ii) the need to consider price uncertainty to design adequate systems and reduce overall costs.

Keywords: Stochastic Programming, Generation and transmission expansion planning, Integrated systems, Power-to-gas, Decarbonisation.

Plenary Session
Tuesday September 2nd 09:20am - 10:20am
Main Room
Chair: Marco Trubian

How can researchers regain control of publication?

Marie Farge
CNRS-INSMI and ENS-Paris

Electronic publishing is a technological revolution that makes it possible to publish articles at virtually zero marginal cost. A few commercial publishers have anticipated this evolution and bought the main journals that researchers need to share their results, and whose articles they peer review.

In the past, researchers sent their manuscripts to publishers to be formatted, printed and distributed by post. Today, publishers require researchers to submit their articles camera-ready and give their copyright to them free of charge. Publishers thus acquire exclusive ownership of research articles, from the date of publication until 70 years after the death of the last surviving co-author, enabling them to sell articles at any price they wish. Since publishers own most of research journals they control the entire process, from electronic submission and peer review to article processing charges, subscription prices, journal impact factors, and much more...

I will present a model that we have proposed in 2012 to regain control of the peer review and publication of our articles, based on the following principles:

- editorial board members collectively own the journal because they are responsible for peer review,
- authors retain their copyrights and allow free access to their articles under a CC-BY licence (`https://creativecommons.org`),
- readers and authors pay nothing as articles are processed by an electronic publishing platform, which is an infrastructure to which research journals can apply on a competitive basis to obtain the service free of charge (*e.g.,`https://www.centre-mersenne.org`).*

These publishing platforms are designed to meet the needs of researchers and are developed in open-source software, so that algorithms and data processing can be verified and shared. Our aim is that commercial publishers become service providers rather than content owners, a model that dates back to the days of the printing press which they are determined to retain.

Keywords: Publication, peer-review, open access

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ed. Carlos Moedas, The European Commission, pp. 73-81

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European Mathematical Society Newsletter, June 2018, pp. 35-40
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eds. G. Peruginelli and S. Faro, IOP Press, pp. 110-124

To get these articles `http://openscience.ens.fr/MARIE_FARGE/ARTICLES`

Session: Crowd-shipping

Tuesday September 2nd 11:00am - 12:40am

Main Room

Chair: Claudia Archetti

Public Transportation-based Crowdshipping: Advancing the Transition from Theory to Practice

Renata Mansini[1], Filippo Ranza[1]

[1]Department of Information Engineering, University of Brescia, Italy

Public Transportation-based Crowdshipping is an emerging last-mile delivery paradigm that relies on existing travel patterns of commuters and private individuals to transport parcels on a public transportation (PT) network, while providing a promising strategy to lower operational costs and mitigate the environmental impact of urban logistics, significantly reducing congestion and emissions in dense metropolitan areas.

In this talk, we present two complementary problems that tackle the two fundamental challenges in designing effective PT-crowdshipping systems: (i) the strategic placement and sizing of Automated Parcel Lockers (APLs) at the PT network stations [1], and (ii) the time-dependent operational management of parcel deliveries through the network [2].

We handle the strategic planning phase by solving a bi-objective optimization problem that maximizes customer satisfaction and network coverage while accounting for fixed and variable costs. For the operational phase, we solve a time-dependent problem that determines pickup and drop-off stations for each parcel, assigns parcels to commuters, and routes them through the public transport network while complying with locker capacity constraints at intermediate stops and sequencing of parcel paths when handled by multiple crowdshippers to ensure timely and coordinated transfers. The objective is to minimize total system costs, including transportation, handling, crowdshipping remuneration, and backup operations for undelivered parcels.

For both problems, we propose compact mixed-integer programming formulations strengthened with valid inequalities. These are validated on large instance sets, with extensive sensitivity analysis, including the impact of potential disruptions on system performance. We also highlight several open research directions.

Keywords: Last-mile delivery, Crowdshipping, Public Transportation Network, Automated Parcel Locker location

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2. Mikele Gajda, Olivier Gallay, Renata Mansini, and Filippo Ranza (2025). Optimizing last-mile delivery through crowdshipping on public transportation networks. *submitted*

A Hybrid Simulation-Optimization Approach to the Restaurant Food Delivery in Dublin (Ireland)

Adrian Serrano-Hernandez[1], Peter Keenan[2], Luis Cadarso Morga[3], Javier Faulin[1]

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[3]European Institute for Aviation Training and Accreditation (EIATA), Rey Juan Carlos University, Fuenlabrada, Madrid, Spain

The Restaurant Food Delivery Problem addresses the logistical challenges restaurants face in delivering orders efficiently, aiming to ensure timely service, reduce costs, and enhance customer satisfaction. Traditionally, restaurants depend on their own fleets, often motorbikes, which can be expensive and inefficient. Recently, alternative delivery models like crowdshipping have gained attention, offering a more flexible and affordable solution for restaurants of all sizes. This study evaluates the potential performance of a crowd-based bicycle delivery system in Dublin, Ireland. To do so, an agent-based simulation model is developed, incorporating key features of the city population, restaurants, and delivery riders. Optimization components are embedded in the simulation to guide agent decisions, including a biased-randomization savings heuristic to address Vehicle Routing Problems (VRPs) associated with traditional delivery fleets. The simulation explores various scenarios, varying delivery models, demand intensities, and levels of crowd-based rider participation, and yields promising results in terms of economic efficiency and customer satisfaction.

Keywords: Crowdshipping, Agent-Based Simulation, Vehicle Routing Problem (VRP)

Dynamic demand acceptance and allocation for parcel lockers under uncertain pick-up times

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We study the problem of dynamically managing a network of parcel lockers to serve both premium and standard customer over a multi-day planning horizon, where customer delivery requests must be managed in real time under operational constraints and uncertainty. The system consists of a finite set of lockers, each containing a fixed number of compartments of various size categories. Requests arrive sequentially yielding different profits according to customer class. To ensure service feasibility, the system must guarantee that at least one compatible compartment (i.e., a compartment of size greater than or equal to the parcel) will be available on delivery day. The core operational challenge lies in managing locker space dynamically while facing uncertainty in customer behavior, specifically the unknown pickup time of parcels. Accepted parcels are delivered the following day and remain in the locker until collected by the customer that may retrieve their parcel at any time within a maximum of m days, after which the parcel is removed and returned to the depot. We formulate this problem as a multi-stage stochastic optimization model including two decision phases: (1) Real-time Acceptance and Locker Assignment, and (2) End-of-Day Compartment Allocation. The first stage involves immediate decisions at request arrival: acceptance or rejection and locker assignment. These decisions are made without knowing how long the locker space will be occupied. The second stage occurs at the end of each day, when the system allocates accepted parcels to specific compartments based on updated availability data, including newly freed compartments and recent pickups. The objective is to maximize total profit from accepted deliveries while ensuring operational feasibility and efficient locker utilization. Different decision policies will be discussed at the conference and detailed results will be provided.

Keywords: Dynamic stochastic Optimization, Last-Mile Delivery, Lockers

An Exact Column Generation Approach for the Public Transport-Based Crowdshipping Problem

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In recent decades, the rapid growth of e-commerce and on-demand services has led to a surge in delivery activities, resulting in increased traffic congestion and negative externalities for city inhabitants, such as noise, pollution, and higher accident risks. Crowdshipping, which involves engaging regular commuters in the delivery process, has emerged as a promising strategy to address these issues [1].

In particular, public transport-based crowdshipping, where commuters move goods using metro or bus services, offers significant potential to reduce traffic volumes and operational costs while ensuring reliable deliveries. In this paper, we propose an exact solution method for the Public Transport-based Crowdshipping Problem (PTCP) [2], a system where the logistics service provider integrates parcel delivery with the public transportation network. A subset of stations is equipped with automated parcel lockers, which are preloaded each morning with packages to be delivered. Commuters then transfer parcels between lockers according to the recipients' specifications. A backup service handles parcels that cannot be transferred by crowdshippers. We introduce a new set partitioning formulation for the PTCP and solve it through a column generation approach, demonstrating its effectiveness in exactly solving large-scale instances.

Keywords: Last-mile Delivery, Crowdshipping, Column Generation

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Pricing and bundling decisions considering drivers' behavior in crowdsourced delivery

Claudia Archetti[1], Alim Buğra Çınar[2], Wout Dullaert[2], Markus Leitner[2], Stefan Waldherr[2]

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[2]Department of Operations Analytics, Vrije Universiteit Amsterdam, Netherlands

Challenges in last-mile delivery such as high costs, rising customer expectations, and congested urban traffic have encouraged innovative solutions like crowdsourced delivery, where online platforms leverage the services of drivers who occasionally perform delivery tasks for compensation. A key challenge in crowdsourced delivery is that occasional drivers' acceptance behavior towards offered tasks is uncertain and influenced by task properties and compensation amount.

We formulate an optimization problem that maximizes total expected cost savings by offering bundles of tasks to occasional drivers. To this end, we simultaneously determine the optimal set of task bundles, their assignment to occasional drivers, and the corresponding compensation values for each bundle-driver pair while considering bundle and compensation dependent acceptance probabilities of occasional drivers.

The vast number of potential task bundles, combined with incorporating occasional drivers' acceptance probabilities via logistic functions, leads to a mixed-integer nonlinear programming (MINLP) formulation with exponentially many variables. Using mild assumptions, we address these complexities by exploiting properties of the problem, leading to a linearization of the MINLP which we solve via an exact column generation algorithm. Our algorithm considers a variant of the elementary shortest path problem with resource constraints (ESPPRC) that features a nonlinear and nonadditive objective function as its subproblem, for which we develop tailored dominance and pruning strategies.

We introduce several heuristic and exact variants, and perform an extensive set of computational experiments. The results indicate the efficiency of exact and heuristic algorithm variants for instances with up to 120 tasks and 60 drivers.

Keywords: Crowdsourced delivery, compensation schemes, occasional driver behavior, logistic function

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Session: OPTSM - Railway optimization

Tuesday September 2nd 11:00am - 12:40am

Room 1

Chair: Manuel Schlenkrich

Dynamic Seat Control for Parallel High-Speed Trains with Passenger Choice

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This paper describes a network revenue management problem for a set of parallel high-speed trains. Each train stops at a certain set of stations, which determines the itineraries it can cover. We consider a choice-based dynamic seat control problem to maximize revenue. For each passenger with a specific itinerary request, we offer a set of trains that stop at both the origin and destination stations of the itinerary. The passenger then either chooses a train from the offered set or leaves without a booking. Upon observing the passenger's choice, the seller must instantly assign the passenger to a uniquely numbered seat on that train for the entire itinerary, without allowing any later adjustments.

We develop a modified network revenue management model for this problem. First, we consider a static choice-based problem in which all requests are known and propose a column generation algorithm to solve the problem effectively. Next, we discuss the dynamic choice-based problem and propose two bid-price control policies: one based on the dual of the static choice-based problem and the other based on the dual of a maximal sequence formulation. Finally, we propose a re-solving policy that achieves uniformly bounded revenue loss. Using real data from China Railway High-speed, we conduct numerical experiments to validate our policies and highlight the benefits of dynamic choice-based seat control for parallel trains.

Keywords: High-speed trains, Seat control, Revenue management

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Freight Rolling Stock Rescheduling by Stochastic Local Search

Roberto Maria Rosati[1], Valentina Cacchiani[2], Vera Hemmelmayr[1]
[1]WU Vienna University of Economics and Business, Austria
[2]DEI, University of Bologna, Italy

Railway disruptions are a cause of economic and reputational damage, which give railway transportation a perception of unreliability. Rescheduling is a critical task for the need to find high-quality solutions in relatively short computing times [1].

In this work, we consider a Rolling Stock Rescheduling Problem for freight transportation, based on the planning problem proposed by Frisch et al. [2], originated from a real-world setting in Austria. Disruptions affect the network, making some trips infeasible and some sections unavailable for deadheading. Locomotives are forced to take longer paths, which could prevent them from reaching next trip's initial station of the on time and from performing scheduled maintenance. As this would lead to cancellations, the objective of the problem is to reschedule the locomotives minimizing additional trip cancellations, missed maintenance appointments, and, finally, deviations from the original plan.

As solution methods, we propose a Mixed Integer Linear Programming model and a Stochastic Multi-Neighborhood Local Search based on the combination of three neighborhoods (Change, Move and SwapLocomotive). A Simulated Annealing metaheuristic guides the search. The initial solution is derived from the disrupted plan, repaired for feasibility.

We perform our computational experiments on instances derived from real-world data, with disruptions of varying severity and duration. Experimental results show that the mathematical model solved by CPLEX obtains acceptable results on small instances, while our Multi-Neighborhood Search approach, properly tuned, achieves high-quality solutions in low computational times also on instances with thousands of trips.

Keywords: Rail transport, Multi-Neighborhood Search, Rolling stock rescheduling

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Coordinating Partially Periodic Railway Timetables Across Scenarios Using Logic-Based Benders Decomposition

Florian Fuchs[1], Thomas Dubach[1], Francesco Corman[1], Bernardo Martin-Iradi[1]
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Strategic railway timetables are typically designed years in advance to define a stable and memorable passenger-oriented offer. However, transforming these long-term plans into operationally feasible daily schedules requires adapting to real-world fluctuations in demand, rolling stock availability, freight services, and infrastructure works. Despite such day-to-day variability, passengers expect consistent departure and arrival times. This creates a coordination challenge: trains recurring across operational days must comply with a shared commercial schedule, never departing earlier nor arriving later than publicly announced.

We present a scalable optimization framework to address this challenge at the microscopic level. Our approach extends a Logic-Based Benders Decomposition (LBBD) scheme [1] to jointly optimize train order, routing, and timing across multiple daily scenarios. It supports both periodic and non-periodic services while enforcing cross-scenario consistency on commercial train events. As the number of scenarios and periodic replications grows, the complexity increases rapidly. To ensure tractability without compromising solution quality, we introduce an effective conflict-pruning procedure that reduces constraints by over 95%.

Using real data from the Rhätische Bahn (RhB) network, we benchmark three planning strategies: synchronized, independent, and sequential. The direct MIP formulation struggles to solve non-trivial instances due to weak scaling and numerical instability. In contrast, our LBBD-based method, enhanced by fast branching and conflict aggregation, consistently produces feasible, synchronized timetables with moderate overhead. The proposed approach is implemented in the `openBus` optimization toolbox [2], enabling practitioners to transform long-term strategic plans into consistent and operationally viable daily timetables.

Keywords: railway scheduling, logic-based Benders decomposition, periodic timetabling, scenario coordination, microscopic modeling

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Implication learning for disjunctive formulations in railway scheduling

Bjørnar Luteberget[1], Giorgio Sartor[1], Carlo Mannino[1]
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Disjunctive graphs are widely used to model scheduling problems and have been the main underlying formalism both for theoretical advances and for practical solving of railway scheduling problems. Implication rules for disjunctive graphs can speed up optimization algorithms by quickly eliminating parts of the search space by deriving additional logical conditions from the disjunctive constraints. Earlier work in railway scheduling has studied pre-computing implications or computing implications in the current partial solution [1]. Extending on this, we study an *implication learning* scheme where infeasible partial solutions found during optimization are analyzed, and a minimal implication rule is extracted and kept in a table to be re-used in other partial solutions. The procedure is analogous to no-good constraints from the constraint programming literature and theory learning from the Boolean satisfiability literature [2].

We present the theory and the algorithm for generating implications from cycles in the disjunctive graph, and we demonstrate the impact this has on solver performance in the framework of a state-of-the-art custom branch and bound algorithm for real-time train dispatching. The reduction in search space has a special relevance in the real-time context where a sequence of similar optimization problems is solved continuously with a frequency of minutes or less. Here, the implication rules learned in one problem are easily transferrable to the next problem in the sequence, and the effect on performance can be significant.

Keywords: railway scheduling, train dispatching, branch and bound, disjunctive graph

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Railway crew rescheduling for disruptions in freight transportation with weekly planning horizon

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An efficient transport system is essential for supporting economic activity. Disruptions due to track blockages or technical failures are difficult to avoid in daily operations. Thus, an adequate response in the form of a rescheduling tool is required. In this work, we focus on the task of crew rescheduling in the case of disruptions in freight transportation. This phase is usually preceded by the timetable and locomotive rescheduling steps, where decisions are made regarding the new train schedules and the rolling stock assignment. The goal of crew rescheduling is to create new duties according to the new schedules that are similar to the original ones, while respecting the given restrictions [1]. Labor rules and work time regulations need to be taken into account. Most of the existing literature on railway crew rescheduling focuses on passenger transportation. In freight transportation, there are several differences: trips are generally longer than in passenger transportation, making it more difficult to plan the required rest periods between duties and possibly necessary overnight stays [3]. In addition, freight transportation often requires planning over multiple days. Therefore, it is important to consider a longer planning horizon of a week, rather than just a single operating day [2].

In disruption management decisions need to be made within a short time. Therefore, we present a Variable Neighborhood Search metaheuristic to quickly compute high quality feasible crew duties recovering the original plan. The metaheuristic method makes use of several neighborhood structures of different size and aims to minimize the deviation from the original crew schedule, while respecting all labour rules and regulations to guarantee the feasibility of the new duties. We experiment with disruptions of varying duration and severeness and test the approach on real-world data from Austria's largest freight railway operator.

Keywords: Crew rescheduling, Railway freight transportation, Disruptions

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Session: PRINSUPERSONIC

Tuesday September 2nd 11:00am - 12:40am

Room 2

Chair: Maurizio Bruglieri

A survey on the recharging policies in the Electric Vehicle Routing Problem with Time Windows

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This work provides a comprehensive review of the most recent literature on the Electric Vehicle Routing Problem with Time Windows (E-VRPTW), a problem introduced by Schneider et al. (2014) that, along with its variants, is attracting attention from researchers. Compared to existing surveys, the present work focuses specifically on the recharging policies assumed in the E-VRPTW. In fact, the E-VRPTW aims to route a fleet of electric vehicles (EVs) to serve customers within their time window, minimizing the total travel distance. The fleet is based at a common depot, to which each EV must return within a maximum time. Due to the limited driving range, EVs can stop at recharging stations (RSs) during their trips. In the literature, RSs are assumed with either an unlimited or a limited number of chargers. In addition, they are either public or owned by the transportation company. These distinctions lead to different recharging policies and variants of the E-VRPTW. We adopt a systematic methodology to select relevant literature from scientific databases (i.e., Scopus and Web of Science), guided by defined research questions. The selected papers are then analyzed through a classification scheme that organizes them on key dimensions, crucial to the topic. First, we introduce the problem and motivate the importance of focusing on recharging policies. Next, we describe in detail the methodology used to select the most pertinent contributions. We then analyze the literature, grouping papers according to the recharging policies they adopt. Finally, we discuss promising directions for future research, identifying gaps and challenges that have yet to be tackled. This research is within the project "SUPporting Ecological tRanSitiOn iN mId-haul logistiCs (SUPERSONIC)", funded by the MUR program 'Bando relativo allo scorrimento delle graduatorie finali del bando Progetti di Ricerca di Rilevante Interesse Nazionale" (PRIN) 2022 (code: 2022WXFN5B, CUP: I53C24002250006).

Keywords: Literature Review, Electric Vehicle Routing Problem, Recharging Policy

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An approximate dynamic programming approach for the Electric Vehicle Routing Problem with Time Windows and Stochastic Travel and Recharging Times

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Mid-haul logistics concerns the transportation of goods over distances from 50 to 300 kilometers. In this context, adopting Electric Vehicles (EVs) is challenging due to their limited range: medium-duty EVs typically travel no more than 80 kilometers before needing a recharge. Routing EV fleets while managing recharges leads to the Electric Vehicle Routing Problem with Time Windows (E-VRPTW) [1]. However, classical E-VRPTW does not account for stochastic travel times (due to traffic), energy consumption (affected by driving behavior and environment), or charging delays (caused by queuing).

Our study incorporates these uncertainties—realistic energy consumption, stochastic travel times, and waiting times at charging stations—and frames the problem within a two-phase stochastic optimization model. In the first phase, routes are planned. In the second, EVs are dynamically routed with real-time recharge decisions. Due to problem size and uncertainty, exact solutions are impractical. Thus, we develop a heuristic approach combining column generation for route selection and approximate dynamic programming for recharging management.

We validate our method on benchmark instances. Furthermore, recognizing that full recharges are time-consuming, we compare flexible partial recharge strategies against full recharge policies to assess their impact on efficiency.

Acknowledgement: This research is part of the project "SUPporting Ecological tRanSitiOn iN mId-haul logistiCs (SUPERSONIC)," funded by the MUR program "Bando relativo allo scorrimento delle graduatorie finali del bando Progetti di Ricerca di Rilevante Interesse Nazionale" (PRIN) 2022 (code: 2022WXFN5B, CUP: I53C24002250006).

Keywords: Electric Vehicle Routing Problem, Stochastic travel time, Stochastic energy consumption, Approximate Dynamic Programming

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A Matheuristic for the Electric Vehicle Routing Problem with Capacitated Public Recharging Stations

Maurizio Bruglieri[1], Lorenzo Moreschini[1]

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Several countries in the world are promoting the use of electric vehicles (EVs) to contrast the obnoxius CO_2 emissions due to the transport sector. Since EVs have a limited driving range, they may need to recharge during their trip. Moreover, as the charging process takes time and the recharging stations (RSs) are not currently widespread on the territory, the EVs' routes need to be properly planned also including stops at RSs. In this context, the seminal work [1] introduced the Electric Vehicle Routing Problem with Time Windows with the aim to plan the routes of a fleet of EVs, each one starting from the depot and returning to it within a given time limit, serving customers on time, scheduling stops at RSs, and minimizing the total travel distance.
In [1] the authors assume the EVs to be always fully recharged when they stop at a RS. Instead, we address a variant in which partial recharges are allowed. Moreover, we make the realistic assumption that each RS has a limited number of chargers and we also assume that the RSs are public, i.e. chargers can be occupied by third-party EVs. To avoid that no charger is available when an EV arrives at a RS, we consider chargers that must be reserved in advance. This implies that multiple time windows associated with the different chargers at each RSs must be managed to consider the reservations made by other EVs.
We model this optimization problem as a Mixed Integer Linear Program (MILP). Moreover, we use the MILP formulation in a matheuristic framework to efficiently solve also large-sized benchmark instances adapted from [2].
Keywords: Vehicle Routing, Mixed Integer Linear Programming, Capacitated Stations, Partial Recharges, Matheuristic

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2. Lam, E., Desaulniers, G., Stuckey, P. J. (2022). Branch-and-cut-and-price for the electric vehicle routing problem with time windows, piecewise-linear recharging and capacitated recharging stations. Computers & Operations Research, 145, 105870.

A metaheuristic for the Electric Vehicle Routing Problem with Time Windows and Capacitated Recharging Stations

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We address the Electric Vehicle Routing Problem with Time Windows (E-VRPTW), introduced in Schneider et al. (2014). It aims to route a fleet of electric vehicles (EVs) at minimum total travel distance. Each EV starts from a common depot, serves some customers within their time window, and returns to the depot within a maximum time. Due to the limited driving range of EVs, en-route stops at recharging stations (RSs) may be needed. In fact, the context taken as a reference in this work is that of Mid-Haul Logistics where it is often difficult to cover distances greater than 80 kilometers without recharging even while traveling (Schiffer et al., 2021). We assume that RSs have a limited number of chargers. In addition, contrary to the existing papers, we assume that RSs are not owned by the transportation company (i.e. they are public), introducing an additional degree of complexity. In fact, it is not assured that each time an EV stops at an RS, it finds an available charger, and then it must wait its turn, with no guarantee that it will be able to serve the rest of customers on time. To avoid queuing at RSs, the chargers can be reserved through an app, and therefore, each EV can use a charger only within the reserved time window. We propose a GRASP in which the construction phase applies a density-based clustering algorithm, followed by a route definition phase through a biased randomized approach. The solution is refined by a VND-based local search. To explore the solution space more thoroughly, infeasible solutions are allowed and evaluated using a penalty function. Preliminary results will be presented and discussed. This research is within the project "SUPporting Ecological tRanSitiOn iN mId-haul logistiCs (SUPERSONIC)", funded by the MUR program 'Bando relativo allo scorrimento delle graduatorie finali del bando Progetti di Ricerca di Rilevante Interesse Nazionale" (PRIN) 2022 (code: 2022WXFN5B, CUP: I53C24002250006).

Keywords: Greedy Randomized Adaptive Search Procedure, Variable Neighborhood Descent, Clustering

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A Matheuristic for the Electric Vehicle Routing Problem with Time Windows, Realistic Energy Consumption and Multiple Recharge Technologies

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The European Commission is promoting the use of Electric Vehicles (EVs), especially in road transport, which causes about 70% of the transportation sector harmful emissions. However, the limited driving range still prevents their diffusion. In mid-haul logistics, scenario considered here, the need of recharging is particularly significant, since the driving range of medium-duty EVs is usually limited to 80 kilometers [1]. Furthermore, since Recharging Stations (RSs) are not widespread in the territory and the recharge process is time consuming, the EVs routes must be properly planned also including their stops at RSs. Starting from [2], we address the Electric Vehicle Routing Problem with Time Windows, a realistic Energy Consumption Rate and Multiple Recharge Technologies. This problem aims at routing EVs to serve customers within their time windows, with possible (partial) recharges en-route, minimizing the total cost due to used EVs, energy and drivers' wage. Each EV serves some customers, starting from the depot and returning to it within a maximum time. The energy consumption depends on both the load and speed of the EV, where the latter is a decision variable that can vary between a minimum and a maximum value. Moreover, in this work, we assume that the RSs are equipped with different recharging technologies allowing faster recharge with higher cost. A Mixed Integer Linear Programming (MILP) model is formulated in which RSs can be used more than once in the routes without cloning them. Large and medium-sized instances are efficiently addressed by an LNS-based matheuristic. Some preliminary results, on a set of instances generated for this work, are presented.

Acknowledgement: This research is within the project "SUPporting Ecological tRanSitiOn iN mId-haul logistiCs (SUPERSONIC)", funded by the MUR program PRIN 2022 (code: 2022WXFN5B, CUP: I53C24002250006).

