# ODS2023

## INTERNATIONAL CONFERENCE on OPTIMIZATION and DECISION SCIENCE

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ODS2023 - Book of Abstracts

The ODS2023 Organizing Committee

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This is the book of the abstracts accepted and then presented during the International Conference on Optimization and Decision Science, ODS2023, held in Ischia from September 4th to September 7th, 2023.

ODS2023 is organized within the *Italian Operations Research Society* (AIRO), with the support of the Department of Mathematics and Applications "Renato Caccioppoli" of University of Napoli Federico II.

ODS 2023 gives a special focus on the theme *Optimization in Green Sustainability and Ecological Transition* because we believe that the recent climate change requires operations researchers to think about how mathematical optimization models and methods can support a more environmentally sustainable world.

The book contains more than 250 abstracts, 33 of which associated to papers accepted for publication in the AIRO Springer Series volume devoted to the conference.

This year, in the context of the stream *OPTSM Optimization in Public Transport and Shared Mobility*, ODS 2023 also hosts the *4th International Workshop on Artificial Intelligence for RAILwayS*. In particular, on September 4th, five sessions are devoted to the contributions of the workshop.

From September, 5th, the ODS2023 contributions are organized into five parallel streams. In total, ODS2023 has about 45 sessions, 20 of which are invited sessions.

Finally, three plenary sessions, given by worldrenowned researchers, enrich the scientific part of ODS2023.

The remaining part of the present book contains, day by day, session by session, the detailed abstracts with information about the authors and their affiliations.

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We also acknowledge the financial contributions from:

## Invited Sessions and AiroYoung

A special thank to the organizers of the following Invited Sessions:

- **Bilevel Optimization**, Prof. V. Lurkin;
- **Combinatorial Optimization Problems in Maritime and Multimodal Logistics**, Prof. A. Sciomachen;
- **Equilibria, variational models and applications**, Prof. M. Passacantando;
- **Health Care Planning**, Prof. G. Carello and Prof. E. Tanfani;

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- **The Optimizer's Guide to the Sustainable World**, AIROYoung;
- **Topics in Combinatorial Optimization**, Prof. P. Toth;
- **Urban logistics and sustainable transportation: optimization under uncertainty and machine learning**, Prof. F. Maggioni.

A special thank gives to AIROyoung for having organized the special session *AIROYoung Dissertation Award 2023*, with a selected group of PhD thesis presentations.

# Workshop AI4RAILS
# Delay prediction and analysis
### Chair: Stefano Ricci

## Evaluation Method of Data-driven Train Delay Prediction Models

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*Abstract* The accurate prediction of train delays is a critical issue for ensuring safe and reliable train operations, as well as for providing passengers with up-to-date and reliable information. Despite an extensive amount of literature on train delay prediction models [1-3], the absence of a reliable standard evaluation framework raises critical questions as posed by [4]: “Are we confident that our models are better, in terms of accuracy, than models developed 30 years ago?” As both research and practice mature, thorough testing and evaluation of prediction algorithms is needed to establish a solid knowledge foundation for the development of future robust real-time train delay prediction algorithms. To address this challenge, this paper proposes a comprehensive evaluation framework for real-time train delay prediction that takes into account three different dimensions: overall, spatial, and temporal performances. The proposed framework aggregates data at various levels, enabling a more comprehensive assessment of prediction models’ performance and facilitating the identification of prediction patterns. The study applies the evaluation framework to three different prediction algorithms and evaluates their performance across multiple Swedish train stations over a three-month period. The results demonstrate that the AI solution outperforms both the graph and manual methods. The graph method predicts train delays better on weekends but struggles during peak hours on weekdays. The AI solution exhibits stable performance in predicting train arrival delays, especially during peak hours, and with greater accuracy at busy stations. The study suggests that a combination of AI and graph methods can complement each other in predicting train arrival delays across different time periods and station types. The proposed evaluation framework can be used to assess the effectiveness of different prediction models and can facilitate the development of more reliable and accurate train delay prediction algorithms. This research can have important implications for improving the safety and reliability of train operations, as well as enhancing the overall passenger experience.

*Keywords*: Train delay prediction, performance evaluation, k-means clustering , principal component analysis

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## Machine learning-based evaluation of risk of delay for the real-time Railway Traffic Management Problem

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*Abstract* The real-time Railway Traffic Management Problem (rtRTMP) aims to generate new schedules that minimize delay propagation due to unexpected disturbances. Typically, most models consider the problem as deterministic, with both structural and numerical elements often assumed to be fixed and known in advance [1,6]. While the usefulness of such approaches has been studied and proven to be adequate, uncertainty may still affect plans and their expected quality in terms of service level or risk mitigation. We consider the