Keywords: Matheuristic, Mixed Integer Linear Programming, Partial Recharges, Large Neighborhood Search

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Session: Economy

Tuesday September 2nd 11:00am - 12:40

Room 3

Chair: Matteo Cosmi

Modeling and solving the first pan-European Guarantees of Origin market with Artelys Knitro

Stefania Pan[1], Enrico Bettiol[1], Michaël Gabay[1]

[1]Artelys

Guarantees of origin (GOs) are a tool to trace and guarantee the renewable origin of electricity. Using GOs enables electricity suppliers to provide specific contracts to customers such as renewable energy contracts or even more specific contract such as, for instance, German non-subsidized wind electricity. This also encourages investments in renewable energy technologies and provides an additional source of revenues for energy producers. The European Power Exchange (EPEX SPOT) have launched in 2022 the first pan-European spot auction for GOs. GOs may differ in issuing country, production technology, subsidy schemes or production month. This auction is uncommon as it gives market participants the option to bid for products which are either specific or generic, enabling purchasers to express precise requests, stimulate competition and create reliable price indices.

Artelys has worked closely with EPEX in the auction design and was in charge of the development of the market clearing engine. The algorithm has to ensure that various business rules are respected, and to strike the right balance between flexibility, complexity, fairness and intuitiveness. The algorithm objectives are to maximize the social welfare, the traded volume, and to compute all specific and generic market clearing prices. The problem consists in a multi-staged mathematical optimization algorithm which is solved using the state-of-the-art numerical solver Artelys Knitro.

Keywords: Guarantees of Origin, Market Clearing, Linear and Quadratic Optimization

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Cost optimization in cycling networks: a case study in the city of Parma, Italy

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Promoting more sustainable modes of transport, such as cycling, is fundamental in urban environments as a way to address issues like traffic congestion and carbon dioxide emissions [1]. One way to encourage bicycle usage is by providing suitable infrastructure to accommodate cyclists, who are interested not only in traveling the shortest routes but also in choosing safer and more comfortable ones, among other factors. Therefore, we propose an optimization strategy with the goal of building the most suitable cycling network for the city of Parma, Italy. Specifically, given a set of possible interventions, such as building new bicycle lanes/paths, improving the pavement quality of existing lanes, and others, we aim to select those that minimize the perceived cost by cyclists under budget constraints. In the proposed strategy, we formulate the problem as a mixed-integer optimization model, where the cyclists' costs, when traveling from different origins to different destinations in the city, are defined as a combination of three road features: length, safety, and practicability. To solve the problem, we develop a branch-and-bound algorithm, combined with two heuristics based on the dynamic programming method for the knapsack problem as initialization procedures. Computational experiments are performed using synthetic data representing networks with up to 1600 nodes, as well as real data collected from Parma. It is also important to highlight the collaboration with a group of architects, who assisted us in quantifying qualitative aspects, such as road safety.

Keywords: Transportation networks, discrete and combinatorial optimization, Branch-and-Bound method.

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Closing the Loop and Shifting from Selling to Servitization: Economic and Environmental Effects

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Changing the supply chain structure or business model is considered as one of the beneficial options to increase the sustainability of a supply chain. Motivated by this fact, in this study, we investigate the individual and joint effects of closing the loop and adopting servitization business model in a supply chain including a manufacturer and a retailer. To this end, we formulate Stackelberg Game models for four cases as (i) selling and (ii) servitization in forward supply chains, and (iii) selling and (iv) servitization in closed-loop supply chains. We obtain the equilibrium decisions in each case and compare them with each other. Analytical and numerical comparisons bring several managerial insights. First, we observe that both closing the loop and shifting from selling business model to servitization business model generally improve the environmental performance of the supply chain although there are instances in which they lead to a deterioration in the environmental performance. Moreover, closing the loop tends to improve the profits of both manufacturer and retailer. On the other hand, shifting from selling business model to servitization business model deteriorates the manufacturer's profit although it improves the retailer's profit.
Keywords: Selling, Servitization, Forward Supply Chain, Closed-Loop Supply Chain, Game Theory

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A Feasibility Study on the Construction of Park and Concert Hall through Cost-Benefit Analysis

Kim Dong-Guen[1], Sung Taeyeop[1], OH Yoonjung[1], Lee SeoYoung[1]
[1]The Seoul Institute

The Seoul Metropolitan Government is planning a redevelopment project to revitalize a section of downtown Seoul by demolishing two large existing buildings and replacing them with a ground-level park and an underground concert hall. This study conducts a comprehensive feasibility analysis of the proposed project through cost-benefit analysis, aiming to assess the economic and social validity of public investment in non-market assets such as parks and cultural infrastructure.

To estimate project costs, land compensation expenses are calculated using both the official land value and recent real estate transaction prices in the surrounding area. Construction costs are derived by referencing unit prices from comparable facilities, and operational costs are projected based on average operating expenditures of similar public venues.

On the benefits side, this study applies the Contingent Valuation Method (CVM) to quantify the non-market value of the urban park, capturing the public's willingness to pay for environmental and recreational amenities. For the underground concert hall, the Travel Cost Method (TCM) using the performance of a similar concert hall is employed to estimate user benefits based on the opportunity cost of time and travel incurred by visitors.

Keywords: feasibility study, contingent valuation method, travel cost method

Profitability and sustainability in complex chemical value chains under product-specific carbon footprint constraints

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[2]BASF, AI Solutions, Stockport, United Kingdom

The global effort to combat climate change has led many countries to adopt legally binding net-zero targets for the next 25–30 years. Since indirect emissions are also considered, a key strategy for companies is to require suppliers to produce cleaner products by meeting strict emissions standards per unit or weight. This study introduces the Product-Specific Carbon Footprint Optimization (PSCFO) problem, a deterministic multi-objective value-chain model aimed at minimizing CO_2 emissions while maximizing a company's total contribution margin. The objective is to achieve these goals while ensuring compliance with external customer demands for product-specific carbon footprint limits. To address the PSCFO problem, we propose a bilinear programming model using a "flow-like" formulation based on existing models from [1] and [2].

Keywords: Sustainable value chain, multi-objective optimization

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Session: Communicating mathematics and O.R. (MaddMaths!)

Tuesday September 2nd 14:20 - 15:40

Main Room

Chair: Alice Raffaele

Invited Session

Communicating Mathematics and Operations Research: The *MaddMaths!* Experience

Maria Francesca Carfora[1], Marco Menale[2], Roberto Natalini[1], Alice Raffaele[3]

[1]Institute for Applied Mathematics "Mauro Picone", National Research Council of Italy

[2]Department of Mathematics and Applications "R. Caccioppoli", University of Naples "Federico II", Italy

[3]Department of Information Engineering, University of Padova, Italy

Born as a website in 2009 and become also a non-profit association in 2024, *MaddMaths!* [1] is an online platform that aims to be not only a showcase of Italian and international mathematics but also a meeting and discussion point for students, teachers, researchers, academics, or, simply, curious people who know mathematics only by hearsay. Contributions available on the platform range from short written articles and series of posts to podcasts and participation in public events. Most of these contents are made by passionate scientists from different areas of mathematics who are doing research themselves and can speak with competence and complete mastery even on very advanced topics. However, when communicating science is more than ever a necessity and not only an academic duty in terms of "third mission", how can we present mathematical topics to ensure that everyone understands, at least in broad terms? How can we promote mathematics as a fundamental cultural enrichment for a person inserted in an advanced society? How can we increase people's interest and motivation towards mathematics to hopefully make some of them think of making a profession out of it?

In this special session, through individual presentations and a roundtable discussion, we will present projects, strategies, and tools implemented and tested over the last 16 years by the MaddMaths! group. Moreover, focusing on our field of Operations Research, we will summarize what has been done so far and discuss which topics would be more suitable to be delivered to different audiences, as well as which media and techniques could be more effective in several cases, with the overall goal to increase Operations Research awareness and knowledge [2].

Keywords: Mathematics education, Science communication, OR teaching.

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2. Raffaele, A. Becoming visible: Why we should be better communicators now. *Operations Research Forum.* Vol. 2. No. 1. Cham: Springer International Publishing, 2021.

Session: Scheduling 2

Tuesday September 2nd 14:20 - 15:40

Room 1

Chair: Alessandro Agnetis

Optimizing a Cutting Work Center: Multi-Criteria Approach to Pattern and Single Cut Sequencing

Claudio Arbib[1], Fabrizio Marinelli[2], Andrea Pizzuti[2]

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[2]Dept. of Information Engineering, Università Politecnica delle Marche, Italy

This work presents a multi-criteria optimization framework developed in collaboration with a leading company in the production of automatic machines for iron manufacturing. The study focuses on optimizing the workflow of a cutting machine and its unloading system, aiming to enhance efficiency and minimize idle times.

The manufacturing process involves several sequential steps. Initially, iron bars are cut according to pre-computed cutting stock patterns and transported via a conveyor belt to two temporary buffers. From there, a portal equipped with pliers relocates the bars through lengthwise movements into a depot consisting of identical parallel buffers, where they are consolidated by order. The finalized orders are then transferred to unloading tracks upon request from downstream processing steps. The first step essentially resembles a single-machine batch scheduling problem, whereas portal management incorporates features from several classical problems, such as dynamic berth allocation, virtual machine packing, and dynamic bin packing.

A key challenge arises from potential idle periods of the sequential cutter when the unloading stations reach capacity, leading to machine blocking. To address this, a three-step optimization approach, combining local search techniques and enumeration, is proposed. First, a local search minimizes order spread by optimizing the sequencing of cutting patterns. Second, a branch-and-bound procedure determines the optimal dispatching of parts to the unloading stations, reducing cutter breaks and portal movements. Finally, a sequential value correction heuristic dynamically allocates consolidated lots into the depot, balancing the minimization of portal translations with the reduction of fragmented orders.

Computational experiments on real-world industrial instances validate the effectiveness of the proposed methodology, demonstrating improvements in cutter utilization, order consolidation, and overall workflow efficiency.

Keywords: Pattern Sequencing, 1D stock cutting, manufacturing

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Fair Scheduling of Jobs with Utilities Decreasing in Completion Time

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A new family of multi-agent single-machine scheduling problems is considered, where each job is associated with a self-interested agent. Each agent has a utility function which depends on the completion time of the agent's job. All utility functions are decreasing with increasing completion time. We focus on finding a schedule under a max-min criterion, which seeks to maximize the minimum utility experienced by any agent and thus strives for a fair solution.

For the general case of the problem a binary search procedure for the largest possible minimum utility is given. As an alternative, a greedy-type algorithm can be employed. We proceed to analyze several variants of this problem, characterized by properties of the scheduling environment, such as release dates and due dates. In particular, it can be shown that the problem is strongly NP-hard for arbitrary release dates, weakly NP-hard for only one job with release date, and polynomially solvable for general release dates, if all jobs share the same processing time.

An interesting perspective arises if the utility functions can be adapted up to a certain budget constraint. We concentrate on linear utility functions and describe algorithmically the impact on the optimal solution if either the intercepts of the utility functions can be increased, or their slopes can be decreased. If both intercept and slope are taken as flexible, we characterize the solution process if the area under the function is bounded. Taking the perspective of a single agent, we study the change of the solution structure, if this agent can improve its linear utility function while the other agents' utilities remain fixed.

Our study contributes to the growing literature at the intersection of scheduling theory, multi-agent systems, and algorithmic fairness, and highlights the relevance of fairness-oriented objectives in competitive scheduling environments.

Keywords: multi-agent scheduling, fairness

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Approximation algorithms for the $Qm||C_{max}$ problem via mathematical programming modeling

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We consider the so-called uniform machine scheduling problem $Qm||C_{max}$, where there are n jobs with processing times $p_1, \ldots, p_n$, and m parallel machines, each with a corresponding speed factor $q_1, \ldots, q_m$. The goal is to find the best assignment of the jobs to the machines in order to minimize the makespan. A general methodology is proposed to derive approximation results for different algorithms that share the following structure: a specific procedure is first applied to a list of long jobs, followed by a standard List Scheduling approach. This algorithmic framework is based on theoretical results that allow us to analyze instances with a limited number of jobs. We evaluate the worst-case performance of several algorithms using mathematical programming formulations and derive both existing and new approximation ratios for the problem with up to seven machines. Our approach provides a valid and flexible alternative to traditional analytical proof techniques for studying the $Qm||C_{max}$ problem, as well as potentially other related problems.
Keywords: Approximation algorithms, Mathematical Programming, Uniform parallel machine scheduling

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The Unreliable Job Selection and Sequencing Problem

Alessandro Agnetis[1], Roel Leus[2], Emmeline Perneel[2], Ilaria Salvadori[1]

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We address the following problem, denoted as the Unreliable Job Selection and Sequencing Problem (UJSSP). Given a set J of jobs, a subset $S \subseteq J$ must be selected for processing on a single machine that is subject to failure. Each job j incurs a cost c_j if selected and yields a reward R_j upon successful completion. A job j is completed successfully only if the machine does not fail before or during its execution, with job-specific failure probabilities p_j. The objective is to determine an optimal subset and sequence of jobs to maximize the expected net profit. We establish the computational complexity of UJSSP, proving its NP-hardness when job costs are not identical. The relationship of UJSSP with other submodular selection problems is discussed [1,2], showing that the special cases in which all jobs have the same cost ($c_j = c$ for all j) or, respectively, the same failure probability ($p_j = p$ for all j) can be solved in polynomial time. Additionally, we present a compact MILP formulation and derive an efficiently computable upper bound for the optimal solution. To tackle large problem instances, we develop an exact implicit enumeration method and evaluate its performance through extensive computational experiments.
Keywords: Submodular optimization, unreliable jobs, selection problems

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Session: PRIN ACHILLES

Tuesday September 2nd 14:20 - 15:40

Room 2

Chair: Claudio Sterle

Sustainability Meets Strategy: A Model for Flexible Production Networks

G. Colajanni[1], P. Daniele[1], D. Sciacca[1]

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In the context of increasingly complex and sustainability-oriented industrial ecosystems, Flexible Production Value Networks (FPVNs) represent a novel paradigm for integrating economic competitiveness with environmental responsibility. This paper introduces a comprehensive network-based optimization framework for modeling and analyzing decentralized FPVNs, where suppliers, manufacturers, retailers, and customers interact competitively under environmental and operational constraints. Each agent operates independently within a non-cooperative game-theoretic setting, aiming to maximize its own profit while considering the network-wide effects of production, transportation, emissions, and uncertain demand. The framework adopts a Generalized Nash Equilibrium approach formalized via a variational inequality formulation, ensuring the existence and uniqueness of equilibrium under suitable monotonicity assumptions. The model incorporates nonlinear cost and emission functions, penalizes over- and under-production, and includes stochastic demand to enhance realism. An illustrative numerical study shows the decision-making dynamics of the agents, quantifies the emissions footprint, and highlights the role of transportation mode selection in achieving both environmental and economic objectives. The results confirm that the equilibrium configuration promotes efficiency by deactivating suboptimal links, minimizing waste, and aligning production with market demand.

Keywords: Flexible Production Production Network, GNEP, Stochastic Optimization Problem

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Mathematical Modeling of Parcel Locker Networks in Urban Delivery Systems

G. Colajanni[1], P. Daniele[1], D. Sciacca[1]

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In the context of growing e-commerce demand and increasing pressure on urban logistics, parcel lockers have emerged as a promising solution to optimize last-mile delivery. This paper presents a mathematical modeling framework for the design and optimization of parcel locker networks in urban environments. The model aims to minimize the overall delivery cost while maximizing customer accessibility and ensuring efficient resource allocation. It considers both existing and potential locker locations, allowing for dynamic decisions on installations and removals, and incorporates key operational constraints such as locker management costs, installation and removal costs, customer behavior, and accessibility thresholds. Our results highlight the importance of adaptive planning and location flexibility in urban parcel locker networks, particularly under constraints of sustainability, urban space, and evolving consumer habits. The proposed model offers valuable insights for logistics providers and city planners aiming to build resilient and scalable delivery infrastructures.

Keywords: Last-mile delivery, Logistics optimization, Variational inequalities

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On Tackling Logarithmic Charging Functions in the Electric Vehicle Problem

Tiziano Bacci[1], Claudio Gentile[1], Emanuele Pizzari[2]

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Using electric vehicles in a vehicle routing problem poses serious challenges. The charging process is particularly difficult, being divided into two distinct phases: in the first phase, the charging current is held constant (CC phase) and the battery level increases linearly with time until a certain value, which is around 80% of the entire battery capacity. Then, to avoid damage to the battery, the voltage is kept constant (CV phase) while the current decreases exponentially with time, and the battery level increases concavely with time. In the literature, this non-linear function is dealt with piecewise linear approximation [1]. A higher number of breakpoints yields higher complexity, although higher accuracy. The common vehicle routing formulation with node-tracking or arc-tracking constraints also poses a serious challenge. Indeed, practitioners would need to know or find how many copies of the same charging station nodes to insert in the formulation. [2] proposed a novel path formulation that avoids this issue. Although the number of paths is staggering, a preprocessing algorithm can assist in eliminating infeasible or dominated paths. [2] proposed such an algorithm, although dependent on the piecewise linear approximation.

In this work, we proceed with a two-fold contribution: we provide a way to approximate time spent charging at charging stations using perspective cuts, and we provide a general preprocessing algorithm that is not dependent upon any kind of approximation.

Empirical results to assert the validity of our method are reported.

Keywords: Vehicle Routing Problem, Sustainability, Non-Linear Optimisation, Perspective Cuts

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A new MILP formulation and a Matheuristic Approach for the TSP with Release Dates and Drone Resupply

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Drones are playing an increasingly important role in last-mile logistics. While synchronized truck-and-drone systems, where trucks act as mobile depots, have been extensively studied, direct drone-to-customer deliveries still face major regulatory and safety challenges. A promising alternative involves drones resupplying trucks in transit, streamlining deliveries without the need for direct customer contact. This approach enhances delivery speed and improves the system's overall flexibility, cost-effectiveness, and sustainability. Drones resupplying trucks on the move allow for real-time order fulfillment, reduced detours, and better adaptation to fluctuating demand, particularly in rural areas. This operational setting leads to the definition of the Traveling Salesman Problem with Release Dates and Drone Resupply, where a single truck, starting from a depot, receives other packages via drone deliveries while serving customers. TSPRD-DR was initially introduced by Dayarian et al. (2020) in a same-day delivery context and later tackled through simulation approaches (Moshref-Javadi et al., 2023). A formal mathematical model for the TSPRD-DR was first proposed by Pina-Pardo et al. (2021) as a variant of the TSP with Release Dates introduced by Archetti et al. (2018). They presented a MILP formulation along with a heuristic decomposition method for larger instances. However, the model suffers from scalability issues due to big-M constraints, which significantly hinder performance even on small problems. In this work, we propose a new formulation for the TSPRD-DR that aims to overcome these dimensional limitations. Additionally, we develop a Matheuristic algorithm to solve medium and large scale instances of the problem efficiently. Preliminary computational results demonstrate the effectiveness of our approach compared to existing approaches, highlighting significant improvements in both solution quality and computational time.

Keywords: TSP, release dates, drone resupply, last-mile logistics

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Session: Optimization under uncertainty 2

Tuesday September 2nd 14:20 - 15:40

Room 3

Chair: Francesca Maggioni

Data-Driven Multi-Energy Management with Price-Responsive Demand

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The increasing integration of multiple energy carriers and the introduction of new dynamic pricing strategies in the energy retail market call for advanced decision-making frameworks that can handle the responsiveness of users' behavior to price signals.
This work addresses a multi-energy management problem, where an energy hub acts as the central operator coordinating electricity, gas, and heat flows. The energy consumption of a group of users is supposed to be partially sensitive to the day-ahead tariffs set by the hub. The demands for electricity power and heating depend on energy tariffs following an unknown relationship. To capture this dependency, a pretrained neural network (NN) is embedded into the optimization model, according to the constraint learning procedure. The NN learns the uncertain cross-relationship between the demands and the prices in an aggregated way to reflect how demand uncertainty evolves with the varying of the offered rate.
The resulting optimization model allows the energy hub to optimize multi-energy dispatch and pricing under realistic behavioral uncertainty, providing a new data-driven approach to represent the uncertainty with respect to the traditional stochastic and robust optimization framework. A realistic case study is presented to demonstrate how the resilience and the economic performance of the hub are improved by the application of the methodology.
Keywords: Artificial Neural Networks, Constraint Learning, Multi-Energy Systems

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A partition-based method for K-adaptability in two-stage stochastic optimization

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[2]University of Amsterdam, Amsterdam, Netherlands

Two-stage stochastic programs are used to model problems with uncertain data, where a decision maker first decides the values of first-stage decision variables, then observes the values of the uncertain data, and finally decides the values of second-stage decision variables. We focus on the case where uncertainty can be modeled by a finite number of scenarios $\ell \gg 0$ and we define and study the so-called K-adaptability approach for two-stage stochastic programming. Extending some of the ideas proposed in [1,2], our aim is to detect feasible values of first-stage decision variables and a corresponding set of $K \ll \ell$ second stage solutions so that two goals are achieved. On the one hand, we want that each scenario is *covered* by at least one of the computed K second stage solutions. On the other hand, we want to select the K second stage solutions so that the objective value of the best of these, calculated in each scenario independently, is optimal in expectation. Similarly to [1,2], we present a quadratic programming formulation of the problem. With the aim of defining an exact algorithm for the K-adaptability two-stage stochastic problem, we proceed by enumerating partitions of the scenario set. A complete enumeration is avoided thanks to properly defined lower and upper bounds on the optimal partition. Preliminary numerical results on two-stage stochastic instances from the literature are shown.
Keywords: Two-stage stochastic programming, K-adaptability, Exact algorithms

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Surrogate neural networks for multi-horizon stochastic programs

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Multi-horizon stochastic programming is a modelling approach that incorporates multi-timescale uncertainty efficiently. Problems concerning multi-timescale uncertainty include long-term infrastructure planning, such as energy system investment and operational planning. A multi-horizon stochastic program has a block separable structure, which allows it to be decomposed into a master investment planning problem and several operational planning subproblems. The bottleneck for such decomposition is that the subproblems are usually large. Several enhanced Benders decomposition algorithms were proposed to solve multi-horizon stochastic programs very efficiently via cut sharing, by utilising the block separable structure to avoid solving all subproblems exactly. In this talk, we present an alternative method that obtains the subproblems' objectives using a surrogate neural network. We apply the method to a UK power system planning problem and present preliminary results.

Keywords: Stochastic programming, Multi-horizon stochastic programming, Surrogate neural networks

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Dynamic approaches for a new variant of the Team Orienteering Problem

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Inspired by two real-world applications – the swab tests collection during the COVID-19 pandemic and the ambulance routing for post-disaster management – the Team Orienteering Problem with Service Times and Mandatory & Incompatible Nodes (TOP-ST-MIN) [1] emerges as a new variant of the traditional Team Orienteering Problem (TOP). The TOP-ST-MIN extends the TOP formulation by introducing three additional features: (i) service times at nodes, (ii) a set of mandatory nodes and (iii) a set of incompatibilities between nodes.

Since finding a feasible solution for the TOP-ST-MIN has been proven to be NP-complete [1], the problem is inherently difficult and becomes significantly more complex when incorporating uncertainty in service and travel times or dynamic factors such as the arrival of new node requests or the emergence of new incompatibilities and mandatory nodes.

The Branch & Regret paradigm [2,3] is a scenario-driven approach designed for dynamic problems, combining discrete event simulation with online optimisation. It provides an effective framework for handling dynamicity by integrating a branching mechanism that helps to choose a specific high-level feasible action with a consensus-based function that evaluates outcomes across various scenarios, interpreted as subsets of potential future requests. As service and travel times may be inherently uncertain, the problem also deserves to be investigated under stochastic conditions by modelling these two quantities as Normal random variables. Consequently, the entire Branch & Regret framework has been modified to account for this uncertainty.

Four different Branch & Regret algorithms have been developed to tackle this problem and were compared using a newly generated set of TOP-ST-MIN instances, specifically designed to emphasise the three key features that define the problem. Extensive computational experiments are presented to validate the proposed approaches and to offer insights into their performance.

Keywords: Team Orienteering Problem, Online Optimisation, Stochastic Optimisation

References

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2. L. M. Hvattum, A. Løkketangen, G. Laporte (2007). *"A Branch-and-Regret Heuristic for Stochastic and Dynamic Vehicle Routing Problems".* Networks 49, 330–340.
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Session: Graph theory

Tuesday September 2nd 16:20 - 17:20

Main Room

Chair: Sara Mattia

Characterizing Path-Length Matrices of Unrooted Binary Trees

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We extend the results in [1, 2] on necessary and sufficient conditions for a symmetric integer matrix to encode the *Path-Length Matrix* of an *Unrooted Binary Tree* with n leaves. This problem is central to the combinatorics of the *Balanced Minimum Evolution Problem* (BMEP), a $\mathcal{NP}$-hard problem studied in phylogenetics. We show a reduced set of conditions for $n \leq 11$ that, interestingly, does not include the so-called Buneman's four-point conditions [2]. For such values of n, this result also enables an Integer Linear Programming formulation that outperforms the current state-of-the-art one for the BMEP [3].

Keywords: Combinatorial optimization, Unrooted binary trees, Path-length matrices, Balanced minimum evolution

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A branch-and-price algorithm for the Cluster Vertex Deletion problem

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[2]IDO Department, ESSEC Business School, Cergy-Pontoise, France
[3]Department of Mathematics, University of Salerno, Fisciano, Italy

The Cluster Vertex Deletion (CVD) problem is a well-studied problem in graph theory and combinatorial optimization, often arising in the context of data clustering and network analysis. The goal of this problem is to transform a given graph into a *cluster graph*, that is, a graph where every component is a clique (i.e., a set of mutually adjacent vertices). The transformation is achieved by deleting the fewest possible vertices from the original graph.

We model the CVD problem through two formulations, both involving an exponential number of variables. Such an inherent complexity renders standard integer programming approaches impractical, even for medium-size instances. To tackle this, we develop a branch-and-price algorithm, a decomposition-based exact method that combines column generation with branch-and-bound. The method is particularly well-suited for problems where an explicit enumeration of all variables is computationally infeasible, as it dynamically generates only the most relevant variables during the solution process. We analyze the theoretical properties of both proposed formulations, and introduce a dedicated pricing heuristic to accelerate the column generation process by quickly identifying promising variables. Preliminary computational experiments on benchmark instances highlight the potential of the approach and suggest promising directions for further development.
Keywords: cluster deletion, graph modification problems, branch-and-price

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On the complexity of the clique interdiction problem on K_3-free graphs

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Given a graph, the clique interdiction problem is a bilevel programming problem, where the leader interdicts a set of nodes and/or edges, while the follower computes the maximum clique on the remaining graph. This problem is, in general, in Σ_2. Although there exist cases where the problem was demonstrated to be polynomially solvable, no cases where it is NP-hard but not Σ_2-hard are known. This paper identifies the first class of graphs having this property

Keywords: maximum clique, clique interdiction, bilevel programimng, complexity

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Session: Applied machine learning 1

Tuesday September 2nd 16:20 - 17:20

Room 1

Chair: Filippo Bonafé

Advanced Machine Learning Techniques for Investment Forecasting: An Integrated Approach

Aivaras Bielskis[1]

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Stock price forecasting is a highly challenging task influenced by complex market dynamics, macroeconomic factors, and investor behavior. Although the Efficient Market Hypothesis (EMH) suggests that prices fully reflect all available information and are thus inherently unpredictable, numerous studies have shown that machine learning models can identify exploitable inefficiencies and patterns in financial time series.

This study evaluates five predictive models: Long Short-Term Memory (LSTM), Gated Recurrent Unit (GRU), a Transformer-based model for time series forecasting, XGBoost, and Deep Multi-Layer Perceptron (DMLP)—using data from five major indices: the S&P 500, NASDAQ-100, Dow Jones, FTSE 100, and DAX. The dataset spans from 2000 to early 2025 and is divided into training, validation, and testing sets to ensure a robust evaluation process.

A core contribution of the research is implementing an ensemble learning approach, which combines forecasts from all five models. Unlike traditional averaging, optimized weight assignments are computed using Gradient Descent, Elastic Net, and Linear Regression techniques, allowing the ensemble to dynamically adapt to market shifts.

Model performance is assessed using statistical metrics (MSE, MAE, R^2) and financial performance indicators such as Maximum Drawdown, Total Return, Calmar Ratio, and Sharpe Ratio. The study also incorporates a Long-Short trading strategy driven by model predictions.

Results confirm that the ensemble method improves forecasting accuracy and delivers better risk-adjusted returns than any single model alone, offering a practical framework for financial forecasting and decision-making.

Keywords: stock forecasting, machine learning, ensemble methods, trading strategy

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Sample-Efficient Tuning Of Quantum Circuit Parameters Via Bayesian Optimization

Alessandro Pannone[1], Federico Tosone[1], Daniel Faccini[1], Francesco Romito[1], Nicolò Mazzi[1]
[1]Spindox S.p.A., Applied AI department, Milan

In this work, we present a Bayesian optimization (BO) approach to tune the parameters of the quantum approximate optimization algorithm (QAOA) for solving max-cut problems. Our black-box optimization framework demonstrates that BO achieves competitive solutions with significantly fewer quantum circuit evaluations compared to non-Bayesian global optimizers. Our results highlight the potential of BO to improve the efficiency and effectiveness of quantum algorithms.

Quantum Approaches for Drivers' Emotions Analysis in Clustering-related Optimization Problems

Filippo Bonafé[1], Mirko Mucciarini[1], Buse Tezçi[2], Gizem Belkis Ceylan[2], Cristiano Pifferi[2], Nicholas Bianchini[2], Gabriella Bettonte[3], Simone Rizzo[3], Matteo Barbieri[3], Daniele Gregori[3], Manuel Iori[1], Roberto Montanari[2]

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[2]RE:LAB s.r.l., Reggio Emilia, Italy
[3]E4 Computer Engineering Spa, Scandiano, Italy

The QUACK (Quantum Customer Knowledge) project investigates the application of Quantum Computing to driving behavior analysis. The potential of quantum computing is being explored in mobility-related applications where fast decision-making over high-dimensional, temporally structured data is essential (Rattan et al., 2025).

For QUACK, a dataset was created using simulated driving sessions, during which participants were exposed to specific emotional stimuli designed to produce noticeable changes in their driving behavior. Changes were recorded as multivariate time-series data and organized into time windows that aligned with the structure of the administered stimuli, each representing a discrete driving episode. The resulting segments were clustered using classical and quantum-based optimization techniques to identify structurally coherent and recurring behavioral patterns.

To this end, the clustering problem is formulated as a Quadratic Unconstrained Binary Optimization (QUBO) problem, where binary variables represent the assignment of each driving segment to a specific cluster. For each driving feature, dedicated distance matrices between segments are computed and aggregated into a unified dissimilarity representation via weighted combination. The objective function minimizes intra-cluster dissimilarity while enforcing unique assignments with a penalty term.

This work computationally compares classical techniques (Simulated Annealing and a MILP solved exactly with Gurobi) with Quantum Annealing (QA) executed on D-Wave machines. Gurobi obtains the highest solution quality, whereas Quantum Annealing achieves faster performance and may be a good choice in scenarios where accuracy loss is acceptable within an operational tolerance threshold. Future research directions include the evaluation of the Quantum Approximate Optimization Algorithm, implemented through quantum emulators (e.g., CUDA-Q) and other quantum physical machines (e.g., neutral atom quantum computers).

Acknowledgement: Project QUACK "Quantum Customer Knowledge" was financial supported within CN00000013 HPC "National Centre for HPC, Big Data and Quantum Computing" and funded under the National Recovery and Resilience Plan (PNRR), supported by the European Union through the NextGenerationEU program.

Keywords: Quantum Computing, Drivers' Behavior Analysis, Clustering, Optimization Problems

References

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Session: PRIN WOW

Tuesday September 2nd 16:20 - 17:20

Room 2

Chair: Raffaele Cerulli

A GRASP for the q/1/D/V problem in automated warehouses

Daniele Ferone, Paola Festa, Tommaso Pastore, Alessio Petricciuolo

This paper focuses on an optimization problem arising in automated warehouses, where a crane with a fixed capacity must deliver a set of items while respecting a predefined loading order. We introduce the problem and classify it according to the established taxonomy of crane optimization problems. Additionally, we present a linear integer programming model that formally describes the problem. To efficiently find solutions for large-sized instances, we discuss the implementation details of a GRASP metaheuristic algorithm. The experimental results from our computational tests demonstrate that the GRASP algorithm can find near-optimal solutions in a short amount of time, while the linear integer programming model guarantees optimal solutions only for smaller instances.

Dynamic programming for an order picking problem with deadlines

Giovanni Righini[1]
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In this paper I consider the problem of optimally sequencing a set of pickup-operations in an automatic storage/retrieval system, where a shuttle runs along a single rail, visits the required storage locations along it and carries the required items to an input/output location at an endpoint of the rail. For each of the trip of the shuttle, two items can be accommodated on it. Pick-up operations can be executed in any order but each item has an associated deadline, represented by the maximum allowed position of its trip in the trip sequence. The objective is to minimize the total distance traveled by the shuttle.

Although the problem without deadline restrictions is trivial, its variation with deadlines is not. The problem can be polynomially solved when items are partitioned into two groups with a deadline for each group. For the general case, I present a dynamic programming algorithm. In spite of its exponential time complexity, it was observed to be very effective in practice.
Keywords: Order picking, Dynamic programming

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A mixed-integer program and a carousel greedy algorithm for the scheduling of pick-up and delivery operations in automated warehouses

Francesco Carrabs[1], Raffaele Cerulli[1], Carmine Sorgente[1]
[1]University of Salerno (Italy)

We tackle a scheduling problem arising in the context of automated storage and retrieval systems, where boxes are stored and need to be positioned and retrieved according to a series of pick-up and delivery requests, minimizing the operation time [1,2]. We consider a scenario characterized by a three-dimensional layout, a generic crane capacity, and mixed operations with multiple alternative positions. On the one hand, we formulate the problem as a mixed-integer program. On the other hand, we devise a constructive heuristic that produces a set of tours, and we enhance this solution by embedding the heuristic procedure in a carousel greedy framework. We present the results of a computational study performed to evaluate and compare the performance of the proposed approaches on a newly generated set of benchmark instances.
Keywords: Automated warehouse, Scheduling, Carousel greedy

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Session: Multi-objective optimization

Tuesday September 2nd 16:20 - 17:20

Room 3 Chair: Donatella Granata

From warehouse to store: A multi-day shipment planning and consolidation based on lexicographic multi-objective optimization

Marta Cavaleiro, Andrea Bettinelli, Andrea Degiorgis, Simone Gherardi

A fundamental aspect for an efficient outbound shipment planning is the order consolidation, which involves aggregating multiple orders for the same destination into a single shipment. This often requires postponing some orders to merge them with future ones (existing or forecasted), thereby reducing operational and transportation costs. This paper addresses the problem of generating an optimal multi-day shipping plan with consolidated orders, that satisfies multiple and conflicting objectives, such as respecting delivery windows, respecting store capacity limits, balancing warehouse workload and creating efficient logistic consignments. To tackle this challenge, we propose a multi-objective optimization model based on the lexicographic minimization of several Mixed-Integer Linear Programs, with seasonally-updated objective priorities. Our experiments on real-world instances validate the effectiveness of the proposed approach in meeting the different objectives.

Multiple Criteria Decision Making Under Xorness

Amin Hocine[1], Sergio Ortobelli Lozza[2]
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[2]Dipartimento di Management, Universitá degli Studi di Bergamo, Italia

Multiple criteria decision making (MCDM) addresses decision problems that involve multiple, often conflicting, criteria, objectives, or goals. In practice, MCDM focuses on evaluating the performance of a set of alternatives based on a given set of criteria. However, this evaluation process is complicated by the uncertainty inherent in the chosen criteria, which can take various forms and arise from different sources. One such form is Xorness. Conceptually, Xorness refers to a state of indeterminacy that decision-makers face when attempting to define true performance but are unable to do so due to either an epistemic limitation -where knowledge is incomplete- or an ontological condition -where the structure of the decision system lacks fixed or determinate features. These circumstances give rise to exclusivity, where the decision-maker is compelled to employ the exclusive disjunction "or" to cope with this indeterminacy. This, in turn, leads to hesitancy -a cognitive state in which multiple evaluations vie for attention, yet none is sufficiently dominant to be selected over the others. To quantify this type of uncertainty, the XOR number is proposed. This number captures the presence of distinct, mutually exclusive evaluations that are inherently indeterminate. In other words, while it is known that exactly one of the evaluations is true, its identity remains undefined. This paper establishes the theoretical foundation and practical application of this concept, proposing a framework for multiple criteria decision making under conditions of Xorness.

Keywords: XOR Numbers, Xorness, Uncertainty Modeling, Uncertainty Quantification, indeterminate information, Hesitant information, Uncertainty measure, Exclusive Disjunction, Ranking under Uncertainty, Multi-Criteria Decision Making

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A Bi-Objective approach to Penalized Reload Cost Path Problem

Donatella Granata[1]

[1]Istituto per le Applicazioni del Calcolo "Mauro Picone", National Research Council

Edge labeled graphs provide a valuable framework for modeling heterogeneous infrastructures in network design. The penalized reload cost (PRC) expands the standard notion of "reload cost" to include not only the costs of traversing a structure but also the internal costs that are obscured in the remaining graph. This paper introduces and investigates the Bi-Objective Penalized Reload Cost Path (BOPRCP) problem. The goal is to find a path between a source and a destination that simultaneously minimizes two conflicting objectives: (1) the standard reload cost (r_c) incurred along the path, and (2) the reload cost component (r_{cc}) in the remaining connected components after path removal.We propose a novel Bi-Objective Mixed- Integer Linear Programming (MILP) formulation, termed FBO-PRCP, to precisely model this problem. To explore the Pareto optimal solutions, we apply the weighted sum method to the MILP formulation across a wide range of generated benchmark instances. Our computational experiments validate the inherent trade-off between the r_c and r_{cc} objectives and demonstrate the capability of the exact formulation to identify non-dominated solutions for small to medium-sized problems. The results also highlight the computational scalability challenges of the exact method for larger instances, particularly affected by network parameters as label density.

Session: Packing and cutting

Wednesday September 3rd 08:00am - 09:40am

Main Room

Chair: Michele Monaci

The 0–1 Knapsack Problem with Group Fairness

Enrico Malaguti[1], Paolo Paronuzzi[1], Alberto Santini[2]

[1]Department of Electrical, Electronic and Information Engineering, Alma Mater Studiorum University of Bologna

[2]Department of Economics and Business, Universitat Pompeu Fabra

This paper presents exact algorithms for a generalisation of the classic 0–1 Knapsack Problem, called the Knapsack with Group Fairness. In this problem, items are partitioned into classes, and fairness constraints affect the number of items that can or must be chosen from each class. The problem was introduced by Patel et al. (2021), who discuss approximation algorithms. This paper describes the first exact solution approaches for the Knapsack with Group Fairness, based on integer linear programming formulations and a dynamic programming algorithm. The latter allows us to establish the complexity of the problem. Finally, computational experiments on benchmark instances derived from the knapsack literature compare the effectiveness of the two proposed solution approaches.

Keywords: packing, knapsack problems, fairness, integer linear programming, dynamic programming

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Mathematical Formulations for the Robust Bin Packing Problem with Fragile Objects

Heloisa Vasques da Silva[1], Alberto Locatelli[2], Silvio Alexandre de Araujo[3], Manuel Iori[2]

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In the Bin Packing Problem with Fragility Objects (BPPFO), we are given a set items, each item with a weight and fragility, and a large number of uncapacitated bins. The problem consists in packing all items into the minimum number of bins, ensuring that the total weight packed in any bin does not exceed the smallest fragility among the set of items assigned to the bin. This problem appears, for example, in the telecommunication field, where each call is characterized by a noise and a noise tolerance. Therefore, the assignment of calls to available channels cannot exceed the noise acceptance limit of the fragilest call in the channel. Considering the fact that the noise of the calls is not exactly known in advance, but typically belongs to a given interval, we address a variant of the BPPFO designed to represent data uncertainties affecting the weights. The resulting Robust Bin Packing Problem with Fragility Objects (RBPPFO) generalizes the well-known BPPFO by incorporating a budgeted uncertainty set to model data uncertainties. To solve the RBPPFO, we propose three formulations: a compact mixed-integer linear programming formulation, an arc-flow formulation, and a constraint programming formulation. Additionally, we develop heuristic techniques to initialize these formulations and enhance their convergence. We also introduce a valid lower bound for the problem by transforming the RBPPFO into a corresponding BPPFO and subsequently applying the well-known fractional lower bound introduced by Bansal et al. [1]. To evaluate the efficiency of our models and compare their performance, we tested them on a set of instances adapted from the literature. Our results demonstrate the effectiveness of the proposed arc-flow formulation in solving the RBPPFO, highlighting its potential for application beyond the RBPPFO to other packing problems where handling uncertainty is crucial.
Keywords: Bin Packing, Robust Optimization, Arc Flow, Constraint Programming

References

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A Two-Stage Bin Packing Algorithm for Minimizing Machines and Operators in Cyclic Production Systems

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This study presents a novel, two-stage algorithm that minimizes the number of machines and operators required to produce multiple product types repeatedly in cyclic scheduling. Our algorithm treats the problem of minimum machines as a bin packing problem (BPP), and the problem of determining the number of operators required is also modeled as the BPP, but with constraints. The BPP is NP-hard, but with suitable heuristic algorithms, the proposed model allocates multiple product types to machines and multiple machines to operators without overlapping setup times (machine interference). The production schedule on each machine is represented as a circle (donut). By using lower bounds, it is possible to assess whether the number of machines required by our model is optimal; if not, the optimality gap can be quantified. The algorithm has been validated using real-world data from an industrial facility producing 17 types of products. The results of our algorithm led to significant cost savings and improved scheduling performance. The outcomes demonstrate the effectiveness of the proposed algorithm in optimizing resource utilization by reducing the number of machines and operators required. Although this study focuses on a manufacturing system, the model can also be applied to other contexts.

Keywords: algorithm, bin packing problem (BPP), integer linear programming (ILP), first fit decreasing algorithm (FFD), cyclic scheduling, machine interference

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Column Generation-Based Heuristic for Stochastic Bin Packing with One Defect per Pattern

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In manufacturing systems where industrial components are produced by cutting bars of raw material, production efficiency can be significantly compromised by unpredictable defects occurring along the bars. Similarly, in non-preemptive parallel machine scheduling, machines may become temporarily unavailable due to unforeseen disruptions, thereby delaying job completion. Altogether, these uncertainties can pose a serious threat to process reliability and economic performance.

In this work, a 0-1 pattern-based formulation is proposed to deal with such disruptions – up to one per pattern – and is solved through column generation. Specifically, by solving the pricing problem we compute a one-dimensional cutting pattern (or job-to-machine assignment) that can be reconfigured in response to the defect (or machine downtime) observed: the objective is to maximize resource utilization and, consequently, save economic value. To the best of our knowledge, this model represents the first exact formulation devised for the problem addressed.

Numerical tests on benchmark instances derived from literature assess the quality of the model under the assumption of uniform defect distribution. Primal bounds obtained by means of Price-and-Branch procedure are compared with the heuristic framework developed in Arbib et al. (2023). The effectiveness of the methodology to cope with stochastic disruptions is finally discussed.

Acknowledgement: This work is supported by the Italian Ministry of Research via the PNRR Project *eAdaptive*, D.M. 12-31 2021 and D.D. 03-18 2022, contract F/310361/01-02/X56.

Keywords: Bin Packing, Scheduling, Stochastic Defects, Manufacturing

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Column generation approaches for cutting and packing problems

Marco Antonio Boschetti[1], Stefano Novellani[2]
[1]University of Bologna, Department of Mathematics
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Column generation, combined with set partitioning or set covering models, can be employed to optimally or heuristically solve cutting and packing problems, as shown in several articles proposed in the literature. We describe a basic exact method for solving several combinatorial optimization problems based on a column generation procedure that generates multiple columns at a time [1]. We apply this approach to the bin packing problem, and some of its variants, using new Dynamic Programming (DP) algorithms to compute the k-best solutions for Knapsack Problems. These DP algorithms optimize memory usage and have the potential to include additional constraints as well as allowing their use in a cutting plane approach. We also describe how the proposed approach can serve as a good basis for the development of matheuristics [2]. This approach can also be extended to other cutting and packing problems and other combinatorial optimization problems. To analyze the performance of the proposed DP algorithms and the exact algorithm for the bin packing problem, we present some computational results.
Keywords: Column Generation, Dynamic Programming, k-Best Solutions

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Session: Equilibria, variational models & applications 1

Wednesday September 3rd 08:00am - 09:40am

Room 1

Chair: Fabio Raciti

Renewable Energy Communities with Peer-to-Peer Exchanges: a Chance-Constraint Approach

Elisabetta Allevi[1], Abdel Lisser[2], Giorgia Oggioni[1], Rossana Riccardi[1], Santo Saraceno[1]

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[2] Université Paris-Saclay, CNRS, CentraleSupélec, Laboratoire des Signaux et Systèmes (L2S), Gif-sur-Yvette, France

This work presents a chance-constraint model for the management of renewable energy communities, focusing on prosumers and peer-to-peer electricity exchanges. The scope of the energy community is to share energy reducing the amount of electricity withdrawn from the main grid. The entities included in the energy community receive an incentive for each MWh of electricity that is shared among members. The model considers the point of the energy community manager (aggregator) who aims to minimize the total operating costs of the community, while ensuring energy balance and satisfying a set of technical constraints. Uncertainty in solar photovoltaic generation and electricity demand is addressed using individual and joint chance-constraints that are modeled using normal distributions and approximated through piecewise-linear techniques when necessary. The model is tested on a prototype example of community and is implemented in Python using Pyomo.

Keywords: Energy Communities, chance-constraint model, uncertainty

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Distributed Consensus of Graph Vertices with Different Activation Schemes

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We consider a multi-agent distributed scenario in which several vertices of a graph (e.g., sensors/autonomous robots) need to exchange data in real time in order to perform their tasks. Due to the possible presence of energy/bandwidth constraints, some vertices may enter a low-power consumption modality in which their data exchange is reduced. We investigate distributed activation schemes wherein the vertices seek to minimize an objective consisting of a positively weighted sum of the average time to reach consensus and the energy consumption of active vertices. We compare how distributed activation schemes perform in terms of this objective function, considering a non-cooperative game-theoretical approach where optimal activation sets are seen as the Nash equilibria in pure strategies of an appropriately designed potential game. Furthermore, as asymmetric equilibria are often found, which are not associated with a fair use of resources, we investigate a specific symmetric activation scheme, by considering a variation of the first non-cooperative game-theoretical model, for which symmetric Nash equilibria in mixed strategies are searched for. Then, distributed asymmetric/symmetric activation schemes are compared with global centralized optimization as a benchmark. Numerical results show that the loss in efficiency achieved when moving from the centralized to the distributed case is small, for a wide range of values for the unit activation cost of each player.

Acknowledgement: The work has been supported in part by the project ROBOFARM, granted by the Tuscany Region (CUP: D63C23000520009); in part by the European Union by the Next Generation EU, Ecosistema dell'Innovazione, Tuscany Health Ecosystem (THE, PNRR, Spoke 9: Robotics and Automation for Health) under Project ECS00000017; in part by the Italian Ministry of Education and Research (MIUR) in the Framework of the CrossLab and ForeLab Projects (Departments of Excellence).

Keywords: Consensus, Non-cooperative game theory, Sensor networks.

References

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Alternative Payment Strategies: Adapting to Change in the Mobile App Industry

Tatyana Chernonog[1], Priel Levy[1]
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In this paper we study a new business model designed by prominent distribution platforms in the mobile-app industry, following court rulings against the platforms' monopoly provision of the payment process. The model is based on new guidelines in which platforms allow app developers to offer additional payment options for users of apps distributed via the platform's store. Using a game-theoretical approach, we investigate the decisions made by the developer, platform and app users. Some counterintuitive results are obtained and managerial recommendations are provided.

A Comparative Analysis of Game Theory Solution Concepts for Feature Selection

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Feature selection is a critical aspect to promote interpretable and efficient machine learning models, particularly in high-stakes domains. Although traditional approaches such as filters, wrappers, and embedded methods are still widely adopted, some works based on cooperative game theory have shown promising results. Nonetheless, most of these works have only focused on taking into account the Shapley value for value allocation. Despite the interesting properties of Shapley value, alternatives such as the Banzhaf index and core-based solutions offer different perspectives and axiomatic properties. In this paper, we model feature selection as a transferable utility cooperative game and apply three different solution concepts: the Shapley value, the Banzhaf index, and the egalitarian least core. First, we evaluate the performance of these game theory methods against well-known techniques such as Lasso and sequential feature selection applied to logistic regression on both synthetic and real-world datasets. Results show that game theory methods achieve comparable or superior performance. Second, we compare the three solution concepts themselves to investigate their strengths and limitations. To support this comparison, we analyze some properties of the feature selection games, enabling a more informed choice of solution concept. Preliminary results suggest that core-based methods offer enhanced robustness and interpretability

Optimizing Katz-Bonacich Centralities Arising from Nash Equilibria in Non-Cooperative Network Games

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Assessing the importance or centrality of nodes in a graph is a central problem in network analysis and design. One well-known measure of centrality is the Katz-Bonacich centrality, which emerges both as the steady state of a dynamical process involving local interactions on an undirected graph and as the pure Nash equilibrium of a non-cooperative game where the nodes themselves are the players. Within this framework, the present article investigates the relationship between the Katz-Bonacich centrality vectors that arise in the deterministic and stochastic settings, and examines the implications of this connection for network design—particularly in identifying the so-called key player, that is, the node whose presence most significantly boosts the aggregate equilibrium activity in the network. Theoretical findings are supported by numerical experiments.
Keywords: Katz-Bonacich's centrality, Nash equilibrium, stochastic dynamical systems

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Session: Freight transportation and city logistics 1

Wednesday September 3rd 08:00am - 09:40am

Room 2

Chair: Massimo Di Francesco

Optimizing Freight Distribution in a Retailer's Network Through Sponsored Search Advertising

Faten Afandi[1], Chefi Triki[1]

[1]University of Kent

This study addresses inefficiencies in long-haul freight transportation, where trucks often operate with underutilized capacity, increasing costs and environmental impact. To tackle this, we propose an innovative integration of transportation optimization (TO) with Sponsored Search Advertising (SSA). By aligning SSA bidding strategies with optimized transportation routes, the approach targets regions with significant logistical inefficiencies, driving demand, improving vehicle utilization, and ensuring optimal resource allocation.

We employ a multi-objective optimization framework to minimize transportation distances, reduce truck underutilization, and maximize the sales impact of SSA campaigns.

At the core of this research is Adaptive NSGA-III, an enhanced version of the traditional NSGA-III evolutionary algorithm. It incorporates refined population initialization, dynamic diversity preservation, and advanced selection strategies to address the complexities of integrating SSA with TO. The framework generates high-quality Pareto-optimal solutions, ensuring effective resource allocation. Validation with real-world data and scenario testing under varying demand demonstrates robustness against operational uncertainties.

Results show Adaptive NSGA-III delivers superior performance over state-of-the-art heuristics, achieving notable improvements in hypervolume, diversity spread, and computational efficiency. Moreover, adaptive SSA strategies enhance truck utilization and advertising returns, bridging logistics and marketing to provide data-driven solutions for dynamic retail environments.

This research highlights the potential of adaptive optimization to integrate TO with digital advertising. It paves the way for scalable, data-driven solutions in retail and offers opportunities for broader applications of Adaptive NSGA-III. Future work will refine the model to address additional constraints, extend it to broader supply chains, and adapt it for short-haul transportation.

Acknowledgement: Research reported in this abstract was supported by the Qatar Research Development and Innovation Council [ARG01-0430-230029]. The content is solely the responsibility of the authors and does not necessarily represent the official views of Qatar Research Development and Innovation Council.

Keywords: Sponsored Search Advertising, Retail Transportation, Multi-Objective Optimization

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On Combining Conventional Point-To-Point and Automated Waste Collection Systems

Maryam DehghanChenary[1], Richard F. Hartl[1], Stefan Irnich[2], Christian Tilk[1]
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[2]Johannes Gutenberg University Mainz, Mainz, Germany

The global demand for sustainable waste management has spurred initiatives to improve the efficiency of urban waste collection, discussing the advantages and disadvantages of different systems. We analyze a new combined waste collection problem that uses two systems simultaneously: a point-to-point system, in which waste is collected using trucks, and an automated system, where waste from inlets is transported through a network of pipes. The resulting combined waste collection problem is a two-stage decision problem: At the first stage, for each collection point, it must be decided whether it is served by truck or the pneumatic system. At the second stage, a Capacitated Vehicle Routing Problem (CVRP) must be solved for the collection points served by truck, and a cost-minimal tree must be determined for the collection points assigned to the pneumatic system. Both stages and the respective problems are interdependent, making the optimization of the whole system a difficult task. We develop a holistic solution approach based on a set-partitioning formulation utilizing route and tree variables. Because of the large number of variables, we solve the formulation heuristically using a column-generation-based matheuristic. The resulting subproblems are an elementary shortest-path problem with capacity constraints and a variant of the node-weighted Steiner tree problem. Our approach is empirically evaluated on two datasets, an extended variant of the well-known CVRP benchmark and real-world data from Vienna. The results indicate that the proposed matheuristic can provide high-quality solutions to realistic instances of the combined waste collection problem.
Keywords: Conventional waste collection systems, Automated waste collection systems, Elementary shortest path problem, Node-weighted Steiner tree problem, Column-generation algorithm.

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A Simulation-Optimization approach for Multimodal Transportation by Incorporating Waiting Time as a Key Decision Variable

Amin Roshani[1], Anna Sciomachen[1], Carmine Cerrone[1]

[1]University of Genova, Business and economics

Port logistics and container flow optimization have been widely studied to reduce costs and alleviate dwelling time. This study proposes a novel approach that incorporates waiting time as a measurable variable to improve container logistics efficiency. A discrete-event simulation model is employed to estimate the dwelling time of containers in a yard for a real-world case study. The resulting waiting time, combined with other cost variables, is then integrated into a bi-objective optimization model aimed at simultaneously minimizing yard congestion and transportation costs in a multimodal system involving both rail and road transport. The ϵ-constraint method is applied to explore trade-offs between these objectives, which operate on different scales. Real-world data from the PSA Genova PRA port, where containers are allocated to vehicles based on capacity and availability, are used to validate the model. Although trains are more cost-effective than trucks, their operational limitations, potential delays, and restricted daily availability necessitate strategic vehicle assignment to balance cost and port traffic

Designing a resilient and responsive supply chain network under supplier and facility disruption risks

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We address the design of a resilient and responsive three-echelon supply chain network to prepare for and handle unforeseen disruptions. At the upper echelon, contracts are established with primary suppliers over a multi-period horizon. Backup suppliers are activated when primary suppliers experience capacity losses due to disruptions. In the intermediate echelon, facility location planning takes place, using fortification as a resilience strategy. Some candidate sites are reliable, while others are disruption-prone, with the extent and duration of their failure depending on the level of investment in their protection. At the customer tier, responsiveness is ensured by enforcing a minimum service level and (partially) meeting demands through delayed deliveries.

Uncertainty is modeled using a finite set of scenarios representing joint realizations of demand, distribution costs, and disruptive events. We propose a bi-objective, two-stage stochastic program minimizing total expected cost and total expected unmet demand. First-stage decisions define a schedule for opening facilities, selecting fortification levels in unreliable locations, and choosing primary and backup suppliers. After uncertainty unfolds, second-stage decisions activate backup suppliers for the periods of time during which primary suppliers face capacity losses, and determine material flows across the network.

We use the ε-constraint method to generate Pareto-optimal solutions and solve the associated sub-problems with a customized MIP-based heuristic. The latter constructs a feasible solution and improves it by selectively revising earlier decisions through tailored procedures. Computational experiments on randomly generated instances show the heuristic's effectiveness, with performance comparable to or better than a general-purpose optimization solver such as CPLEX. Trade-offs between cost efficiency and supply chain responsiveness are analyzed for selected Pareto-optimal solutions.

Keywords: Resilient and flexible supply chain, two-stage stochastic programming, MIP-based heuristic

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A double ALNS metaheuristic for a service network design problem in a 2-tiered city logistic system

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

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[2] Interuniversity Research Centre on Enterprise Networks, Logistics and Transportation (CIRRELT), Canada

We investigate a service network design problem that arises in the field of city logistics. A fleet of containers, which carry pallets that need to reach destinations within the city, must be moved from the port. However, containers are restricted from traversing city streets and are moved to facilities located on the outskirts of the city, where pallets are unpacked from containers, transshipped into smaller vehicles and delivered to their final destinations. We must select facilities and vehicles, assign containers to the facilities, determine the paths of the vehicles, and the flows of pallets. A mixed-integer programming formulation is presented for this problem.

To solve large instances, we propose a metaheuristic, which decomposes the problem into two sub-problems in an iterative procedure. The first sub-problem is addressed by an ALNS determining the configuration of facilities' locations and container-to-facilities assignments. The second sub-problem is faced by another ALNS which returns the routes of vehicles and the flows of commodities, according to the configuration set in the first sub-problem.

The performance of the algorithm will be discussed and some management insights will be presented.

Keywords: City logistics, Service Network Design, Combinatorial Optimization

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Session: Routing and scheduling in health care systems

Wednesday September 3rd 08:00am - 09:40am

Room 3

Chair: Andrea Eusebi

Comparison of Exact and Matheuristic Approaches for Solving a Home Health Care Routing Problem

J. Isaac Pemberthy-R.[1,2], Juan Carlos Rivera[2]

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[2]Universidad EAFIT, Medellín, Colombia

This study addresses a vehicle routing problem with pickups and deliveries, time windows, coupling, and precedence constraints arising within a home healthcare (HHC) service in Medellín, Colombia. The service delivers monthly visits to 1,063 low-income, mobility-restricted patients, ensuring rotational care by different specialized professionals (psychology, nutrition, nursing, physiotherapy). Current manual scheduling and routing processes result in operational inefficiencies. This work initially simplifies the problem by focusing on single-day routing, which can serve as a building block in a decomposition strategy to be developed in a subsequent phase of the project. Daily, a shared vehicle transports a four-professional team to serve geographically clustered patients, managing drop-offs and subsequent pickups. To optimize this daily routing, a mixed-integer linear programming (MILP) model is formulated. The objective is to minimize total travel time while adhering to constraints such as service durations, work shifts, mandatory lunch breaks, and patient availability windows. Due to the computational complexity of solving the exact MILP model, a matheuristic approach is developed. This method first generates an initial delivery route using a traveling salesman problem with time windows (TSPTW) formulation. Pickup nodes are then incorporated via an insertion heuristic. Finally, a local search-based refinement phase improves the solution by exploring neighborhood structures, effectively blending exact optimization fragments with heuristic strategies. Computational tests on instances involving 15 to 32 patients show that the matheuristic significantly outperforms the direct MILP solution, achieving a better trade-off between solution quality and computational time. These results offer valuable insights for enhancing HHC logistics, thereby improving service efficiency and operational planning for this population.

Keywords: Vehicle routing problem, home healthcare, mixed integer linear programming, matheuristics, lunch break, precedence and coupling constraints, sharing vehicles.

Modelling of home healthcare routing problem with mixed fleet under carbon emission and waiting time

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This study aims to address the routing and scheduling problem in home healthcare services, with a particular focus on a mixed fleet that includes both conventional and electric vehicles (HHC-RSP-MF). The distinction between these problems and the vehicle routing problem is that not every nurse can serve every patient due to limitations in their competence. In the context of a mixed fleet, allocating nurses to vehicles is a crucial consideration. The objective function of HHC-RSP-MF comprises the costs associated with travel, charging, carbon emissions, waiting time of the healthcare team, unvisited patients, and carbon tax. This is the first study to consider all of these costs simultaneously. A further novel aspect is the consideration of the minimum charge level. In addition, the constraints on waiting times, the charging of EVs during routing, and relevant decision variables are reformulated. Subsequently, a mathematical model of HHC-RSP-MF is constructed.

Keywords: Home healthcare, OR in healthcare, carbon emission, waiting time

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An agent-based approach to simulating states of sentiment spread within a depression-centric online social network

Kurt Marais[1]

[1]Stellenbosch University

Social epidemiology involves investigating the distribution of social phenomena, interactions and collective human activities. Literature confirms that it is possible for emotional states to be transferable via text-based computer-mediated communication. Emotional contagion can pose as mental health concerns for individuals who are sensitive to emotional shifts or negative sentiments. An agent-based simulation model is constructed to investigate the behaviour of emotional contagion by way of sentiment spread based on interactions between individuals that have spoken about depression on Twitter. Network topology and transition probabilities are induced from observed Twitter data. Temporal dynamics and individual susceptibility factors are incorporated based on observed online behaviours. Discrete sentiment states are derived from a RoBERTa method used to score texts for their valence. This model parameters are based on observed data from Twitter between individuals that may have disclosed being diagnosed with depression or not. Scenarios involving intervention strategies are applied to agents to determine how best to improve the emotional well-being of all agents that may be susceptible to negative rhetoric. This work contributes to a better understanding of emotional contagion on social media amongst individuals that may or may not be diagnosed with depression. This model provides the computational framework for testing interventions for individuals and social media platforms to employ to promote healthier online discourse and mitigate the spread of potentially harmful sentiment across digital platforms.

Keywords: agent-based simulation, sentiment analysis, social contagion, Twitter

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An Optimization Approach to the Weekly Scheduling of Endoscopic Services: an Applied Case Study

Luca Zattoni, Rossella D'Avenia, Andrea Eusebi, Cristiano Fabbri, Marco Leonessi, Enrico Malaguti, and Paolo Tubertini

Healthcare organizations must dynamically manage their resources in relation to patient needs, especially when responding to unpredictable external factors. A recent example is the COVID-19 pandemic, which required a major reorganization of healthcare services. Among the affected institutions, IRCCS Azienda Ospedaliero - Universitaria di Bologna faced the need to impose additional constraints on endoscopic procedures, restructuring the weekly outpatient and inpatient schedule to accommodate extended sanitization protocols. As pandemic-related restrictions eased, the hospital had to undergo another schedule revision, turning this necessity into an opportunity to optimize resource utilization and better address patients' demand. This study proposes a two-step approach, based on Integer Linear Programming techniques, to optimize the weekly allocation of procedures to operating units and rooms, balancing operational efficiency with demand satisfaction. The model integrates structural, personnel, and procedural constraints while ensuring compliance with regional healthcare production targets. Preliminary results indicate that the proposed approach improves production efficiency while optimizing resource utilization, demonstrating its potential for broader application in healthcare management.

Optimizing Surgical Case Assignment with an ILP Model: Improving the Perioperative Patient Pathway

Andrea Eusebi, Cristiano Fabbri, Marco Leonessi, Enrico Malaguti, Paolo Tubertini, Luca Zattoni

Efficient operating room scheduling is a critical aspect of hospital management, as it significantly impacts both economic performance and patient outcomes. Traditional scheduling approaches typically focus solely on optimizing the use of operating rooms, without fully accounting for downstream resources that are crucial to patient care. This paper presents an assignment model that extends beyond the operating room by incorporating critical post-operative resources and considering the patient's recovery pathway across multiple medical disciplines, such as intensive care units. The proposed model aims to provide a comprehensive view of resource allocation, ensuring that the entire peri-operative process is streamlined. To assess the effectiveness of this approach, we test our model on a real case study from a hospital in northern Italy by comparing the outcomes of the model with the actual schedules implemented by clinical teams. This comparison highlights the potential benefits of our methodology, including improved resource utilization, enhanced patient flow, and the reduction of bottlenecks in critical care units.

Plenary Session
Wednesday September 3rd 09:40am - 10:40am
Main Room
Chair: Giovanni Righini

Beyond Optimization: Rethinking Operations Research as a Decision Science

Gustavo Cevolani
IMT School for Advanced Studies Lucca

Operations research (OR) aims at supporting and improving human decision making by finding optimal solutions to decision problems. I suggest that, to be successful as a genuine "decision science", OR needs to go beyond developing sophisticated techniques to optimize solutions of mathematical models of decision-problem situations. In addition, OR needs at least to integrate i) a well-grounded notion of what a (scientific) model of a decision-problem is; ii) a realistic view of how human cognition works in practice; and, iii) an understanding of how to communicate the uncertainty related to scientific models and solutions to the general public and the policy-makers. Reflecting on these issues through the lenses of philosophy of science and cognitive science helps both to illuminate the foundations of OR and to address current disciplinary challenges, including those posed by "black/box" AI and machine learning systems.

Keywords: Rationality, Decisions, Uncertainty, Cognitive biases, Intelligence, Modeling, Philosophy of Science

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Session: Math programming software (Hexaly)

Wednesday September 3rd 11:20am - 12:20

Main Room

Chair: Alberto Ceselli

Hexaly, a new kind of global optimization solver

Thierry Benoist

Hexaly, 251 boulevard Pereire, Paris, France

Hexaly is a new kind of global optimization solver. Hexaly APIs unify modeling concepts from mixed-linear programming, nonlinear programming, and constraint programming. Its modeling interface is nonlinear and set-oriented. It also supports user-coded functions, thus enabling black-box optimization and, more particularly, simulation optimization. Under the hood, Hexaly combines various exact and heuristic optimization methods: spatial branch-and-bound, simplex methods, interior-point methods, automatic Dantzig-Wolfe reformulation, column and row generation, propagation methods, local search, population-based methods, and surrogate modeling techniques for black-box optimization. Hexaly stands out from traditional solvers like Gurobi, CPLEX, and OR-Tools by delivering super-fast solutions to problems such as routing, sequencing, scheduling, packing, clustering, matching, assignment, and location.

We will illustrate these new modeling concepts on vehicle routing problems (among others) and we will show how Hexaly Optimizer internally leverages Branch-Cut-Price techniques to automatically solve this kind of problem, achieving near-optimal solutions within minutes on a standard laptop for mid-size problems. Here, "automatically" means out-of-the-box: no additional information or parameter tuning is required from the user.

Keywords : optimisation, global solver, industrial problems

Football teams building optimization

Francesco Gallo
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FC Squad Building Challenge is a game mode of a famous football video game. This mode offers challenges to complete. A challenge consists in building a team of players which respects a set of requirements. This problem is related to the Team Composition Problem known in the literature [1]. In the challenges, 11 players have to be selected among between 3000 and 18000 available players which makes the problem highly combinatorial. The objectives of the problem we solve are to maximise the number of priority players selected (if the user has set some priority players) and to minimize the total price of the team. Each player has several characteristics: a club, a nationality, a league, a quality (Bronze, Silver or Gold), a rating, a price, and a set of preferred positions. Two decisions are thus to be considered in this problem: a Boolean and an integer decision for each player. The boolean indicating if the player is selected in the team and the integer indicating his position in the team. The requirements to fulfil can be constraints on the possible players to select (for example a minimum quality required). There can also be some overall requirements on the team, such as a maximum number of selected players from the same club. One of the demands of this project is to provide solutions which cannot be improved manually by users in a very short computation time (less than 10 seconds). This presentation is about modeling and solving this problem with Hexaly, a mathematical optimization solver which uses various operations research techniques combining heuristics and exact methods.

Keywords: assignment, team composition, industrial problem

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Session: Equilibria, variational models & applications 2

Wednesday September 3rd 11:20am - 12:20

Room 1

Chair: Mauro Passacantando

Modeling Trust and Reputation in Digital Environments as a Variational Equilibrium Problem

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

[1]Department of Mathematics and Computer Science, University of Catania

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

Trust and reputation systems are important within today's digital networks, as they promote cooperative behavior and reduce uncertainty in online environments. In this talk, we introduce a variational modeling approach to study the dynamics of trust and reputation within interconnected systems. By adopting variational methods, we are able to describe user interactions, product evaluations, and trust propagation in a unified and rigorous mathematical framework. The model defines reputation as a function of trust values, appropriately weighted by the reliability of agents. When applicable, an initial reputation is also incorporated for non-new entities in the system. We further characterize equilibrium conditions through a formulation involving weighted trust and the associated Lagrange multipliers that emerge from the system's constraints. Each agent (trustee) is assumed to act rationally, seeking to maximize its gain defined as the difference between utility and associated costs. We demonstrate that these equilibrium conditions can be expressed as a variational inequality problem, and we propose an alternative formulation to capture its structure more effectively. Finally, we present a set of mathematical simulations to investigate the optimal values of the Lagrange multipliers and the trust weights. The analysis includes a sensitivity study, highlighting how variations in agent reliability and initial reputations impact the overall trust-reputation dynamics.

Acknowledgement: The contribution of Attilio Marcianò was supported by the TECH4YOU project, funded by the Italian PNRR-MUR
(CUP: C33C22000290006)

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

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Spatial Price Equilibrium Networks With Flow-Dependent Arc Multipliers And Excesses

Annamaria Barbagallo[1]

[1]Department of Mathematics and Applications "R. Caccioppoli", University of Naples Federico II

In this paper, spatial price equilibrium networks with flow-dependent arc multipliers, in which production and demand excesses are taken in consideration, are presented. The model is formulated as a variational inequality problem. By virtue of the variational formulation, the existence of equilibrium distributions is guaranteed under suitable assumptions. Finally a numerical example is discussed. **Keywords:**

A Network Game Related to the PageRank Centrality

Mauro Passacantando[1], Fabio Raciti[2]

[1]University of Milano-Bicocca, Department of Business and Law

[2]Department of Mathematics and Computer Science, University of Catania

We consider a Nash equilibrium problem, where players correspond to nodes of a directed graph and each player's action is influenced by her neighbors' weighted action. We provide a variational inequality formulation of this game and prove that in the case of interior solution, and also when some components of the solution lay on the boundary, the equilibrium can be expressed in terms of the PageRank centrality of the nodes. Furthermore, we propose algorithms based on the best response dynamics which converge to the unique Nash equilibrium, and study the price of anarchy for a small test problem.

Keywords: Network games; Nash equilibrium; PageRank centrality; price of anarchy

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Session: Air transportation and airspace applications

Wednesday September 3rd 11:20am - 12:20

Room 2

Chair: Luigi De Giovanni

On the Lagrangian Relaxation for the Satellite Constellation Design Problem

Luca Mencarelli[1]

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We consider the satellite constellation design problem [1], an emerging application in the aerospace field, where the aim is to design a constellation with the minimum number of satellites capable of regularly observing one or more targets on the Earth's surface. We use the Lagrangian relaxation approach to derive valid lower bounds. If we relax the observability constraints, the satellite constellation design problem is separable per satellite. Hence, we leverage this characteristic of the problem to speed up the computation of the Lagrangian bound by exploiting `SMS++` [2], a C++ library, to formulate and solve block-structured optimization problems. We also propose an efficient direct approach that can be used as a sub-solver in the Lagrangian relaxation procedure.
Keywords: Satellite constellation design problem, Mixed-integer linear programming, Lagrangian relaxation

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The Flying Dial-A-Ride Problem for Urban Air Mobility

Feilong Wang[1], Alice Raffaele[2], Roberto Roberti[2]
[1]School of Transportation Science and Engineering, Beihang University, Beijing, China
[2]Department of Information Engineering, University of Padova, Italy

Recently, the adoption of flying cars for air taxi services has garnered significant attention due to their potential for enhancing urban mobility and sustainability. Efficient routing and scheduling of flying vehicles are needed to enable their implementation. Although existing studies have progressed in tackling basic problems for flying cars (see, e.g., [1, 2]), critical operational challenges, such as temporal synchronization between vehicles performing operations at the same landing pad, are still overlooked.

In this work, we introduce the The Flying Dial-A-Ride Problem to address these gaps. First, to capture the problem complexities, we present a compact model and a trip-based model, which is transformed into a journey-based model by moving some non-trivial constraints into the pricing problem. Then, we design an exact algorithm strengthened with decomposition techniques for the trip-based model, and a branch-and-price algorithm for the journey-based model. Finally, we construct realistic instances using the New York City taxi data and conduct computational experiments to derive managerial insights and provide practical guidance.
Keywords: urban mobility, exact methods, column generation

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Dynamic Airspace Configuration under Uncertainty

Luigi De Giovanni[1], Martina Galeazzo[1], Go Nam Lui[2], Guglielmo Lulli[3]
[1]Dipartimento di Matematica "Tullio Levi-Civita", Università di Padova, Padua, Italy
[2]Management School, Lancaster University, Lancaster, United Kingdom
[3]Dipartimento di Informatica, Sistemistica e Comunicazione, Università di Milano-Bicocca, Milano, Italy

Air traffic control is crucial in air transportation and faces growing challenges driven by factors factors like increasing air traffic demand, integration of new airspace users, adverse weather conditions. In this context, we consider the airspace as partitioned into sectors. A sector is an airspace region with a defined capacity, the maximum traffic that can be safely monitored within it. A configuration is a specific partition of the airspace into sectors. Dynamic Airspace Configuration improves efficiency by adapting the configuration over time, to align capacity with demand patterns that vary in space and time [1,2]. The goal is to minimize the traffic exceeding sector capacities, thus reducing the need for regulations and delays. We consider a predetermined set of configurations and aim to determine an optimal sequence of configurations that effectively absorbs traffic while satisfying operational constraints on the configuration dynamics to guarantee smooth transitions. Moreover, we consider the problem under traffic demand uncertainty and seek robust solutions that minimize worst-case traffic overflow, with varying degrees of conservatism [3]. We propose Integer Linear Programming models that extend previous formulations [2] to account for uncertainty and provide optimal solutions that are robust against possible traffic demand variations. We devise a cutting-planes approach to deal with different uncertainty sets. In the case this set is a box, a more efficient graph-based formulation is solved by constrained shortest path algorithms. We evaluate the approach on synthetic and realistic instances, using available configurations and historical traffic data. Our computational study explores the trade-off between minimizing traffic overflow and robustness.
Keywords: Dynamic Airspace Configuration, Robust Optimization, Integer Programming, Constrained Shortest Path

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Session: Human and algorithmic decision-making

Wednesday September 3rd 11:20 - 12:20

Room 3

Chair: Giovanni Righini

Reasoning, Rewired: Human Mind and the Art of Decision

Elena Meneghetti[1]

[1]ELEMENS

The vocabulary we increasingly hear for describing artificial systems—terms such as intelligence, neural networks, learning, and even decision-making—bears a semantic weight that differs fundamentally when applied to human beings. While such language may serve as a useful metaphor, it is misused if intended literally in the context of artificial information processing and algorithmic models. How, then, do human beings solve problems and make decisions? This talk offers a brief exploration of how sciences such as neuroscience, biology, linguistics, and physics converge to shed light on the distinctive nature of human cognition. Through an overview of the brain's structure and the layered processes of awareness, we aim to offer a concise inquiry into how we humans operate—and how the brain, far from being a mere processor, orchestrates meaning, context, and insight. Where science explains how we function – and discerns ontology from epistemology, symbolic from semantic - the endeavour of an unconventional C-suite Coach and Advisor lies in activating those inner mechanisms and latent resources: aligning body and mind, perception and reasoning, the conscious and the unconscious, the left and the right cerebral hemispheres to access excellence and unlock full potential.

Keywords: Human decision-making, Consciousness, Cognitive processes, Artificial intelligence, Neuroscience, Brain, Epistemology, Non-algorithmic thinking

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Chess and Business Decision-Making

Gianluca Distratis[1]
[1]KPMG Advisory

In the game of chess, every move requires an evaluation among multiple alternatives, under time constraints, incomplete information, and under pressure from the opponent. In this talk, I will explore how the principles of strategic chess thinking - such as the balance between long-term vision and immediate tactics, risk management and adaptability - offer useful tools for dealing with complex decisions also in the managerial context. Starting from concrete examples drawn from the chess experience, I will highlight analogies with real business scenarios, showing how some heuristics of the game can inspire practical and structured approaches to problem solving, without claiming absolute optimality, but with attention to the robustness of choices. The aim is to propose a bridge between natural and artificial intelligence, between intuition and method.

Keywords: Chess, Management, Decision Making

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5. Willy Hendriks, Prima muovi poi pensa!, Le due torri (2014)

Enhancing Stockfish: A Chess Engine Tailored for Training Human Players

Andrea Manzo[1], Paolo Ciancarini[2]
[1]Alpha-Chess
[2]University of Bologna

Stockfish is widely regarded as one of the strongest chess engines available, yet its superlative playstyle can be demotivating and opaque for human learners. In this work we introduce **ShashChess**, an extension of Stockfish designed specifically for training purposes. ShashChess integrates Alexander Shashin's positional evaluation model and applies controlled perturbations to evaluation scores, alongside a hybrid alpha-beta/MCTS search mode to vary playing style and difficulty level.

We evaluated ShashChess on a corpus of bullet, blitz, and classical time-control games, benchmarking it against unmodified Stockfish in terms of effective Elo and move-choice diversity. Results indicate that while ShashChess retains a comparable playing strength, it delivers more pedagogically valuable feedback: users demonstrate deeper understanding of strategic plans and exhibit reduced tactical bias.

Keywords: Chess engines, Training, Stockfish, Shashin, Human–computer interaction

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Roundtable: Sportello Matematico per l'Innovazione e le Imprese

Wednesday September 3rd 14:00 - 15:20

Main Room

Chair: Serena Fugaro and Emanuele Pizzari

Mathematical Technologies for driving innovation in Industry, Business and Society: the project "Sportello Matematico per l'Innovazione e le Imprese"

Serena Fugaro[1], Emanuele Pizzari[1]

[1]Istituto per le Applicazioni del Calcolo (IAC) del Consiglio Nazionale delle Ricerche (CNR)

Mathematics is a key enabling technology [1, 2] to address today's challenges in industry and society and to drive innovation. To fully exploit the potential of Mathematical Technologies, it is essential to integrate them into diverse areas of production. However, several barriers prevent their adoption, especially in Small-Medium Enterprises: lack of in-house expertise, low awareness of the impact of Mathematical Sciences and Technologies, and limited investment in these tools. Since 2013, the National Research Council has been supporting the "Sportello Matematico per l'Innovazione e le Imprese" (SMII) project as a key tool on the road to innovation. SMII's technology transfer officers facilitate connections between industry and research centres specialising in industrial and applied mathematics, fostering Open Innovation practices [3].

This session will explore the wide range of application areas for Mathematical Technologies, including Energy, Logistics and Materials. Indeed, these technologies enable innovative solutions to improve the quality of life, optimise the use of resources and promote sustainable development, thanks to tools such as Machine Learning, Optimisation and Simulation. Companies that have benefited from collaboration with SMII will present their case studies and, together with the audience, will reflect on the challenges and opportunities of establishing industry-academia collaborations and the wider role of Mathematics in shaping the future.

Keywords: Mathematical Technologies, Technology Transfer, Open Innovation

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Session: Production and inventory optimization

Wednesday September 3rd 14:00 - 15:20

Room 1

Chair: Sara Ceschia

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

Timo Gschwind[1], Eric Fauß[1]

[1]Chair of Logistics, School of Business and Economics, RPTU Kaiserslauter-Landau, 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 supplier and the customers, and the vehicle routes. The latter includes the decisions on which customers to serve and the quantities to deliver. The objective is to minimize the total costs over the planning horizon consisting of production, inventory, and routing cost. In the PRP literature, the production component is typically rather simple and assumes a single commodity to be produced, whereas in practice the consideration of multiple commodities is an important feature. We consider a PRP in which the supplier produces multiple commodities consuming a joint production capacity and each customer demands a single commodity only. We propose different path-based formulations of the problem and derive variants of a branch-price-and-cut algorithm for their solution. Valid inequalities are used to strengthen the mathematical formulations and column generation is employed to generate routes and production schedules. Computational experiments are conducted to evaluate the performance of the proposed BPC algorithms.

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

Proposed cooperative-noncooperative tactical inventory models for NGOs under uncertain demand

Perihan BEKDEMİR[1], Onur KAYA[1], Mehmet ALEGÖZ[1]
[1]Eskisehir Technical University

Non-governmental organizations (NGOs) play an important role in helping victims get the supplies they need after a disaster. Since it is not clear where and when the disaster will occur, the nature and quantity of the aid materials needed are also uncertain. This makes it almost impossible for CSOs to meet the needs on time and completely on their own. However, late responses or failure to respond to needs that arise after a disaster can cause significant harm to disaster victims. For this reason, when CSOs cooperate with each other, it gives NGOs an advantage in improving their services. In this way, NGOs can provide better service to society.

This study focuses on the inventory decisions made by two NGOs serving in two different regions, considering the uncertainty of demand after an earthquake. Models that consider different environments (non-cooperative, cooperative centralized and cooperative decentralized) are analyzed when making inventory decisions. Employing the renewal reward process approach, the models aim to optimally meet the needs of these two regions with the lowest cost, where the earthquake probabilities at these regions are assumed to be independent of each other. First, we develop a mathematical model for the environment where each NGO only deals with earthquakes in its own region, i.e., they do not cooperate with each other. Then, we analyze the model considering both a centralized and a decentralized environment where they cooperate by sending relief materials to each other. We compare these models with a case study of two NGOs operating in Turkey and Indonesia, and observe that cooperation can improve system outcomes even in a decentralized environment.

Keywords: NGO cooperation, Inventory decision, Uncertain demand

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Supply Chain of Perishable Products: Analyzing the Effects of Leadership on Pricing, Profits and Product Freshness

Yael Lahav, Tatyana Chernonog, Tal Avinadav

This study examines the impact of leadership on a perishable product supply chain using an EOQ model with age-dependent demand. Two Stackelberg games are analyzed: manufacturer-led and retailer-led scenarios. The findings reveal that while the selling price remains relatively constant regardless of leadership, each party benefits from being the leader. The retailer-led scenario results in fresher products for consumers. When the cycle length is cooperatively determined, the retailer-led scenario produces slightly higher total channel profits. The study provides insights into pricing strategies, profit distribution and product freshness in perishable product supply chains, contributing to the literature on supply chain management and perishable goods.

Solving the Slab Selection and Relocation Problem in a Real Production Yard using Simulated Annealing

Antonio Cardin[1,2], Sara Ceschia[1] Andrea Schaerf[1]
Davide Armellini[2] Paolo Borzone[3]

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[3]Danieli Automation S.p.A., Corso Perrone 47r, I-16152 Genoa, Italy

We consider a complex real-world problem in slab yard management that deals with block relocation and slab stack shuffling in a single problem.

The specific real-world case examined in this paper arises from a steel production plant managed by Danieli Automation and concerns a slab yard positioned between the continuous casting and hot rolling phases.

The problem regards processing a sequence of orders, such that each order can be satisfied by different slabs with the requested features in terms of sizes and steel grade. The solution consists of a sequence of retrievals and repositionings that fulfill all orders and satisfy several constraints.

For this integrated problem, we propose a local search approach that searches at the level of the slab selections and uses a greedy subprocedure at the inner level to determine the corresponding relocations and retrievals. The local search procedure makes use of the combination of two neighborhood relations. For the greedy subprocedure, we propose and compare two different options, both adapted from GLAH (Greedy Look-Ahead Heuristic) by Jin, Zhu, and Lim (2015), who designed it for a simpler version of the problem. We also developed a MILP model of the problem and implemented it using `cplex` (v. 22.1).

We tested our solution approach on a novel dataset using an actual yard layout and a simulation tool to set its initial configuration. Our search method successfully obtained high-quality solutions, even for large instances involving over 2000 slabs.

In order to obtain an objective assessment of the quality of our solution method, we adapted it to the formulation proposed by Boge and Knust (2023) for the Blocks Relocation Problem with Item Families (BRPIF) by changing both the cost function and the inner greedy subprocedure. We tested the resulting method on their dataset, and the outcome is that we have been able to match their results in most instances, and outperform them consistently on the largest ones.

Acknowledgement: The work was carried out within the Artificial Intelligence 2022–2025 interdepartmental strategic plan project of the University of Udine

Keywords: Blocks relocation, Slab stack shuffling, Simulated annealing

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Session: Freight transportation and city logistics 2

Wednesday September 3rd 14:00 - 15:20

Room 2

Chair: Paolo Dell'Olmo

Capacity Planning and Supplier Selection Under Uncertain Contract Fulfillment

Roberto Bargetto[1], Teodor Gabriel Crainic[2], Guido Perboli[1,3], Walter Rei[2,3]

[1]Department of Management and Production Engineering, Politecnico di Torino
[2]School of Management, Université du Québec à Montréal
[3]CIRRELT

The shipping industry has recently transitioned from long-term contracts between shippers and carriers to a more dynamic environment of short-term contracts and spot-market transactions. This shift has been driven by recent global disruptions, such as the pandemic and geopolitical conflicts, which have increased volatility in transportation rates. Nowadays, carrier suppliers offer "contract rates" for planned operations and higher "spot rates" for last-minute deliveries. We study the problem of a shipper planning the cost-effective delivery of orders through a combination of pre-contracted suppliers and additional capacity acquired at spot rates. The shipper's problem is characterized by uncertain decision factors. Knowledge of future orders is limited, carriers may experience mechanical failures, undelivered orders can clog storage centers, and unexpected events can impact transportation prices, increasing the variability of spot rates. The problem is two-stage by definition. In the first stage, the shipper selects suppliers and determines the capacity to secure at contract rates. In the second stage, any shortfall is covered through spot-rate purchases. We model this two-stage capacity planning problem as a variant of the stochastic variable cost and size bin packing problem [1]. We provide its stochastic integer programming formulation, as well as a solution framework based on state-of-the-art optimization techniques [2].
Keywords: Logistics, Integer Programming, Stochastic Optimization

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Strategic design of distribution systems with consolidation warehouse considerations

Jenn-Rong Lin[1]

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A distribution network with consolidation warehouses allows larger shipments out of the plants, because quantities of a single product destined for multiple retailers can be aggregated in the first level routing. consolidation warehouses also allow groups of products from different plants to be consolidated into larger shipments destined for a single retailer in the second level routing. Both of these consolidations may transport finished goods more efficient, reduce transportation costs and enhance customer satisfaction. Thus, the purpose of this study is to formulate and analyze a strategic design model for three-echelon distribution systems with consolidation warehouse considerations. The key design decisions considered are: the number and locations of consolidation warehouses, the first-level routing between plants and consolidation warehouses, and the second-level routing between consolidation warehouses and retailers. In this study, the concerns are long-term strategic decisions on consolidation warehouse investments and vehicle investments and operational decisions on how to dispatch vehicles to satisfy customer demands. The long-term location decisions and short-term routing decisions are linked together because it is important to consider the routing implication of location decisions at the strategic level, and the routing decisions must be made within the overall structure determined by the strategic decisions. An integer programming model is proposed for this problem. At last, we evaluate the value of introducing consolidation warehouses in a distribution network through a case study.

Keywords: Distribution Systems, Consolidation Warehouses, Two-level Location Routing

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Continuous-Time Scheduled Service Network Design with Piecewise Linear Costs

Giacomo Lanza, Luca Mencarelli

Scheduled Service Network Design (SSND) supports consolidation-based freight carriers in setting up transportation plans by selecting which services to operate, their schedules, and the routing of commodities. Piecewise linear cost structures often arise in such contexts to represent economies of scale, as typically observed in Less-than-Truckload freight transportation. We study a SSND variant incorporating non-convex piecewise linear cost functions for both service activation and commodity routing, which can significantly affect routing and scheduling decisions. We propose a mathematical model extending a recent continuous-time SSND formulation to handle such cost structures and analyze the computational features of three different modeling choices. Preliminary computational results are presented, highlighting the performance of the three formulations in terms of solution quality and efficiency.

A Time Space Network Model for a Truck and Drones Delivery System with Battery Recharging and Variable Speeds

Lavinia Amorosi[1], Paolo Dell'Olmo[1], Justo Puerto[2], Carlos Valverde[2]
[1]Department of Statistical Sciences, Sapienza University of Rome, Italy
[2]Department of Statistical Sciences and Operational Research, University of Seville, Spain

We present a multiperiod mixed-integer quadratic programming formulation based on a time-space network for a delivery problem with a mothership and a fleet of drones. The system is supposed to operate in European cities with high congestion, very narrow streets not reachable by trucks, no parking areas, but where customers demand is located. The mothership can stop only on a set of locations where parking is possible which are different from the customers' locations. During mothership stops, deliveries are performed by drones that can fly at different speeds. The proposed formulation integrates the routing of the mothership and scheduling of the drones problems, including also the charging cycles of drone batteries. The optimization is performed by minimizing the total energy consumption (proportional to the drones and truck traveled distances) and by maximizing the number of served customers. The formulation is also exploited to design an effective matheuristic algorithm. A case study related to the city of Rome with up to 200 customers is presented to validate the model and illustrate the solutions structure. Extensive computational results on a large testbed of artificial instances, up to 200 customers, are reported both for the formulation and the matheuristic algorithm.
Keywords: Delivery system, Time-space network, Hybrid Fleets, Mixed-Integer Quadratic Programming, UAVs, Matheuristic Algorithm

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Session: Health care 2

Wednesday September 3rd 14:00 - 15:20

Room 3

Chair: Giuliana Carello

The Integrated Healthcare Timetabling Competition (IHTC-2024): Formulation, Rules, Results, and Solution by Local Search

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In this talk, we introduce a novel optimization problem that integrates three critical aspects of healthcare operations: surgical case planning, patient admission scheduling, and nurse-to-room assignment. This problem served as the benchmark for the Integrated Healthcare Timetabling Competition (IHTC-2024, https://ihtc2024.github.io/), which aimed to stimulate research on the specific challenges of integrated scheduling in healthcare. We will discuss the problem's features, the competition's rules and infrastructure, its datasets, the search methods employed by the 32 participants, and the general insights gained from organizing and analyzing the competition.

We then present our solution method for the IHTC-2024 problem, based on a Multi-Neighborhood Simulated Annealing approach. The method is fully integrated, meaning that at any point during the search process, any aspect of a patient's stay or nurse assignment can be modified. The search space is designed to exclude infeasible patient assignments while allowing the violation of certain hard constraints to improve connectivity and enable broader exploration. To efficiently navigate this space, we defined a portfolio of five neighborhoods: four focus on different aspects of a patient's stay—including admission schedule, assigned operating theater, and recovery room—while the fifth addresses nurse assignments. Our results are fully consistent with those of the top-performing participants in IHTC-2024, demonstrating the effectiveness of our approach.

Keywords: Integrated optimization, Healthcare, Competitions

A cluster-based approach to support collaborative decision making in elective surgical planning

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Effective scheduling of operating rooms is crucial for optimizing surgical workflows, enhancing patient outcomes, and maximizing healthcare resources utilization [1]. However, despite the huge literature on surgical planning problems, only a small fraction (7%) of all models has been implemented in practice [2]. This study proposes a new approach to surgical planning that balances surgeon autonomy with efficient resource use. While surgeons value decision-making freedom, managers aim to optimize operating rooms and wards utilization. Consequently, the final plan often results from a negotiation between the parties. Our approach aims at supporting such negotiation, pursuing a compromise between professionals' preferences and hospital efficiency. The key idea of our modeling approach is to partition all surgeries into a limited number of surgical groups (clusters), each being relatively homogeneous in terms of resource consumption. Within the framework of a long-term agreed-upon Master Surgical Schedule, our model computes the number of procedures from each cluster to be performed in the next planning period. This ensures efficiency while still allowing surgeons flexibility in patient selection. We illustrate the model and its validation through a long-term simulation of our decision support tool. Different clustering strategies and objective functions have been implemented, and various performance indicators are observed, allowing a comparison between our approach and the current policy.
Keywords: Health care, Decision support systems, Combinatorial optimization

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Elective surgery planning considering length-of-stay: Evaluating the role of prediction accuracy and rescheduling policies

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The interconnected nature of hospitals requires to consider the availability of multiple resources when making planning decision. This is particularly crucial when scheduling the admission of elective surgical patients, as planners need to ensure that any proposed schedule is feasible given the availability of beds for post-surgery recovery [1]. Therefore, it is sensible for managers to incorporate an estimation of patients' lengths of stay (LOSs) into their admission planning to account for the number of bed-days each patient will require. However, actual LOSs can deviate from the estimations used during the scheduling phase, potentially causing inefficiencies or even making the schedule unfeasible. To address this issue, online rescheduling strategies can be iteratively implemented, leveraging on operational flexibility to address issues. Among these real-time modifications, it is possible to include postponements of admissions, reallocations of patients to different wards, or transfers of those already hospitalized. A proactive approach to minimize the need for adjustments is to enhance the quality of LOS estimations by predicting them using machine learning (ML) tools [2]. However, these models can be costly to train and are inherently imperfect and subject to error [3], with no established medical standard for what concerns the methodology that is best to employ [4].

Building on prior research that explores simulated ML for the preliminary evaluations of data-driven strategies [5], this study investigates the relationship between LOS predictive error and rescheduling flexibility under various corrective policies.

Keywords: machine learning, operating room planning and scheduling, predict-then-optimize, simulation

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A disruption-restoration-based approach for surgical scheduling in a Children's Hospital

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Pediatric surgery has some characteristics that are not usually present in adult surgery, among which: i) pediatric hospitals often do not have a dedicated emergency operating theatre and emergencies share the operating rooms with elective surgery, and ii) pediatric patients are more likely than adults to fall ill on the day of surgery and be unable to undergo surgery. Such characteristics pose a challenge to the optimization of pediatric surgical resources. We consider the problem of scheduling elective surgeries in a Children's Hospital, where disruptions due to emergencies and no-shows can occur. Elective surgeries are scheduled by taking into account the time spent on the waiting list and the priority and urgency of the patient, generating a nominal schedule. In parallel, we also generate backup schedules that can be quickly deployed in case of emergencies or no-shows, to ensure that the activity of the operating rooms is restored immediately in the event of a disruption. We propose an Integer Linear Programming-based approach for the problem of jointly optimizing the nominal and backup schedules. The model enumerates a representative subset of possible emergency and no-show scenarios and designs a backup for each of them. The model reschedules patients, minimizes changes to the nominal schedule, and applies an as soon as possible rescheduling policy to ensure that all patients receive timely care. The model proves to be computationally challenging, so we propose a decomposition-based heuristic approach. The approach is effective in managing disruptions, ensuring that the waiting list is properly managed, with a balanced mix of urgent and less urgent patients. The approach can help hospitals to manage their resources more efficiently, and provides a set of backup plans that can be easily deployed whenever the nominal schedule is no longer feasible.

Keywords: Pediatric surgery scheduling, Disruption-restoration, Emergency and no-show management

Session: Reviewing papers and responding to reviewers (roundtable)

Wednesday September 3rd 16:00 - 17:00

Main Room

Chair: Matteo Cosmi

Session: Health care 1

Wednesday September 3rd 16:00 - 17:00

Room 1

Chair: Elena Tanfani

A Decision Support System for Blood Component Production

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The production of blood components has received limited attention in the Blood Supply Chain literature [1], with no structured planning or scheduling methodologies developed so far [2]. Structured DSSs could significantly improve the efficiency of blood component production by supporting planning activities, production scheduling, and the design of production systems. Furthermore, blood production shares features with disassembly and chemical processing systems, where quantitative and optimization approaches have been widely applied [2].

Effective DSSs for improving blood component production can include optimization and simulation models. Mathematical optimization models can schedule separation activities and allocate resources, ensuring a time-optimized production process and avoiding inefficiencies. In parallel, simulation models can create a digital twin of the production system, enabling "what-if'' analyses to assess the impact of potential changes prior to actual implementation. For example, different system configurations, e.g., sequential (in-line) versus parallel (cell-based) workflows, could be compared.

We analyzed the blood component production laboratory of the Niguarda Hospital, Milan, Italy. We developed a DSS with two components. A scheduling tool includes two discrete-time mixed-integer linear programming (MILP) models, each covering a specific production time period and aiming to minimize the production makespan. A digital twin includes a discrete event simulator, developed in ARENA, which captures variability and system dynamics. Both tools were validated with real data from the Niguarda Hospital, successfully replicating the real-world system and providing insights to support more efficient and effective blood production operations.

Keywords: Blood Component Production, Decision Support System, Scheduling, Simulation

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Surgical Agenda Design via Distributional Clustering and Stochastic Programming

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The growing demand for outpatient surgeries raises the challenge of minimizing two key performance indicators: direct waiting time, experienced on the day of surgery, and indirect waiting time, defined as the number of days between surgical request and procedure. While direct waiting time depends on short-term allocation decisions, indirect waiting time emerges from a sequence of decisions made over time, making it inherently more complex to control. Efficient management of both aspects is crucial not only for operational performance but also for ensuring equitable access to care and enhancing patient satisfaction. In addition, these objectives depend on the level of resource utilization and robustness, resulting in conflict since reducing one requires trade-offs in the other.

To address these challenges, we propose a dual-horizon approach that combines clustering and multi-objective stochastic programming to jointly manage direct waiting time, indirect waiting time, and overtime. In our work we propose the design of a cyclic surgical agenda that structures the long-term allocation of surgical procedures, providing a framework to systematically control indirect waiting times. Surgical procedures are grouped using K-Means-type algorithms based on the similarity of their duration distributions, considering either Euclidean or Wasserstein distances. These clusters form the building blocks of the cyclic agenda, improving predictability and enhancing fairness across patient groups.

A case study based on real data from the Obstetrics and Gynaecology Department of Policlinico San Matteo in Pavia, Italy, is used to validate our optimization and machine learning framework. The results show how different clustering metrics influence the trade-off between direct and indirect waiting times, demonstrating the potential of the dual-horizon approach in improving surgical scheduling performance under uncertainty.

Keywords: healthcare management, operating room scheduling, optimization under uncertainty

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Interday and Intraday Chemotherapy Appointment Scheduling

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The number of cancer patients is expected to rise in the coming years, increasing the demand for chemotherapy treatments. We consider a setting where the treatments are delivered in an outpatient shared cancer center, adopting a per-pathology policy. Managing such centers involves a hierarchy of decisions [2]. First, at a strategic level, the capacity planning of the main resources involved must be determined. Then, at a tactical level, the available resources must be allocated to the cancer types. At this stage, the Master Chemotherapy Planning (MCP), which gives the days when the different cancer types can be scheduled, and the clinician rostering that covers the cyclic schedule are determined [1]. Finally, at an operational level, short horizons are considered, and the weekly and daily activities are optimized.

Our work focuses on the operational level. We assume that the MCP is given, as well as the set of patients to be treated in a weekly planning horizon. We address two interrelated problems: assigning patients to treatment days (interday scheduling) and scheduling their appointments within each day (intraday scheduling). We tackle the problem as a multi-appointment scheduling problem [3], where we have to decide the day and start time of the oncologist visit and infusion for each patient.

First, we focus on the cancer center perspective, minimizing the overtime. Then, we consider other objectives aimed at enhancing the patient experience. The problem is formulated as a multi-objective optimization model and solved through a sequence of three ILP models in a lexicographic fashion. Additional inequality and heuristic-based warm starts are applied to speed up the solution process. We validate the models and approaches using real-world data from an Italian hospital and discuss the results for different metrics.

Keywords: Appointment Scheduling, Multi-objective optimization, ILP models, Goal programming

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Session: Logistics network design

Wednesday September 3rd 16:00 - 17:00

Room 2

Chair: Diego Delle Donne

Coping with geodiversification to improve the resilience of telecommunication networks

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The resilience of a network is related with the ability of facing and adapting to changes in the network, as well as with the capacity of recovering from possible disruptions. In this context, incidents like natural disasters can compromise an extensive area, and therefore damage a big part of the network. Ensuring the geodiversity of a set of possible solutions for routing between two points in the network is a way of enhancing the resilience by preparing for such type of events, by imposing a safety geographical distance between alternative paths [1,4].

Given $K \in \mathbb{N}$, $K \geq 2$, and $D \in \mathbb{R}^+$, we address the problems of: 1. Finding a set of K paths between those two nodes, such that the paths are separated by a geographical distance of at least D; 2. Finding the maximum D for which K paths separated by a geographical distance of at least D exist [2,3].

We discuss integer linear programming formulations and a heuristic method for these problems. Some of the formulations are compared and the different models and method are tested computationally in the context of the application to reference telecommunication networks.
Keywords: Geodiverse routing, integer linear programming, heuristic methods

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An Improved Exact Method for the Interval Immune Transportation Problem

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The Interval Transportation Problem (ITP) is a variant of the Transportation Problem (TP) that allows supply and demand levels to vary within given intervals. For each configuration (a scenario) of the supply and demand levels, a potential TP is defined. In our case study, TP consists of finding the minimum-cost transportation plan that satisfies the demand levels without exceeding supplier capacities. In [1] the authors introduced the challenge of determining the minimum and maximum optimal TP costs, corresponding to the best and worst scenarios, respectively. While finding the best scenario is an easy task, only recently [2] proved that finding the worst scenario is NP-hard. We observe that this latter problem, can also be seen as an adversarial bilevel problem where the leader seeks the worst supply and demand values and then the follower solves the associated TP. Here, we study the Interval Immune Transportation Problem (IITP) [3], that is the ITP with a cost matrix such that an increase in either the demand, the supply, or both leads to an increase of the optimal TP cost (the cost matrix is immune to the transportation paradox [4]). [3] provided theoretical properties of the IITP and proposed a first heuristic algorithm. Later, [5] introduced new problem properties, an enhanced heuristic and a first exact algorithm for IITP. Here, we present an improved version of the first exact approach based on some theoretical properties of the TP. Test results, on benchmark instances, show the effectiveness of the new exact approach.

Keywords: transportation problem, interval right-hand sides, transportation paradox

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ILP formulations for the power dominating set problem with channel limitation

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The power dominating set problem (PDS) is a graph optimization problem with applications related to the control and monitoring of electric power systems using devices called phasor measurement units (PMUs). The objective of PDS is to find a minimum set of vertices on which to install PMUs that allow monitoring all remaining vertices by recursively applying two observation rules. In particular, the *domination* rule assumes that a vertex with a PMU can monitor all its neighbors. In real-world applications, PMUs have a predefined number of channels that limit the number of neighbors that they can monitor. This work proposes a novel integer linear programming formulation for PDS and for its variant that considers PMUs with channel limitation. The formulation is based on a set of constraints to forbid circular precedences that might arise in the application of the observation rules. As the number of constraints grows exponentially, an algorithm is developed to handle them dynamically (as lazy constraints) with an efficient separation routine. Computational experiments are performed on benchmark instances with up to 13.659 vertices to compare the performance of the new formulation with others adapted from the PDS literature. An interesting behavior is observed, where the choice of the best-performing formulation strongly depends on the number of limited channels. In particular, the new formulation is effective in instances with moderate channel limitation.

Keywords: Integer programming, Power dominating set, Channel limitation, PMU placement.

Session: PRIN HEXAGON

Wednesday September 3rd 16:00 - 17:00

Room 3

Chair: Stefano Gualandi

Optimization on the Italian power grid: Voltage Regulation and Wind Curtailment

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Optimization problems arising in the management of the transmission and the distribution of electric power in the power grids constitute a broad class of problems, the so-called Alternate Current Optimal Power Flow (ACOPF) problems. The main characteristic is the presence of the power flow constraints, which are nonlinear, nonconvex constraints that are very challenging for general-purpose optimization solvers.

Since the 1960s, several different approaches have been proposed, but so far we still lack solid and robust solution methods: modeling these constraints with an eye for practical solvability is nontrivial.

In real-time operations, some simplifications are made and the system operators solve the Direct Current OPF problem, which is a linear approximation of the ACOPF. Anyway, the obtained results are not valid for the ACOPF, due to the oversimplifications, so a post-optimization is applied in order to generate feasible solutions.

In this work we present the the mathematical formulations for Voltage Regulation and the Wind Curtailment problems, which fall into the broad class of ACOPF problems. We describe the specific constraints and the objective function which are used; moreover, we exploit the similarities/differences with the more general ACOPF instances.

The modeling step is crucial to find global solutions in reasonable time: we study the impact of different modeling techniques on the ability of a general-purpose mixed-integer nonlinear optimization solver to find tight lower bounds (good convex relaxations). For finding feasible solutions in relatively short time, we use a local solver.

We run our models on few real-world instances arising from the Italian transmission power grid and we discuss the impact of our techniques in finding good solutions and tight lower bounds.

Keywords: Nonlinear Programming, Global Optimization, Optimal Power Flow

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A bilevel optimization model for transformer rating optimization and a heuristic solution method

S. Coniglio[1], F. Garuba[2], A. Martinez-Sykora[2], C. Tomasi[1], A.B. Zemkoho[2]

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We investigate the Bilevel Transformer-Rating Optimization (BTRO) Problem, which models a Stackelberg game between two players: a transmission network owner (leader) that seeks to set transformer ratings that minimize asset aging costs, and a system operator (follower) that, given the ratings, minimizes redispatch costs by solving a rating-constrainedAC Optimal Power Flow(ACOPF) problem.We propose a bilevel formulation combining a (simulation-driven) transformer thermal model with a scenario-based representation of system operation under varying loads. The lower-level problem embeds a full ACOPF formulation with rating constraints, while the upper level captures the inter-scenario thermal dynamics that drive transformer degradation. We solve the resulting nonconvex, mixed-integer bilevel program using a black-box optimization approach based on Differential Evolution, where the ratings are optimized in an outer loop and redispatch costs and thermal effects are computed via an inner ACOPF oracle. Preliminary experiments show the promise of the proposed solution method.

AC Optimal Power Flow problem: a study on Jabr relaxation

Ambrogio Maria Bernardelli[1], Arthur Mazeyrat[2], Gabor Riccardi[1], Stefano Gualandi[1]
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The Alternating Current Optimal Power Flow (AC-OPF) problem, in its most realistic form, is large-scale, non-smooth, non-convex, and nonlinear. It generally exhibits multiple local minima and presents a feasibility problem that is strongly NP-hard. In recent years, the study of the AC-OPF problem in its polar form has gained attention, particularly due to the second-order cone program relaxation introduced by the Jabr inequality. When the graph representing the network is a tree, the corresponding equality relaxation yields an exact model. In general, additional conditions must be satisfied for the Jabr equality model to be exact: specifically, loop constraints must be incorporated into the formulation to ensure that the sum of voltage angle differences along cycles in the graph is a multiple of 2π. In this work, we focus on studying violations of the loop constraints in the Jabr inequality model, with the aim of better understanding how network topology affects the feasibility of the relaxation. Bound-tightening techniques are applied, and networks with particular topologies (i.e., those with few interconnecting cycles) are further investigated.
Keywords: AC-OPF, MILP, Network Topology

Session: OPTSM - Public transport optimization 1

Thursday September 4th 08:00am - 09:40am

Main Room

Chair: Yin Yuan

Context-independent multiobjective train unit scheduling optimisation

David Watling[1], Zhiyuan Lin[1]

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Train Unit Scheduling assigns train units to timetabled trips, with flexibility for coupling or decoupling units to meet varying rolling stock configurations. A variant of TUSO aims to balance two objectives via multiobjective optimisation (MO): satisfying higher-level passenger demand and minimising rolling stock usage. Real-time emergencies such as signal failures or rolling stock shortages often result in a new "context" (e.g. reduced timetables or altered operational rules). In MO, it is typically assumed that decision-makers (DMs) select appropriate solutions according to their preferences. However, in real-time scenarios, consulting DMs is impractical. A common workaround is to apply linear-weighted combinations of objectives, but fixed weights often reflect priorities suited to specific contexts and thus bias solutions towards a small portion of the Pareto front, failing to adapt to broader, context-dependent preferences. Therefore, a more flexible approach is needed for real-time decision-making across diverse contexts.

We introduce a novel Context Independent Multiobjective Train Unit Scheduling Optimisation (CIMO-TUSO) model designed for such situations. CIMO-TUSO is pre-trained offline over a wide range of contexts to capture the parts of DMs' choice behaviour that are invariant across situations. It autonomously applies this learned behaviour in real-time, effectively emulating DM involvement without requiring their direct input. Rather than relying on fixed objective weightings, CIMO-TUSO offers a probabilistic metric to assess solution desirability, allowing representation of different experts' or operational rules' perspectives through adjustable parameters. This flexibility extends beyond simple notions of efficiency or inefficiency in traditional Pareto-based MO, providing a richer, more resilient decision-making mechanism. Our approach is particularly suited to scenarios involving imperfect information, uncertainty, or urgent operational needs.

Keywords: Multiobjective optimisation, Real-time decision making, Train unit scheduling

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A time-dependent model for the modular bus assignment problem

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Urban transit systems usually operate according to fixed-route and fixed-schedule schemes by employing fixed-capacity vehicles, despite the mobility demand is unevenly spread out in both space and time. Modular buses are an emerging technology in which modules of relatively small capacity can be dynamically docked together to form greater capacity buses and can, therefore, make the transit system capable of adapting the capacity to the actual mobility demand. A module can be shifted from one line to another at pre-defined intersections and can be relocated when empty, if beneficial. We call these two operations sharing and rebalancing, respectively. Given a transit network comprising multiple bus lines and a mobility demand unevenly distributed in space and time of the day, we formulate a time-dependent model for the the modular bus assignment problem introduced in [1], allowing for a more precise allocation of the modules and a better estimation of the size required to maintain high levels of service.
Keywords: modular buses, transit systems, flexible-capacity vehicles

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A Heuristic Algorithm for Timetabling and Vehicle Scheduling with Electric Buses

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Passengers' satisfaction and environmental issues are two key aspects in public transport optimization. This study addresses Timetabling (TT) and Vehicle Scheduling (VS) for bus transport systems that employ mixed fleets of electric and internal combustion engine buses. TT requires to define appropriate bus frequencies to guarantee high-quality service to the passengers. VS concerns assigning buses to timetabled trips to minimize the operational costs given by vehicle utilization, idle times, deadhead journeys, and CO_2 emissions. The use of electric buses introduces additional constraints, such as limited travel range and necessity for adequate charging infrastructure, making the bus scheduling problem more complex (see e.g., [2]). We propose a sequential heuristic approach, based on Integer Linear Programming models, that initially optimizes TT and then solves VS. TT is modelled in a similar way as in [1], while for VS we employ an exponential-size model. We test the heuristic algorithm on realistic instances to evaluate its performance.

Keywords: Public Transport, Electric Vehicle Scheduling, Heuristic Algorithm

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Integrated vehicle and crew scheduling optimization in MAIOR

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Traditionally, vehicle and crew scheduling planning stages have been approached sequentially, optimizing vehicle duties first followed by driver duties in urban areas (where many exchange points allow to more freely switch drivers, making vehicles the more constrained resources), and vice versa in regional areas (where very few exchange points are present and therefore constructing drivers' duties is harder). The challenge of integrated optimization has for a long time remained untakled in the practical setting due to its significant difficulty. In the last decade, however, simultaneous optimization of vehicle and driver duties has become essential, in particular in the extra-urban setting, because the introduction of electric vehicles makes it impossible to ensure proper service coverage by optimizing driver shifts while ignoring the fact that vehicles need to recharge at appropriate stations for a non-negligible amount of time ([1], [2]). Fortunately, the increased methodological and computational power available to support decision-making makes it possible to address the problem in a concrete way.

We will present the modeling and algorithmic approach used in MAIOR, based on two set partitioning problems linked together by (many) constraints that are dynamically inserted to efficiently manage the feasibility of the joint problem. A number of algorithmic improvements, exploiting all forms of structure in the models, is required to attain the efficiency and effectiveness that allows us to handle the increasingly complex demands of the European market: multi-depot vehicle shifts, flexibility to change buses during the duty at the depot, at the terminus, and within the trip. The algorithm is computationally validated on real-world instances up to 2000 trips to cover.

Keywords: Vehicle and Crew Scheduling, Set Partitioning

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Dynamic bus bridging strategy in response to metro disruptions integrated with routing, timetabling and vehicle dispatching

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Unplanned metro disruptions always result in severe confusion and delays, while bus bridging can provide a promising resolution by efficient evacuating stranded passengers. This article investigates the dynamic bus bridging problem under metro disruptions to generate the routing, timetabling and vehicle dispatching schemes for bus bridging services in an online fashion. Specifically, we formulate a mixed-integer non-linear programming model for each decision stage, with the objective of minimizing passenger travel times and operational costs. This model focuses on the role of multimodal transportation in improving the overall urban public transportation network's responses to metro disruption emergencies, which involves the utilization of temporary bus bridging services and the spare capacity of unaffected metro lines, passenger transfers and path choices. To address the model complexity, we propose a two-level decomposition approach to split the original problem into the master problem and subproblem. The approach can ensure the optimal solution in finite iterations. To further improve the performance of the solution approach, we design multiple acceleration techniques. Extensive experiments verify that the proposed method can effectively evacuate stranded passengers, improving passenger satisfaction and meanwhile reducing operational costs. The proposed two-level decomposition approach with multiple acceleration techniques demonstrates higher computational efficiency than the common commercial solver and standard two-level decomposition approach, facilitating timely disruption responses. Additionally, according to the computational results, we derive a series of managerial insights for decision-makers.

Keywords: Metro disruptions; Bus bridging; Mixed-integer non-linear programming; Two-level decomposition

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Session: Clustering and classification

Thursday September 4th 08:00am - 09:40am

Room 1

Chair: Edoardo Amaldi

Investigating K-Nearest-Neighbors binary classification conterfactual analysis with focus on a medical application

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Machine Learning (ML) methods act as black-box predictive models as their decision mechanism is not transparent to the user. Recently, the counterfactual analysis has been proposed [1] to improve ML interpretability and usability. Given a ML model producing a label y for a given input vector $\mathbf{x}$, counterfactual explanations provide interesting information concerning the minimal modifications of the $\mathbf{x}$ components required to guarantee a variation of the predicted label y. Determining counterfactual explanations is carried out by solving challenging optimization problems, embedding someway the complicated prediction mechanism of the underlying ML model. Growing attention is devoted to K-Nearest Neighbors (KNNs) counterfactual (e.g., [2,3]), as including the KNNs decision mechanism in the counterfactual optimization problem can be easily done. Nonetheless, determining KNNs conterfactuals is still challenging. In this work we investigate binary classification KNNs counterfactual analysis, with specific focus on a medical application related to the Continuous Renal Replacement Therapy.

Keywords: Counterfactual analysis, Machine learning, Nonlinear optimization

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Soft decision trees for survival analysis

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Decision trees are widely used in survival analysis due to their interpretability and capacity to capture complex relationships (see e.g. [1,2,3]). Survival trees, which estimate the timing of specific events based on censored historical data, are traditionally constructed using heuristic methods. Recently, there has been increasing interest in globally optimized trees, where the entire tree is trained by minimizing an error function over all its parameters. We propose a new soft survival tree model (SST), with a soft splitting rule at each branch node, trained via a nonlinear optimization formulation amenable to decomposition. SSTs provide for every input vector a specific survival function associated to a single leaf node, satisfying the conditional computation property. SST and the training formulation combine flexibility with interpretability: any smooth survival function estimated through maximum likelihood can be used, while the leaf nodes represent clusters of distinct survival curves corresponding to different data points. Numerical experiments on 15 well-known datasets show that SSTs, with parametric and spline-based semiparametric survival functions, trained using an adaptation of the node-based decomposition algorithm proposed in [4] for soft regression trees, outperform three benchmark survival trees in terms of four widely-used discrimination and calibration metrics. Moreover, we show how SSTs can be extended to consider group fairness.

Keywords: Machine Learning, Survival Analysis, Globally optimized trees

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Sparse soft classification trees: model variants and improved decomposition algorithm with pruning

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Classification trees are widely used Machine Learning models due to their interpretability and good accuracy. During the last decade there has been increasing interest in globally optimized trees, where all tree parameters are optimized simultaneously. Blanquero et al. introduced in [1,2] a nonlinear optimization formulation for training Soft Classification Trees (SCTs) with soft splits at branch nodes. In [3] Amaldi et al. presented a first node-based decomposition algorithm for training them. In this work, we propose and compare two SCT variants where every input vector falls into a single leaf node and the corresponding prediction is the class label associated to it. Such SCT variants satisfy the conditional computation property and are suitable for decomposition. Since training them is computationally challenging, we investigate a decomposition algorithm with different working set selection strategies, including an ad hoc data points rerouting heuristic at branch nodes. To obtain sparse and compact SCTs, we combine it with concave approximate ℓ_0-norm regularization and a pruning step. The performance of the decomposition algorithm with different working set selection strategies is assessed on 15 well-known datasets. The impact of sparsity and pruning is evaluated in terms of tree size and testing accuracy.
Keywords: Machine Learning, Soft classification trees, Decomposition algorithms, Sparsity

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A Hierarchical Clustering Mathematical Programming Model and Matheuristic Algorithm

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Hierarchical clustering is a statistical technique used to identify groups (clusters) within a dataset by constructing a hierarchy of nested clusters. This hierarchy is typically represented by a rooted tree, or dendrogram, where the leaves correspond to individual data points, and each internal node represents a cluster that includes all its descendant leaves. Among the various hierarchical clustering methods, agglomerative approaches rely on greedy procedures that produce a sequence of nested partitions: at each level, two clusters from the previous partition are merged based on a local criterion. In this work, motivated by the lack of exact methods that guarantee global optimality, we propose a unified mathematical programming formulation that encompasses both single and complete linkage clustering. Through preliminary experiments, we compare the dendrograms obtained from the exact solutions of these formulations with those produced by standard greedy algorithms, using several commonly adopted evaluation metrics. Additionally, we introduce a scalable matheuristic algorithm, based on the proposed formulation, which is capable of generating higher-quality dendrograms than those produced by greedy approaches, even on large-scale datasets.

Keywords: Data science, Hierarchical clustering, Mathematical programming

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Exact and Heuristic Algorithms for Constrained Biclustering

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Biclustering, also known as co-clustering or two-way clustering, simultaneously partitions the rows and columns of a data matrix to reveal submatrices with coherent patterns. While constraints such as must-link and cannot-link have been widely used to guide one-way clustering, their integration into biclustering remains underexplored. As a model problem, we study a constrained version of the k-densest disjoint biclique problem, which aims to identify k disjoint complete bipartite subgraphs (bicliques) in a weighted complete bipartite graph, maximizing the total density while satisfying pairwise constraints [1]. We propose both exact and heuristic algorithms. The exact approach is a tailored branch-and-cut algorithm supported by a semidefinite programming (SDP) relaxation, strengthened with valid inequalities and solved in a cutting-plane fashion. For large-scale graphs, we introduce an efficient heuristic based on the augmented Lagrangian method, where the primal subproblem is solved by decomposition through a globally convergent block-coordinate projected gradient algorithm. Experiments on synthetic and real-world datasets demonstrate that the exact method outperforms general-purpose solvers, while the heuristic algorithm delivers high-quality solutions.
Keywords: Biclustering, Data mining, Global optimization, Local optimization

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Session: PRIN SMACROS + SMOTION 2

Thursday September 4th 08:00am - 09:40am

Room 3

Chair: Francesco Carrabs

Improving sustainability in last-mile logistics with a combination of autonomous delivery robots and parcel lockers

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The exponential growth of the e-commerce sector is putting mounting pressure on last-mile delivery networks, which must now deal with higher volumes and expenses while improving both efficiency and sustainability. This has encouraged the investigation into novel approaches for reducing costs and environmental and health impacts. In this work, we propose an innovative delivery system centered on the combination of autonomous delivery robots (ADRs) (Chen et al., 2021) and public parcel lockers (PLs) (Deutsch and Golany, 2018), aimed to cut costs, emissions, and unsuccessful deliveries.

Our suggested last-mile system is set in a smart-city environment, where cities are covered with a dense network of publicly managed PLs. In this context, direct home delivery is restricted, except for priority customers (e.g., elderly or disabled individuals), whose packages are delivered by ADRs. This system has several advantages. Consolidating deliveries at PLs decreases the number of delivery stops, which minimizes travel distances and emissions. It also minimizes the cost of logistics and prevents failed delivery attempts. Moreover, as ADRs move on sidewalks, they contribute to alleviating road congestion. A side effect is promoting a healthier way of life for citizens who walk to pick up parcels.

To render this system as efficient as possible, we make use of tailored destroy-and-repair operators within a neighborhood-search framework. We evaluate the performance of our model through a real-case study in Rome, Italy. Our findings show the environmental and economic promise of this novel last-mile delivery solution with respect to traditional methods.

Acknowledgments: This research was partly supported by the Ministero dell'Università e della Ricerca (MUR) of Italy, PRIN project "Optimizing sustainable multi-modal and multi-tasking last-mile distribution system with carbon-free autonomous vehicles, ground robots, drones, and public transport", CUP Master H53D23002000006, CUP F53D23002720006. This support is gratefully acknowledged.

Keywords: Last-mile logistics; Autonomous delivery robots; Parcel lockers; Metaheuristics

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The traveling salesman problem with time windows and non-linear energy consumption

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We propose an extension of the well-known Travelling Salesman Problem with Time Windows (TSP-TW) that considers energy consumption constraints (Electric TSP-TW, ETSP-TW). We model the ETSP-TW as a mixed integer nonlinear problem, with the aim of minimising energy and routing costs. We model the energy consumption as a nonlinear function of the vehicle speed. Unlike most existing approaches that rely on linearisation, we preserve the non-linearity by representing the framework as a two-stage decision problem, hence applying a decomposition strategy. The first-stage problem, namely RP, is a classic TSP which provides a feasible routing solution, i.e., $\bar{x}$ with minimum cost. The second-stage problem, namely SP($\bar{x}$), is related to the definition of the speed along the arcs, and the verification of the time windows constraints. In the proposed decomposition approach, the RP is the master problem, iteratively refined through the addition of specific classes of consistent cuts separated by solving the SP($\bar{x}$) for each solution $\bar{x}$ of the RP. Preliminary computational experiments on synthetic and benchmark instances assess the validity of the proposed approach.

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Keywords: Traveling Salesman Problem (TSP), Non-Linear Energy Consumption, MINLP model.

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3D Path Planning of Unmanned Aerial Vehicles for Image Collection in Precision Agriculture

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Precision agriculture is an approach to farm management that uses advanced technologies to monitor, analyze, and optimize agricultural operations. We particularly focus on the use of Unmanned Aerial Vehicles (UAVs), equipped with multispectral or thermal cameras, whose task is to collect images at given target sites on an agricultural field. We introduce a mixed-integer linear programming formulation, of the Close-Enough TSP type, which determines the sequence of target locations to be photographed, linked to each waypoint, and calculates the optimal flight path for the UAV. Such a path is aimed at minimizing energy consumption, ensuring sufficient coverage while accounting for flight altitude. In order to cope with the computational difficulties arising when exact solvers face problems with around 20 nodes, we also propose a heuristic approach that uses a fixed sequence of targets calculated in advance by means of standard TSP approaches.

Acknowledgement: This work was supported by a grant awarded by "European Union – Next Generation EU" under the PRIN 2022 PNRR project "Smart Agriculture by Collaborative Robot Swarms" (P2022E38SJ)

Keywords: Precision Agriculture, Unmanned Aerial Vehicle, Path Planning

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A Cluster-First Route-Second Approach for the Multiple Close-Enough Traveling Salesman Problem

Francesco Carrabs[1], Raffaele Cerulli[1], Ciriaco D'Ambrosio[1], Gabriele Murano[1]
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In this work, we address the Multiple Close-Enough Traveling Salesman Problem (mCETSP). Given a fleet of m drones and a set of target points in a Euclidean space, where each target is associated with a circular compact region centered at the target, the mCETSP consists of planning m routes that ensure each target is covered — that is, each neighborhood must be intersected by at least one route. The goal is to minimize the length of the longest route.

The mCETSP finds applications in precision agriculture [2]. A fleet of drones can collect information from sensors on the ground, such as plant health, soil moisture, and other key indicators that influence agricultural decisions. To this end, it is sufficient for a drone to fly close enough to a sensor to gather its data. The goal of the problem is to plan the drone routes so that every sensor is covered and the total time to collect all the data is minimized.

In this work, we present a heuristic approach divided into three phases. After applying an effective strategy to discretize the neighborhoods of the target nodes [3], in the first phase, the nodes are grouped into m clusters. In the second phase, the mGTSP problem is solved heuristically to obtain m routes. In the final phase, these routes are further improved using an algorithm that considers the entire neighborhood instead of only the discretization points [4].

We tested the effectiveness of our heuristic by using the benchmark instances of the Close-Enough Traveling Salesman Problem available in the literature [1].

Keywords: Close-Enough, Multiple Generalized TSP, Neighborhoods, Drones

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A MILP based Heuristic Approach for the Multiple Close-Enough Traveling Salesman Problem

Francesco Carrabs[1], Raffaele Cerulli[1], Ciriaco D'Ambrosio[1], Gabriele Murano[1]
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The Close-Enough Traveling Salesman Problem (CETSP) is a variant of the Euclidean traveling salesman problem, in which the traveler visits a node if it passes through the neighborhood set of that node. We assume that the neighborhood of a node is represented by a circle with this node as a center. In this work, we tackle a variant of CETSP, named mCETSP, in which m identical vehicles are used to visit the nodes, and the objective function consists of minimizing the length of the longest route.

The mCETSP finds applications in precision agriculture [2]. A fleet of drones can collect information from sensors on the ground, such as plant health, soil moisture, and other key indicators that influence agricultural decisions. To this end, it is sufficient for a drone to fly close enough to a sensor to gather its data. The goal of the problem is to plan the drone routes so that every sensor is covered and the total time to collect all the data is minimized.

To find feasible solutions of mCETSP, we apply an effective strategy to discretize the neighborhoods of the nodes [3], obtaining, in this way, an instance of the Multiple Generalized Traveling Salesman Problem mGTSP. For mGTSP we propose two Mixed Integer Programming Models. Finally, to obtain tighter upper bounds of the optimal solution value of mCETSP, we improve the solutions of the models by using an algorithm that uses the whole neighborhood instead of its discretization points only [4].

We tested our models by using the benchmark instances of the Close-Enough Traveling Salesman Problem available in the literature [1].

Keywords: Close-Enough, Multiple Generalized TSP, Neighborhoods, Drones

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Session: Location

Thursday September 4th 08:00am - 09:40am

Room 2

Chair: Serena Fugaro

Solution approaches for a fair multi-source capacitated facility location problem

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We incorporate a fairness measure, known as the conditional β-mean, into the classic Multi-Source Capacitated Facility Location Problem (MSCFLP). We term the resulting problem the Fair MSCFLP (F-MSCFLP) and we develop four mathematical formulations to model it: a mixed-integer bilevel model, a mixed-integer bilinear model, and two mixed-integer linear programs (MILP). To solve large-scale instances, we devise a Variable MILP Neighborhood Descent (VMND) algorithm. This matheuristic follows the general lines of a variable neighborhood descent algorithm, where each neighborhood is explored by solving one or a few MILPs. To validate the performance of the proposed VMND, we also implement four simple heuristic approaches, each one corresponding to the solution of a MILP model approximating the F-MSCFLP. Extensive computational experiments conducted on benchmark data sets for the conventional MSCFLP, consisting of up to 100 facilities and 1,000 customers, show that the mathematical formulations can solve in reasonable computing times only small-scale instances. Results on the latter test problems reveal that VMND always found the optimal solution within a few seconds. Experiments on large-scale instances indicate that VMND outperforms the other methods in terms of the quality of the solution found.

Keywords: Facility Location, Fairness, Matheuristics

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Backup Covering Problems: a tailored Branch-and-Benders-Cut algorithm

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Backup covering problems represent a special class of covering location models that are extremely important in applications involving decisions that need to comply with service redundancy. Among these models, the most used are the BACOP1 and the BACOP2 [1], which can be seen as different generalizations of the well-known Maximal Covering Location Problem. Given an available budget in terms of facilities to open, BACOP1 aims at maximizing the demand covered twice while ensuring that the total demand is covered at least once, whereas BACOP2 aims at maximizing a weighted combination of the demand covered once and twice without any guarantee on the single coverage. Despite their practical importance [2], little attention has been given to the development of tailored solution algorithms for backup covering problems of such types. In this work, we exploit the special structure of BACOP1 and BACOP2 to derive a branch-and-cut approach based on the separation of different Benders cuts. Differently from classical Benders decomposition approaches, the cut separation is performed by leveraging combinatorial properties of the resulting subproblems and not through the solution of a linear program [3]. We study dominance properties among the obtained cuts and validate the efficiency and effectiveness of our method versus state-of-the-art solvers against an extensive set of large-size instances. Notably, despite the great similarities between the two problems studied and the development of a unified approach, the characteristics of the solution procedures and their computational results differ in a substantial way.

Keywords: Backup Covering Problems, BACOP1, BACOP2, Benders decomposition, Branch-and-cut

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Bilevel Design And Pricing Of Ev Charging Stations With Deviation-Flow

Isabella Presutti Gasbarro[1], Andrea Pizzuti[2], Oya Ekin Karaşan[3]

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Electric vehicles (EVs) represent a promising alternative to internal combustion engine vehicles, offering benefits such as lower operating costs, improved driving experience, and reduced environmental impact. However, the continued growth of EV adoption depends heavily on the availability of a well-designed and accessible charging infrastructure. In this study, we propose a novel bilevel programming model for the location and pricing of capacitated EV charging stations in urban areas. The upper level models the decisions of a central planner seeking to maximize the total revenue through optimal station location and design, and dynamic price selection across multiple time periods. The lower level model represents user behavior through a deviation flow capturing approach, where drivers minimize charging costs based on supply prices and station availability, while accounting for preferences related to location attractiveness. Computational tests on a set of randomly generated instances demonstrate the viability of the approach and highlight the impact of temporal demand distribution and charging duration on instance hardness.

An exact approach for the multimode set covering problem

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Covering problems aim to optimize the location of facilities to serve demand points, focusing either on minimizing costs or maximizing coverage. Traditional models, such as the Set Covering Location Problem (SCLP) and the Maximal Covering Location Problem, address this by minimizing the number of facilities needed to cover all demands or maximizing the number of covered points with a limited number of facilities. However, these approaches typically assume the existence of a single facility type, which limits their applicability to real-world settings where individuals often require access to multiple types of services during the same trip. In such contexts, different facility types may compete for the same locations, creating dependencies that prevent the problem from decomposing into independent subproblems. Furthermore, simply ensuring proximity to one facility of each type may not be sufficient. Indeed, individuals frequently combine visits to several services within a single trip, making the spatial arrangement of facilities critical to travel efficiency. Therefore, facility locations should be planned not only to guarantee coverage individually, but also to support the feasibility and convenience of multi-purpose trips.

To address this gap, we introduce the Multimode Set Covering Problem (MSCP) an integer linear programming model to solve it. The MSCP extends the SCLP by ensuring coverage by multiple facility types while promoting the formation of clusters composed of diverse facilities. By incorporating a cluster compactness measure as a proxy for travel efficiency, the model encourages facility placements that support multi-purpose trips. Computational experiments on real-world datasets demonstrate the effectiveness of our approach in improving trip efficiency compared to classical formulations. Moreover, to address large-scale instances, we develop a branch-and-cut algorithm that significantly reduces computation times.

Keywords: Facility Location, Set Covering, Clustering

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Bi-objective Location of Temporary Logistics Hubs for Enhancing Post-Disaster Relief Operations

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[2]Leeds University Business School, University of Leeds, Leeds (UK)

In post-disaster relief operations, the role of Humanitarian Logistics in ensuring a timely and effective delivery of aid is paramount. In particular, *Temporary Logistics Hubs* are essential facilities for the deconsolidation, storage, consolidation, and shipment of relief supplies [3]. In this work, we propose a novel approach to address the hub-and-spoke network design problem associated with the location of temporary logistics hubs for humanitarian logistics in post-disaster environments.

To this aim we address a *Bi-Objective Capacitated Multiple Allocation Hub Location Problem with Splittable Demand*. The decisions to be made include: *i.* where to locate temporary logistics hubs that act as intermediate facilities between the emergency relief providers (e.g., donors, government warehouses) and the affected areas; *ii.* the amount of flow that should traverse the available network links to ensure a timely supply for each relief material.

Two objectives are considered to assess the performance of the designed network: minimising the average arrival time of the flows and minimising the latest arrival time. Indeed, whilst time is a crucial factor in post-disaster operations management, it has received limited attention in humanitarian logistics problems in terms of modelling tools explicitly employed to ensure its adequate representation. In order to bridge this gap, in this work we make use of *Dynamic Flows*, i.e. Flows over time [1].

Actually, these humanitarian logistics operations are characterised by an inherent uncertainty resulting from different levels of accuracy for the related parameters [2]. To represent this aspect, we adopt ad hoc modelling tools; we also propose algorithmic approaches to mitigate the uncertainty while providing valuable decision support in post-disaster relief operations.

Keywords: Hub Location, Dynamic Flows, Humanitarian Logistics

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Plenary Session

Thursday September 4th 09:40am - 10:40am

Main Room

Chair: Roberto Cordone

From Insight to Influence: Advocacy as a Strategic Imperative for Operations Research

Jeffrey M. Cohen[1]

[1]INFORMS

In an era where public trust in institutions is fragile and policymaking is increasingly politicized, the operations research community can no longer afford to remain quiet experts. This plenary explores how advocacy — far from being a political accessory — is a strategic necessity to ensure the visibility, investment, and real-world application of our work. Drawing from INFORMS' experience building a comprehensive advocacy platform in the United States, Cohen will share actionable lessons on how OR societies and individuals can shape public narratives, engage decision-makers, and secure a seat at the table by ensuring that OR and related fields are seen, understood, and valued.

Keywords: Advocacy, Public administration, Operations research

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Session: AIROYoung Dissertation Award

Thursday September 4th 11:20am - 12:40

Main Room

Chair: Matteo Cosmi

Optimisation and Interdiction Problems for Network Safety

Alberto Boggio Tomasaz[1]

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

The rapid advancement of science and technology plays a vital role in improving collective well-being. However, its impact depends heavily on how such progress is used, either beneficially or harmfully. It is therefore crucial to develop tools and strategies that safeguard against malicious or unintended consequences, particularly in the context of system robustness and security. This dissertation focuses on optimization problems related to security. The first is the Safe Set Problem (SSP), a graph optimization problem aimed at partitioning a graph's vertices under specific dominance constraints. This models real-world scenarios where we need to identify "safe zones" in a network, such as streets, buildings, or social systems, so that individuals or resources can be relocated there in the event of a threat. The second focus is on Binary Interdiction Problems (BIPs), a family of combinatorial optimization problems involving two adversarial agents: an attacker and a defender. The attacker disables elements of a system to disrupt the defender's objective, who must then respond optimally. BIPs capture a wide range of applications, including military defence, law enforcement, infection containment, financial investments, and others. For the SSP, we propose both exact and heuristic methods. The exact approaches use branch and bound techniques enhanced with logical reductions and refined relaxations that we solve with a dedicated exact algorithm. The heuristic methods include constructive-destructive metaheuristics and a scatter search. All proposed approaches outperform the existing ones. For BIPs, we introduce several improvements over current state of the art methods. In fact, they all suffer from some major flaws that we are able to correct. In particular, we target the well-studied Shortest Path Interdiction Problem, for which our enhancements significantly reduce computation times and optimality gaps. Additionally, since the literature lacks reliable methods to compute super-optimal bounds for BIPs, we propose a novel technique that generates a set of solutions which can act as "recovery plans". This set enables the computation of a super-optimal bound and also provides useful starting points for exact methods.

Keywords: Safe Set Problem, Interdiction Problems, Exact Algorithms

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Derivative-Free Optimization: worst-case complexity for Line- Search methods and a Mixed Penalty-Barrier approach

Andrea Brilli[1]

[1] Sapienza University, Rome, Italy

This thesis advances the field of Derivative-Free Optimization (DFO) by addressing two critical challenges: the rigorous theoretical understanding of line-search algorithms and the effective handling of general nonlinear constraints in black-box settings.

The first part of this work presents the first worst-case complexity analysis for line-search DFO methods. We establish iteration and function evaluation bounds that match those of established direct search methods, filling a significant theoretical gap. A novel result is also provided, bounding the total number of iterations where the stationarity measure is above a given tolerance. This analysis is extended to bound-constrained problems, where we further prove a finite active-set identification property under standard assumptions, a result not generally available for direct search.

The second contribution is a novel mixed penalty-barrier framework for nonlinearly constrained problems. For the first time in a derivative-free context, this work introduces a logarithmic barrier for inequality constraints, combined with an exterior penalty for equalities. A key theoretical breakthrough was proving convergence to stationary points without requiring convexity assumptions on the constrained functions, overcoming the challenge of a non-Lipschitz merit function near the feasible boundary. This framework led to the development of two new algorithms, LOG-DFL (line-search) and LOG-DS (direct search), both equipped with adaptive, problem-driven rules for updating the penalty parameter. The practical efficacy of this framework is demonstrated through extensive numerical experiments, where the proposed methods show competitive and often superior performance against state-of-the-art solvers.

Overall, this work delivers theoretically sound and computationally robust tools that expand the capabilities of DFO for solving complex, real-world constrained optimization problems.

Keywords: Derivative-Free, Nonlinear Constrained Optimization, Penalty-Interior Point Methods

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Advanced optimization algorithms for last-mile logistics

Davide Croci[1]

[1] Politecnico di Milano, Milano, Italy

This thesis presents a set of innovative optimization algorithms tailored to address three complex and large-scale problems in modern last-mile logistics.

First, we introduce the Balanced p-Median Problem (BpMP), a bi-objective variant of the p-median problem where p facilities must be located to serve a set of unit-demand customers. The objectives are (i) minimizing average customer-facility distance and (ii) minimizing the mean absolute deviation of the number of customers across medians. We formulate the BpMP as a bi-objective MILP model, and use a weighted sum method (WSM) to sample its Pareto front. We also develop a primal-dual metaheuristic algorithm for the single-objective subproblem solved by the WSM. We demonstrate the effectiveness of our methods on test instances from the literature, as well as on large instances derived from an industrial application of districting for last-mile delivery.

Second, we study the Distributor's Pallet Loading Problem (DPLP), where a set of cuboid-shaped items is packed in identical pallets. In particular, items may be arranged in multiple orientations, must maintain static stability, and may withstand a limited weight. We develop a beam search algorithm for the DPLP called Tetris Beam Search, which is based on a new constructive heuristic for the same problem called Tetris Heuristic. We demonstrate the efficacy and efficiency of TBS on instances from the literature, as well as on large-scale instances obtained from an industrial partner.

Lastly, we investigate the family of Three-Dimensional Bin Packing Problems with Sequence Constraints (3DBPPS), where items must be arranged in bins such that a collision-free loading order exists. This sequence must respect the geometric limits of the packing device, whether a human loader, a robotic arm, or any other device. We first propose two MILP models, a Constraint Programming model, and a heuristic algorithm for the subproblem where the items' positions are known. Then, we propose two strategies to embed our methods into 3D packing algorithms, thereby generating bins for which a feasible loading sequence always exists. Applied to four state-of-the-art 3DBPP algorithms, we show that our strategies surpass the standard literature baseline for the 3DBPPS.

Keywords: last-mile logistics, districting, pallet loading

Multiobjective integer and mixed-integer non-linear programming: exact approaches and applications

Daniele Patria[1]

[1] Sapienza University, Roma, Italy

Multiobjective optimization comes into play in many real world problems. Some applications require to include integer variables in the optimization modeland thus, multiobjective integer and mixed integer optimization comes into play. This thesis presents new exact approaches and applications in the field of multiobjective integer optimization. First of all, we present new theoretical results about the ε-constraint algorithm for biobjective nonlinear integer programming problems. It can be shown that, under certain assumptions, the algorithm is able to retrieve the complete Pareto frontier. Then, we leverage this theoretical result for building a biobjective model, used for solving the industrial problem that we named "Best Allocation of Resource Size". The problem consists of determining which set of item sizes or volumes to choose in order to carry out the production of certain products. This is done by analyzing the trade-off between the number of items chosen and a cost function, consisting of different cost factors, e.g. purchase cost and stock cost. More specifically, the solutions of the biobjective integer optimization problem are retrieved by means of the ε-constrained method and examined under an industrial point of view. Then, the results concerning the exactness of the ε-constraint method for biobjective problems are extended to the triobjective case. In particular, an exact method able to retrieve all the nondominated points of triobjetive integer nonlinear optimization problems is devised. Such algorithm, named `TrIntOpt`, is then used to solve linear and nonlinear triobjective problems in order to determine sustainable and nutritionally adequate diet plans for elementary school cantines. The model takes into account constraints regarding nutritional factors and attractiveness, while minimizing the carbon dioxide, water and nitrogen footprint. Finally, we also propose an algorithm for finding an approximation of the nondominated set of multiobjective mixed-integer convex quadratic optimization problems. The devised branch-and-bound algorithm, named `DEIA-BB`, solves dual formulations for computing linear outer approximations of subproblems at the nodes of the branch-and-bound tree, where the values of certain integer variables are fixed. The pruning conditions defined and a tailored preprocessing phase allow the nodes to be quickly enumerated. In addition to the enclosure of the nondominated set, `DEIA-BB` also returns a superset of the efficient assignments for the integer variables.

Keywords: multiobjective optimization, nonlinear optimization, mixed integer optimization

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Session: Applied machine learning 2

Thursday September 4th 11:20am - 12:40

Room 1

Chair: Marco Taccini

Enhance Human: The Role of Applied Artificial Intelligence in Process Prediction and Optimization

Gabriele Belloni[1]

[1]Deda Ai

Artificial Intelligence is revolutionizing business value chains, offering innovative solutions for the optimization of b2b processes. This presentation explores how to integrate AI with human capabilities, enhancing predictive capacity and reducing business risks. Through some use cases we will show some of our optimization models dedicated to different business processes, enabling proactive resource management and a reduction in operational costs across different markets. The objective is to demonstrate, through practical examples and best practices, how the integration of AI in companies increases competitiveness and contributes to creating a more sustainable and responsive ecosystem.

Keywords: AIadoption, AppliedAI, Retail, Enterprise, Optimization

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Machine Learning Surrogates for Optimal Membrane System Design

Bernardetta Addis[1], Christophe Castel[2], Veronica Piccialli[3], Giulio Scarponi[3]

[1] University of Lorraine - CNRS - LORIA, Nancy Cedex, France
[2] University of Lorraine - CNRS - LRGP, Nancy Cedex, France
[3] Sapienza University, DIAG, Rome, Italy

In the design of membrane-based gas-separation systems subject to purity and recovery constraints, traditional approaches use discretized differential equations to capture transport behaviour. However the problem becomes significantly more complex when extending from two-gas to three-gas mixtures. In this work, we integrate machine learning (ML) surrogate models into a nonlinear programming framework for the optimal design of a three-gas membrane system, replacing the conventional differential-equation block. In contrast to the two-gas case, this system requires accounting for flow-conservation in the ML surrogates to ensure mass balance. To mitigate target-imbalance effects, we apply sample-weighting strategies that ensure uniform accuracy across all outputs. Prior to optimization, inputs are non-dimensionalized and filtered using a support-vector machine to identify and remove regions of the operating space unlikely to yield physically feasible solutions. We train and compare three neural-network models— a shallow model with softmax output, a network constrained during training to enforce concentration characteristics, and a physics-informed model embedding key differential-equation terms— to replicate the behaviour of a single membrane stage. Resulting designs are validated via detailed simulation. Preliminary results are promising, with the models demonstrating strong capability in approximating system behaviour.

Keywords: Nonlinear Optimization, Neural Networks, Process Synthesis

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Improving Retail Demand Forecasting to Support Inventory Optimization: A Transfer Learning Approach

Hamed Shabani Jirdehi[1], Diego Bazzanella[2], Anna Sciomachen[1]
[1]University of Genoa - Department of Economics, Italy
[2]Zeta Soft, Italy

Accurate demand forecasting is crucial for effective inventory optimization and operational decision-making in the retail sector. However, store-level forecasts often suffer from data sparsity, noise, and unforeseen external factors, limiting their reliability. In this work, we propose a flexible, machine learning-based transfer learning framework to improve forecasting accuracy across multiple retail locations. Our approach begins with a global model trained on pooled historical sales data to capture broad demand patterns, including seasonality and promotional effects. Localized fine-tuning is then performed to adapt the model to the unique characteristics of each store, accounting for differences in customer behavior and store operations. Special attention is given to distinguishing between promotional and non-promotional sales, recognizing that promotional sales often exhibit more predictable patterns. Additionally, we conduct a weather impact analysis on product sales, particularly for weather-sensitive items. We also address the challenges associated with low-volume stores by aggregating sales data over weekly periods to smooth out anomalies, including negative sales figures often associated with returns. Furthermore, cross-store correlation analysis is applied to identify groups of stores with similar sales dynamics, promoting effective knowledge transfer while preserving individual store behavior. Our framework remains lightweight, interpretable, and operationally feasible, avoiding the complexity of black-box models. Experimental validation using real-world retail data will evaluate the forecasting improvements based on standard metrics such as MAE and MAPE. We anticipate that this method will significantly improve forecast consistency and reliability, particularly for stores with limited historical data, and will better support inventory optimization and strategic planning.
Keywords: Retail Demand Forecasting, Transfer Learning, Inventory Optimization, Event-Driven Forecast Adjustment

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Combining Learning and Heuristics for Pallet Prediction in Ceramics Distribution

Marco Taccini[1], Matheus Aguilar de Oliveira[2], André Gustavo dos Santos[2], Thiago Alves de Queiroz[3], Manuel Iori[1]

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[3]Institute of Mathematics and Technology, Federal University of Catalão, Catalão, GO, Brazil

The efficient management of pallet loading operations is crucial for competitiveness in the ceramic tile industry. This study addresses a real-world variant of the distributor's pallet loading problem faced by a leading Italian ceramic tile manufacturer. The problem involves predicting the number and types of shipping pallets required to fulfill customer orders, taking into account operational constraints and warehouse uncertainties. We propose a machine learning-based approach that integrates optimization-derived features and multi-output regression strategies. Three strategies are developed: one based on independent regressors and two based on regressor chains. Computational experiments on real instances demonstrate that all proposed strategies outperform the company's solution. Among them, one of the regressor chain-based strategies achieves the best overall performance, offering the lowest error rates. The results highlight that combining machine learning with optimization provides accurate, scalable, and practical solutions for dynamic industrial environments. This study contributes to bridging the gap between machine learning and operations research for solving complex, highly constrained logistics problems.

Keywords: Ceramic industry, Distributor's pallet loading problem, Machine learning, Heuristic.

Session: OPTSM - DISPLIB competition

Thursday September 4th 11:20am - 12:40

Room 2

Chair: Giorgio Sartor

An Efficient MILP-Based Approach to Train Dispatching with Iterative Resource Conflict Resolution

Venislav Steliyanov Varbanov[1]

[1]Independent Researcher

This work addresses the complex Train Dispatching Problem, where each train follows a directed acyclic graph (DAG) of operations subject to precedence, timing, and exclusive resource usage constraints. We model the problem as a Mixed-Integer Linear Program (MILP) and propose a suite of modelling and algorithmic enhancements to improve both scalability and solution quality. Our approach includes structural graph decomposition into levels, level-wise constraint aggregation via shared time variables, the elimination of redundant variables and constraints, and exploiting repeated successor patterns to compress precedence constraints.

A novel resource conflict resolution method incrementally introduces only necessary non-overlap constraints through iterative refinement, significantly reducing model size and avoiding an upfront quadratic explosion of non-overlap constraints. Additionally, we incorporate dynamic techniques such as controlled variable fixing based on solution stability and relaxed conflict handling with controlled penalties to accelerate convergence. Introducing small release times helps eliminate infeasibilities caused by simultaneous resource swaps, while preserving optimality when applied appropriately.

The framework is implemented with Gurobi and demonstrates competitive empirical performance on the benchmark instances from the DISPLIB 2025 competition. Our method substantially outperforms baseline formulations and can solve instances previously considered intractable - achieving optimal or near-optimal solutions within strict runtime limits for the majority of instances, which include a wide range of challenging cases. The methods presented have broader applicability to scheduling problems involving path-based dependencies, shared resources, and temporal constraints.

Keywords: DISPLIB 2025, Train Dispatching Problem, MILP, Gurobi, Resource Conflict Resolution, Iterative Constraint Refinement, Graph Decomposition, Precedence Constraints, Temporal Constraints, Scheduling

References

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A Parameterized Algorithm for Real-Time Train Dispatching

Luka Stärk[1], Carolin Scholl[1]
[1]DB Systel GmbH

We present a parameterized branch-and-bound algorithm for the DISPLIB 2025 competition, which addresses real-time train dispatching through rerouting and reordering decisions. Our method models the dispatching problem as a generalized disjunctive graph. The core algorithm performs a branch-and-bound depth-first search. Conflict detection is based on interval graph clique detection, and conflicts are grouped to reduce redundant branching. We incrementally add unresolved conflicts from the best solution of the previous iteration, following Kloster et al. (2023). The longest path to a node in the *generalized* disjunctive graph is the minimum time via all predecessor operations of a train, otherwise we consider the maximum time from incoming constraints. In each iteration, conflicts are resolved in chronological order by selecting one of at most four discrete actions: (1) assign precedence to train A; (2) assign precedence to train B – both cases restrict the trains to the involved operations; (3) deactivate the involved operations of train A if an alternative path exists; or (4) likewise for train B. We use a Monte Carlo Tree Search-inspired selection method that guides branching based on past iterations. To accelerate discovery of feasible solutions and upper bounds, we propose a *train-by-train* heuristic that incrementally extends a partial solution, considering a growing subset of trains and their conflicts.

With a branching degree of at most four, the complexity of our algorithm is parameterized by the number of considered conflicts. In other words, the running time remains tractable, depending on the number of conflicts required to find a minimal feasible solution, and is independent of the number of rerouting possibilities. This extends the parameterization by the number of conflicts by D'Ariano et al. (2007), to also include rerouting. In practice, we observe drastically shorter running times in our solver, as we only branch on unresolved conflicts.
Keywords: Branch-and-Bound, Disjunctive Graph, Rerouting & Reordering

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Hybrid Optimization for the DISPLIB Competition: Logic-Based Benders and Mixed-Integer Programming for Railway Dispatching

Florian Fuchs*[1], Thomas Dubach*[1], Jan Lordieck[1], Francesco Corman[1], Bernardo Martin-Iradi[1]

*equal contribution

[1]Institute for Transport Planning and Systems (IVT), ETH Zurich

We present a hybrid optimization approach for real-time train dispatching. Our continuous-time method combines a Logic-Based Benders Decomposition (LBBD) procedure and a Mixed-Integer Programming (MIP) model-solving approach. These two complementary methods tackle the problem from two perspectives.

The LBBD is a three-stage approach: the master, formulated as a MIP, optimizes the objective function; the subproblem, formulated using Satisfiability Modulo Theories (SMT), checks feasibility and returns aggregated cuts to the master [1]. Finally, the discovery module identifies conflicts between trains, dynamically adding only the necessary constraints to the subproblem. Both components enhance tractability: aggregated cuts systematically reduce the master's feasible region, while conflict discovery limits the subproblem to relevant conflicts.

The MIP approach, in contrast, searches for feasible solutions by relaxing conflict constraints into soft constraints and minimizing the extent of their violation. The solution space is reduced by tightening event bounds. Since this can exclude feasible zero-violation solutions, the bound tightening is iteratively adjusted to balance search space reduction and feasibility. Once a valid solution is found, it serves as a warm start for optimizing the true objective.

We implement our method in our in-house optimization toolbox, openBus [2], successfully participating in the DISPLIB 2025 competition [3], which provides a comprehensive set of test instances. We model the instances using an event-activity network incorporating various preprocessing and aggregation techniques [4]. Run in parallel, the hybrid approach solves 61 of the 112 competition instances optimally within 10 minutes, and performs competitively on others. Our results show that, depending on the network topology, each approach can solve instances independently; however, when combined, they provide stronger bounds, thereby improving convergence.

Keywords: railway scheduling, logic-based Benders decomposition, mixed-integer programming, soft constraints

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DISPLIB 2025 Competition Award Ceremony

Oddvar Kloster[1], Bjørnar Luteberget[1], Carlo Mannino[1], Giorgio Sartor[1]
[1]SINTEF Digital, Oslo, Norway

In this talk, we will present the results of the DISPLIB 2025 Competition and announce the winner. This competition was initiated to fill an important gap in the scientific literature on real-time train dispatching. In the last 20 years, this literature has grown very large, but it remains difficult to compare the performance of different algorithms because each work uses different data. In addition, these data sets were typically not openly available, hindering other researchers from even reproducing any results. To improve on this situation, we collected train dispatching instances from different countries and built an openly available benchmark set called DISPLIB. We focused on creating a problem definition and file format that is easy enough to be used and understood by many, but also rich enough to represent real-world problem instances. Then, we announced a competition for solving these problems, running from the fall of 2024 to the spring of 2025. We received many great submissions based on a variety of methods, such as heuristics, MILP, constraint programming, and reinforcement learning. Researchers may now use the DISPLIB benchmark to easily demonstrate the competitiveness of their train dispatching algorithms using an open set of real-world problem instances, which we hope will facilitate interest and progress in the field.
Keywords: Train dispatching, Competition

Session: Vehicle routing

Thursday September 4th 11:20am - 12:40

Room 3

Chair: Matteo Fischetti

A Multi-Picker Routing Problem with Scattered Storage under Precedence and Stock Constraints

Bernis Çolakoğlu[1], Davide Croci[1,3], Ola Jabali[1,2]

[1] Politecnico di Milano, Milan, Italy

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Order picking operations are fundamental in warehouse logistics. In this context, pickers typically collect specified quantities of stock-keeping units (SKUs) from storage locations to fulfill customer orders. Inspired by the practices of our industrial partner, we focus on complex factors that significantly influence these operations: 1) the scattered storage policy i.e., each SKU may be stored in multiple locations and 2) precedence constraints that are derived from precomputed 3D-bin packing solutions. Specifically, the latter impose the SKU picking order. To address these complexities, we introduce the Multi-Picker Routing Problem (MPRP), where each picker, from a given set of pickers, receives an ordered list of SKUs with their respective demand quantities. Each SKU may be stored at a given number of locations, each of which containing a predefined quantity of the SKU. The objective of the MPRP is to determine routes for each picker such that the total traversed distance is minimized. The routes must determine which location (or locations) to pick an SKU from and establish the amount to be collected from each such location, while ensuring that the demand quantities are satisfied. Moreover, the routes must respect the given order of SKUs to be picked. The interdependency between routes stems from the fact that an SKU may appear in several lists. We first propose a compact MILP formulation for the problem, which is independent of the specific warehouse layout. We enhance this formulation with valid inequalities and input filtering techniques. We also derive various lower bounds for our problem. To efficiently solve larger MPRP instances, we develop a heuristic based on decomposing the problem into single-picker subproblems and applying insertion-based techniques to address feasibility issues and optimize the objective. The formulation and heuristic are evaluated on both generated test instances and real-world order instances from our industrial partner.

Keywords: Warehousing, Scattered storage, Order picking, Precedence and Stock constraints, Multi-Picker Routing

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Exact and heuristic algorithms for multi-compartment multi-trip multi-product petrol replenishment problems with time windows

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This study addresses the Multi-Compartment Multi-Trip Vehicle Routing Problem with Time Windows. Despite the substantial attention devoted to individual aspects of this problem in the literature, approaches that account for all these features have rarely been proposed and adopted in industrial instances.

To face this challenge, we develop both exact and heuristic approaches. First, a compact mixed-integer programming formulation is proposed. Next, the problem is reformulated by an extended formulation, in which a feasible trip is an elementary path that respects the capacity constraints and time window constraints. To optimally solve this formulation, we propose a Branch-&-Price algorithm, in which the Pricing Problem is a new Shortest Path Problem with Resource Constraints and is solved by a modified version of the Pulse algorithm.

To address larger instances, we propose an Adaptive Large Neighborhood Search (ALNS) metaheuristic. It introduces novel destruction and repair operators, a customer insertion strategy that prioritizes operational criteria, and advanced local search procedures based on Late Acceptance Hill Climbing and Record-to-Record Travel acceptance mechanisms.

Computational experiments conducted on real-world instances show the validity of the proposed approaches in terms of computational efficiency and solution quality.

Keywords: Multi-compartment vehicle routing, Branch-&-price, ALS

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Hierarchical Facility Location and Inventory-Routing for Joint and Gradual Demand Coverage

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This study introduces the Hierarchical Facility Location and Inventory-Routing Problem within a supply chain network design setting. Given a certain budget, it involves both the location and sizing of distribution centers (DC) and retail branches (RB), as well as the routing of inventory for periodic distributions. We formulate a Mixed-Integer Linear Programming (MILP) model that aims to maximize the demand covered under the gradual coverage assumption, which allows for the joint coverage of demand nodes by a certain number of multiple facilities. As an alternative to solving the problem as a whole, especially for large instances, we propose an iterative two-stage solution methodology that decomposes the problem into two subproblems. At each stage, the first subproblem focuses on the decisions of RB locations to maximize the covered demand. Given the solution to the first subproblem, the second subproblem minimizes the total cost of DC locations and inventory routing. Adjusting for budget gap or surplus, iterations are expected to converge to a good solution according to the tightness of given stopping criterion.
Keywords: Hierarchical Facility Location, Inventory Routing, Joint and Gradual Coverage, Supply Chain Network

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A Benders Decomposition Approach to the Time Window Assignment Traveling Salesperson Problem with Stochastic Travel Times

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We study the Time Window Assignment Traveling Salesperson Problem with Stochastic Travel Times, a two-stage stochastic problem where the first-stage decisions involve the routing aspects and the customer time window definition. Second-stage decisions follow, which integrate real-world uncertainties, notably stochastic travel times, into the optimization process. The objective is to minimize the combined routing and time window cost, including penalties for earliness and lateness, marking a shift from a cost-focused routing strategy to a more balanced approach that considers both cost and service quality aspects in delivery operations.

We introduce a novel formulation inspired by a 3-index formulation for the Time-Dependent Traveling Salesperson Problem, and we report an extensive computational comparison of alternative models and solution methods from the literature. Additionally, we provide a set of benchmark instances characterized by two opposite scenario types, intended to facilitate future research. Our results show that the (by far) most effective solution method is an ad-hoc Benders Decomposition algorithm that leverages our new model, demonstrating substantial improvements over prior state-of-the-art exact solution methods.

Keywords: Travelling Salesman, Benders Decomposition, Stochastic Programming

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Session: OPTSM - Public transport optimization 2

Thursday September 4th 14:20 - 16:00

Main Room

Chair: Valentina Cacchiani

Short-term Adjustment of Train Unit Circulation and Platform Assignment: A Branch-and-Check Method

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This paper investigates the integrated adjustment of the Train Unit Circulation Plan (TUCP) and Train Platforming Plan (TPP) in response to short-term passenger demand. Considering a set of mandatory trips and flexible trips that may be either canceled or implemented, the objective is to minimize operating costs while accommodating extra trips, adhering to train unit maintenance constraints, and ensuring that platform assignments deviate as little as possible from the original plan. We propose an Integer Linear Programming model and an exact decomposition algorithm based on the *Branch-and-Check* framework, which extends the classical Benders decomposition method. The algorithm incorporates problem-specific acceleration techniques to reduce the search space and effectively guide the search process. The proposed model and algorithm are tested on instances derived from China's high-speed railway system, demonstrating that the decomposition algorithm significantly outperforms directly solving the problem by using a commercial solver, and showing the effectiveness of the acceleration techniques. Comparisons with the sequential optimization method—which addresses the TUCP and TPP in sequence—highlight the advantages of integrating these two problems while accounting for platform deviation penalties. Finally, the stability of the algorithm is further validated through experiments varying the number of flexible and extra trips in large-scale instances involving approximately 1000 trips and 100 train units.
Keywords: Train Unit Circulation, Train Platforming, Discrete and Combinatorial Optimization.

A Hybrid Heuristic Framework for the Railway Integrated Scheduling Problem

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This research introduces a new hybrid heuristic algorithm that incorporates an instance reduction strategy, which selectively activates subsets of the original problem, using probabilistic techniques. This method is an extension of the previously established Activate-and-Generate (A&G) framework. A&G is a basic instance reduction framework, which randomly activates subsets from the original problem instance to form sub-instances that can be efficiently solved by ILP solvers. In contrast to the standard random activation approach, in this study, we explore a probabilistic "oriented" activation strategy in numerical characteristics to inform the activation process.

Scheduling problems are often described in a Directed Acyclic Graph (DAG) with nodes and arcs, where nodes represent trips or tasks, and arcs indicate feasible connections or transitions between two nodes. The number of arcs has polynomial growth with the number of nodes, reflecting the increasing complexity as the scale of the problem increases. Our algorithm adopts an oriented activation strategy by utilizing the relationship between arc features (e.g., length) and their likelihood of being in optimal solutions, integrating this probabilistic relationship into the activation procedure to accelerate algorithm convergence. A key challenge identified in our approach is handling elements that, despite their low probability of selection, have the potential to substantially enhance the optimal solutions.

The algorithm is tested on the integrated railway train unit and driver scheduling problem across 6 randomly generated instances, varying in size from 60 to 300 trips. We compare the probabilistic-based heuristic approach with both the basic A&G framework and the direct ILP solvers. The results confirm the effectiveness of our new approach, which significantly improves the solution speed, solution quality, and overall efficiency.

Keywords: Hybrid heuristic, Instance reduction, Probabilistic, Integrated train unit and driver scheduling problem

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A GRASP-Based Approach to the Real-Time Train Routing Selection Problem

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Efficient real-time traffic management aims to minimize delays in railway networks affected by timetable perturbations. The real-time Railway Traffic Management Problem (rtRTMP) [2], which involves retiming, reordering, and rerouting decisions, becomes increasingly difficult to solve as the number of alternative train routes grows. To address this difficulty, the Train Routing Selection Problem (TRSP) is formulated as a preprocessing step to reduce the rtRTMP search space. Although Ant colony optimization (ACO) has previously been used to solve the TRSP [1], its reliance on memory-based pheromone trails may hinder computational efficiency, especially under strict time constraints.

This work introduces a Greedy Randomized Adaptive Search Procedure (GRASP) for solving the TRSP. The problem is modeled as a minimum-cost n-cliques on a k-partite graph, where each clique represents a compatible set of train routes. The total cost of a clique is calculated as the sum of the costs associated with its vertices and edges, which reflect individual route delays and pairwise route conflicts, respectively. GRASP constructs cliques iteratively through a greedy adaptive process, where candidate vertices are evaluated based on the edge costs that connect them with the current partial clique. During selection, a controlled level of randomization is introduced to diversify the search, followed by a local search phase and a repair procedure.

We perform extensive computational experiments on the station area of Lille Flandres, France. The experiments simulate realistic perturbed traffic conditions. The results show that GRASP is better than ACO for short computational times. In addition, the results highlight that greater clique diversity, even at the expense of slightly higher clique costs, leads to better traffic management outcomes. Future work will refine the cost estimation model and integrate a controlled level of diversity in the solutions.

Acknowledgement: This work has been part of EU-Rail flagship project MOTIONAL, funded by the European Union under Grant Agreement 101101973 (call HORIZON-ER-JU-2022-01).

Keywords: Train routing, Real-time rail traffic management, Greedy randomized adaptive search procedure

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Optimizing metro timetabling and capacity decision considering feeder trains

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Railway transport systems are shifting towards a comprehensive mobility ecosystem, requiring the coordination among various transport modes to provide convenient and smooth travel for passengers. We consider a multi-modal transport network consisting of a high-frequency metro line and multiple rail feeder lines connected by transfer hubs. Considering the wave-like flow of transfer passengers at the transfer hubs, we tackle the problem of jointly optimizing the metro timetables and number of carriages assigned to them. The objective of the problem is to minimize the overall system cost, which includes the metro dispatches, the number of deployed carriages, and passenger waiting times. We propose a new boarding policy applicable to general multi-modal settings. In particular, we classify the passenger flow from the metro line as well as the passenger flows from the feeder trains into discrete time-steps. We assume that passengers are governed by a first-in, first-out (FIFO) principle with respect to the discrete time-steps. Furthermore, we assume that within each discrete time-step, passengers board according to a well-mixed (WM) policy. We denote the overall boarding policy as FIFO-WM. We develop a compact MILP model which is enhanced by several valid inequalities and greatly outperforms benchmark models that exclusively consider a metro line. Based on our formulation, we propose a Benders-based decomposition algorithm, which is enhanced by a number of lower-bounds and several optimality cuts. We conduct extensive computational experiments and demonstrate the effectiveness of our algorithm. Compared to timetables with a fixed metro dispatching frequency, with each dispatched train having the maximum number carriages, our dispatching strategy significantly reduces the overall system cost.

Keywords: Metro timetabling, Multi-modal transport network, Valid inequality, Benders decomposition

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Train Timetable Adjustment with Extra Train Services and Connection Requirements: A Branch-and-Repair Method

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Due to passenger demand fluctuations, short-term adjustments to railway plans often become necessary. In this work, we focus on the problem of adding to the existing timetable extra train services ([1], [3]), characterized by given time windows for their departure and arrival times, and consequently modifying the planned train schedules. Since the adjustments are applied in the short term, one key issue is to preserve the planned train connections required to guarantee passenger transfers and allow for rolling stock turnarounds. In addition, the changes to the existing schedules should be limited as much as possible and the number of unscheduled extra train services should be minimized.

In this work, we propose a Mixed Integer Linear Programming model and a Branch-and-Repair algorithm ([2]), that is a Logic-based Benders decomposition approach in which, when an infeasible solution is found in a subproblem, it is repaired by solving an auxiliary subproblem. To improve the computational performance, several valid cuts are added in a dynamic way. The algorithm is tested on instances, featuring different network structures, based on the real-world high-speed railway network managed by China Railway Shanghai Group.

Keywords: Train Timetabling, Short-term adjustment, Logic-based Benders decomposition

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Session: Optimization and learning

Thursday September 4th 14:20 - 16:00

Room 1

Chair: Matteo Salani

Backtracks-Free Stochastic Line-Searches via Hyperparameter Transfer

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Stochastic Gradient Descent (SGD) and its variants are the de-facto standard to solve large-scale finite-sum problems. Despite the huge success of these methods in training neural networks, their speed of convergence and the generalization abilities of the resulting model strongly depend on the selection of the step size. In recent years, (nonmonotone) line search methods have been successfully applied to SGD and its variants leading to impressive experimental performance, while maintaining strong convergence properties.

In this talk, we discuss a key bottleneck of this class of methods: the number of backtracks required to satisfy the line search condition at each iteration. In fact, especially when training huge networks with billions of parameters, the extra forward steps required by this internal procedure may be too costly. To overcome this limitation, we propose a solution based on hyperparameter transfer. A line of recent works have shown that neural networks can be re-parameterized to preserve certain properties of both the models and the optimization process when scaling the width and the depth of the architecture. This observation can be leveraged to transfer optimal parameters from a small "toy" network, which can be easily tuned, to a larger "target" network.

In this talk, we exploit this technique to enable the transfer of the whole sequence of accepted learning rates from a small architecture to a larger one, obtaining a stochastic line-search algorithm that trains the large "target" architecture without backtracks. We present preliminary results obtained using our approach on a set of supervised learning problems, highlighting the benefits this technique can offer to stochastic line-search methods in real-world scenarios.

Keywords: Finite-sum optimization, Stochastic line-search, Hyperparameter transfer

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Pareto Forests: Multi-Objective Optimization Models for Interpretable Machine Learning

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In this work we propose a classification model based on the combination of Optimal Classification Trees (OCT) [1] with hyperplane splits and Support Vector Machines (SVM) [2]. In particular, we build a model which takes into account the OCT model and that splits the data points at the root node of the tree according to the SVM's hyperplane. This is done by building a compound optimization model taking into account the constraints from both OCT and SVM while optimizing the weighted sum of the two objective functions. By choosing different weights in the objective function, the described model yields an optimal classification tree representing a certain compromise solution between an SVM split at the root node and an OCT. In other words, each tree is linked to a nondominated point from the Pareto frontier considering OCT's and SVM's objective functions. This approach has been tested on different datasets, using k-fold validation and a grid search for hyper-parameters tuning (including the weights related to the objective function). The results show that the model has good performances on the tested datasets. Furthermore, the obtained classification trees are combined in order to create an ensemble of classifiers called forest. Such forests are built considering trees obtained by different choices of weights for the objective function and thus representing different points from the Pareto frontier. It is shown how this approach can lead to an improvement of the performances with respect to the original trees, i.e. a higher accuracy in the prediction.

Keywords: Classification, Optimal Classification Trees, Support Vector Machines

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Data-Driven Exploration of Labeling in Elementary Resource Constrained Shortest Path Problems

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In this work, we investigate whether machine learning can be leveraged to identify promising states in dynamic programming algorithms, focusing on Elementary Resource Constrained Shortest Path Problems (ERCSPP). While our study is centered on ERCSPP, the proposed methodology can be extended to other dynamic programming approaches.

More in detail, we solved 41 single resource instances from SPPRCLIB using iterative relaxation techniques through the PathWyse library, systematically collecting all generated states (i.e. labels). We designed ad-hoc features computable in constant time and constructed two datasets: one containing all generated labels (G) and another with only those inserted into data pools (I), totaling several hundred million labels.

Machine learning tools are then employed to explore these datasets, revealing significant patterns between successive relaxations. Leveraging these insights, we propose a normalization approach and apply supervised learning techniques to distinguish dominating states, both within subsequent relaxations of the same problem and in previously unseen instances. Our results demonstrate the effectiveness of this approach on Dataset G, while for Dataset I, performance varies, showing promising results within the same instance but declining for unseen ones. Overall, these findings open new perspectives for the development of data-driven dynamic programming algorithms.

Keywords: Dynamic programming, Machine learning, Shortest Path Problems

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Bayesian Optimization via Wasserstein Barycenter of Gaussian Processes

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Bayesian Optimization (BO) is a sequential method for the global optimization of black-box, multi-extremal, and expensive to evaluate functions. Its basic components are a probabilistic surrogate model, usually a Gaussian Process (GP), and an acquisition function selecting the next query as the point providing the highest informational utility given the current surrogate model. The sample efficiency of BO is the main factor of its successful application in many domains. However, fitting a GP at each BO iteration requires a computational cost that is cubic in the number of performed queries, which can be quite large for high dimensional problems. Fitting a GP means tuning its kernel's hyperparameters to a set of observations, but the commonly used Maximum Likelihood Estimation (MLE) has shown different criticalities with respect to theoretical analysis (i.e., the Reproducing Kernel Hilbert Space which the objective function belongs to must be known in advance to guarantee convergence) as well as numerical instability (due to kernel matrix inversion) and computational cost.

In Machine Learning the Wasserstein distance has increasingly gained importance during last years: it allows to compare two probability distributions – even of different types – satisfying all the properties of a distance. Exploiting the probabilistic nature of GPs, we present a new approach to avoid MLE by using, instead, a prefixed set of values for kernel's hyperparameters to fit as many GPs and then combines them into a unique model given by their Wasserstein Barycenter. Given a set of probability measures the Wasserstein barycenter is that probability measure which minimizes the weighted average of its Wasserstein distance from the other measures. Importantly, the Wasserstein barycenter is shape preserving and geometry aware. The proposed approach is endowed with a theoretical convergence result and exhibits a good numerical performance on preliminary benchmarks when compared to vanilla BO.
Keywords: Bayesian Optimization, Wasserstein barycenter, Gaussian Process

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Difference of Convex programming in adversarial SVM

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Adversarial machine learning addresses malicious data manipulation from two opposing perspectives: the defender's objective is to safeguard the correct behavior of learning mechanisms, while the attacker's goal is to mislead these mechanisms. In this presentation, we will present adversarial machine learning models, particularly focusing on the Support Vector Machine framework. We will examine both evasion and poisoning problems. The first model is designed to construct effective sparse perturbations of dataset samples, while the second aims to induce a significant rotation of the hyperplane defining the classifier. Both models are formulated as Difference of Convex non-smooth optimization problems. Numerical results on both synthetic and real-world datasets are presented.

Keywords: DC programming, Adversarial machine learning, Sparse optimization

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Session: Scheduling 3

Thursday September 4th 14:20 - 16:00

Room 2

Chair: Gaia Nicosia

Mixed Integer Linear Optimization models for Cricket Farming

Marco Dottor[1], Pietro Belotti[1], Federico Malucelli[1]

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In recent years, the global landscape of food production has seen a growing demand for sustainable and efficient protein sources. Among these, crickets (*acheta domesticus*) have emerged as a promising candidate, offering a sustainable solution to the ever-increasing demand for protein. Managing a cricket farm involves maintaining environmental conditions (temperature, humidity, and lighting) to create an optimal habitat for the insects; formulating a balanced and nutritionally rich diet; and regular cleaning and maintenance of habitats to prevent the buildup of waste and diseases.

Harvesting, a critical phase in cricket farming, requires precise timing to ensure maximum yield while maintaining the welfare of the insects, and is an interesting subject to study because the *acheta domesticus*' growth profile is not linear. This study proposes two optimization models for scheduling the placement of crickets in containers while maximizing yields. Instead of using standardized *condos* (term used to indicate the habitats where crickets live) of the same size for all crickets, a more efficient usage of space can be achieved with the employment of a "two-condo" strategy: using a smaller habitat in the first stage of life of the insects, and moving them to a bigger one for the final stages of their development.

We present two models: one aimed toward small/medium farms that want to reach steady-state production in the shortest time and most efficient way possible, and another aimed at maximizing production cycles, synchronizing the stay in both big and small condos in order to increase profits. We present preliminary computational results that show the promise of both models in managing cricket farms.

Keywords: Cricket farming, Scheduling.

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Solution approaches for the coupled task scheduling problem

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In this work we deal with the single machine coupled task scheduling problem which consists of scheduling a set of jobs each with two tasks on one machine such that the makespan criterion is optimized. The two tasks of a job are separated by an exact delay. The second task of the job must start after the completion of the first task of the job (also known as the initial task) plus the exact delay time. The general single machine coupled task scheduling problem to minimize the makespan is known to be strongly NP-hard [1] even if a sequence for executing the initial (or completion) tasks is given [2].

The problem can be more formally stated as follows. A set $J = \{1, ..., n\}$ of coupled task jobs must be processed on a single machine. A job $j \in J$ is represented by a triple (a_j, L_j, b_j), where a_j and b_j are the processing time of the first and second tasks of job j, and L_j represents the exact time delay between the two tasks of job j. All processing times and delay durations are considered as integral and no preemption is allowed, that is, the operation of a task cannot be interrupted. However, first or second tasks of other jobs can be processed in-between the delay period of any job. The objective is to minimize the makespan denoted as C_{max}. We denote the problem as $1|(a_j, L_j, b_j)|C_{max}$ in the standard three-field notation.

The more recent exact approach for the problem is [4]. In this work we propose both a novel flow-based mixed integer programming formulation, derived from [5], as well as a constraint programming formulation. Since the constraint programming formulation is utterly fast at solving very small problems, we also propose a promising approach that couples the Branch-and-Bound scheme from [3], where single tasks of jobs are forward scheduled, with a constraint programming model that quickly finds an upper bound for the considered tasks set.

Keywords: Coupled Task Scheduling, Mixed-Integer Programming, Constraint Programming

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A Comprehensive Hybrid Flow Shop Approach for Steelmaking and Ingot Casting

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In steelmaking, efficient scheduling is essential to optimize resource use and production flow [1], especially in the relatively under-investigated ingot casting process. This study examines a real case of hybrid flow shop scheduling at the steelmaking plant level [2], [3]. The hybrid flow-shop structure directs the flow of the desired steel type through a system of sequential processing stages, some of which may involve parallel machines. The studied process consists of four distinct stages: melting in the Electric Arc Furnace (EAF), initial refining in the Ladle Furnace (LF), impurity reduction in the Vacuum Degasser (VD), and final casting into ingots (IC). To correctly model the steelmaking factory environment, additional constraints, such as mandatory transit time and no-wait conditions, must be added. Unlike most of the literature, our problem formulation considers alternative objective functions, focusing not only on makespan minimization but also on cost optimization related to the use of raw materials, specifically scrap and ferroalloys. We propose a mixed-integer linear programming formulation for the problem. Given its inherent complexity, and drawing insights from both industrial practice and recent literature, we also design a heuristic method and evaluate its performance against state-of-the-art solvers.
Keywords: Steelmaking, Scheduling, Hybrid Flow Shop

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Vehicle production planning with Artelys' integrated scheduler service

Enrico Bettiol[1], Hugo Chareyre[1]
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Efficient and accurate production planning is crucial in the automotive industry. Artelys has developed a scheduler service for Toyota Motor Europe that creates plannings for post-production workshops operations across Europe. The problem consists in scheduling operations on vehicles on different production lines with available resources. This case study details how this industrial problem differs from the classical Resource Constrained Project Scheduling Problem (RCPSP) with its additional operational constraints (multiple shifts, preemptive breaks, sequence constraints, etc.) and its multi-objectives (minimizing late tasks, late vehicles, maximizing efficiency and workers ergonomics, etc.). Artelys has worked closely with Toyota to deploy this scheduler service as micro-service in order to solve this complex problem in a real-time context and as a flexible decision-support software. The associated constraint programming model is implemented with FICO Mosel modelling language and the model is solved using Artelys Kalis solver. This micro-service has replaced a manual tedious task that was taking place differently in all workshops, by delivering faster and higher quality solutions.
Keywords: Scheduling, Logistics, Constraint Programming

A Mutation-Enhanced Discrete Particle Swarm Optimization Algorithm with Constraint Penalization for Scheduling Sowings in Space Cultivation With an Adaptive Vertical Farm

Seyed Amir Hosseini, Mauro Gaggero, Patrizia Bagnerini

We address the problem of scheduling sowings of multiple crop types in outer space or in-orbit stations within an adaptive vertical farm, that is, an innovative vertical farming technology in which shelf spacing is dynamically adjusted according to crop growth. Owing to the capability of efficiently exploiting the available vertical space, its adoption for resource-constrained environments, such as space, is promising. In particular, a penalty-based particle swarm optimization (PSO) algorithm is proposed to compute a suboptimal scheduling of the sowings with a reduced computational effort as compared to a mixed-integer linear programming (MILP) approach. The proposed algorithm is adapted to discrete search spaces and enhanced with mutation operators to prevent premature convergence and improve solution diversity. From the obtained numerical results, it turns out that, while MILP provides optimal solutions, the proposed mutation-enhanced PSO converges significantly faster and provides near-optimal solutions, thus representing a good trade-off between accuracy and computational requirements.

Session: Energy systems

Thursday September 4th 14:20 - 16:00

Room 3

Chair: Maria Teresa Vespucci

A bilevel revenue adequate generation expansion problem with hybrid complementarity conditions

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The decarbonization of electricity systems requires high renewable penetration, which is already affecting electricity prices. The resulting *missing money problem*, where generators fail to recover investment and operational costs through market revenues, may undermine long-term adequacy.

This research [1] presents an innovative modeling development for the *Generation Expansion Planning* (GEP) problem, customized to the Italian electricity market. The model incorporates side payments that reflect *Capacity Remuneration Mechanism* (CRM)-like auctions, ensuring *Revenue Adequacy* for various generation technologies. Unlike most GEP models in the literature, which overlook the cost recovery issue, our approach explicitly enforces the economic viability of investments and operations. Notably, we overcome the limitations of previous works such as Guo et al. [2], by ensuring meaningful prices.

The bilevel structure of the proposed GEP captures the interaction between a *central planner*, who optimizes investments, unit commitment, and policy targets at the upper level, and the *market operator*, who clears the zonal day-ahead market at the lower level (LL). To account for revenues, the model includes bilinear terms, namely quantities and prices, defined as the dual variable of the LL balance constraint. We develop an exact linearization method, and propose two novel constraint blocks: one to prevent strategic withholding of capacity and another to address price indeterminacy. To enhance the tractability of the MIQP model we introduce specialized cuts and develop auxiliary problems that find good primal solutions by mimicking the hierarchical relationship between levels. Lastly, we propose an effective "hybrid" approach that combines different formulations for complementarity slackness conditions of the lower level problem.

The resulting model is applied to a realistic Italian case study to validate its effectiveness in supporting robust and revenue-adequate investment decisions.

Keywords: Generation Expansion Planning, Bilevel Optimization, Electricity Market Design

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Equilibrium models to analyse the impact of different coordination schemes between Transmission System Operator and Distribution System Operators on market power in sequentially-cleared energy and ancillary services markets under load and renewable generation uncertainty

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The current massive installation of distributed resources in electricity distribution systems is transforming these systems into active dispatching subjects. At the same time, the need to compensate for the intermittent generation of an increasing amount of renewable sources creates the need to acquire more ancillary services. Flexible resources in the distribution system could 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, this requires Transmission System Operators (TSOs) and Distribution System Operators (DSOs) to coordinate their dispatching actions effectively. One critical aspect of this coordination is establishing a market architecture that limits market power.

This talk presents an innovative game-theoretic approach to compare different TSO-DSO coordination models for acquiring ancillary services from distribution resources. Several schemes are considered: some with coordinated market management by TSO and DSOs, others with sequential or independent local markets. For each scheme, the dispatching problem is formulated as a two-stage stochastic sequential game, where the first stage is the day-ahead market and the second stage is the balancing market. Nash equilibrium solutions are obtained by iteratively solving the profit maximization problem of each market player. Numerical tests on a CIGRE benchmark network show that coordination schemes enabling distribution resources to provide ancillary services to the transmission system can significantly increase system costs when congestion occurs in the transmission network.

Keywords: Stochastic programming, Game theory, TSO-DSO coordination

A comparative study of Local Electricity Market design and coordination with the Wholesale Electricity Market

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Recent energy policy developments have focused on the promotion of renewable energy sources [1] and the integration of distributed energy resources (DERs) into the energy system [2] to meet decarbonisation targets. However, the structure of traditional energy markets appears to be ill-suited to future energy scenarios, which anticipate a significant increase in the deployment of DERs and an increase in electricity demand from end users. In this context, Local Electricity Markets (LEMs) have gained considerable attention as a viable framework for local electricity trading. A LEM is defined as a competitive market where small energy producers, prosumers and consumers exchange electricity within a limited area of the grid, called an Energy Sharing Region [3]. Various LEM configurations have been analysed and tested in recent years [4]. However, studies on LEMs do not provide a clear regulatory framework defining their interactions with the Wholesale Electricity Market (WEM).

This paper presents a comparative analysis of alternative LEM designs and coordination schemes for integrating LEMs into the WEM [5]: (i) no coordination between the WEM and the LEMs; (ii) LEMs settled before the WEM, with quantities not accepted on the LEMs further submitted to the WEM; (iii) WEM and LEMs settled independently, with quantities not accepted on either the WEM or the LEMs further submitted to a Zonal Centralised Electricity Market; (iv) all orders submitted to a Nodal Centralised Electricity Market. In order to highlight the potential benefits of the above coordination schemes, a techno-economic assessment has been carried out using real data on energy bids in the Italian Day-Ahead Market (DAM). The results show the potential benefits of such integration in terms of energy prices and increased economic sustainability of DERs.

Keywords: Local Electricity Markets, markets coordination, market design, market pricing, optimization

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Optimizing Cross-Border Balancing: Artelys' Optimization Engine for the European Manual Frequency Restoration Reserve Platform

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Energy supply is a critical economic and societal challenge requiring a continuous balance between supply and demand. To achieve this, energy markets operate across different timeframes, from long-term futures markets to short-term balancing markets. While participants can trade energy up to one hour before delivery, Transmission System Operators (TSOs) manage real-time balancing by activating reserves within seconds to half an hour. In Europe, these reserves were traditionally handled nationally, but the interconnected European power system requires cross-border coordination.

A coupled European market for balancing reserves offers substantial economic benefits. This has led to the development of balancing market through initiatives like MARI, which standardizes the exchange of manual Frequency Restoration Reserves (mFRR) across European TSOs. MARI operates through the Libra platform, a common European system designed to optimize the activation and allocation of balancing energy in real time.

Artelys is contributing to this effort by developing the optimization engine for the Activation Optimization Function (AOF) within MARI, focusing on selecting and allocating mFRR bids efficiently. The algorithms optimize reserve activation across multiple countries, minimizing costs and ensuring grid stability by considering operational constraints and transmission limitations.
Keywords: Market Clearing, Balancing reserves, Mixed-Integer Linear Programming

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Investment Decisions for Perfect and Imperfect Competition in Ireland's Electricity Market

Mel T. Devine

This paper employs a game-theoretic approach to analyze investment decisions in Ireland's electricity market. It compares optimal electricity investment strategies among energy generators under a perfect competition framework with an imperfect Nash-Cournot competition. The model incorporates market price based on competition among generators while accounting for supply capacity of each firm and each technology, along with the System Non-Synchronous Penetration (SNSP) constraint to reflect operational limitations in the renewable energy contribution to the power system. Both models are formulated as single-objective function optimization problems. Furthermore, unit commitment constraints are introduced to the perfect competition model allowing the model to incorporate binary decision variables to capture energy unit scheduling decisions of online status, startup, and shutdown costs. The proposed models are evaluated under three different demand test cases, using Ireland's electricity generation projections for 2023-2033. The results highlight key differences in investment decisions, CO2 emissions, and the contribution of renewable technologies in perfect and imperfect competition structures. The findings provide managerial insights for policy makers and stakeholders, supporting optimal investment decisions and generation capacity planning to achieve Ireland's long-term energy objectives.

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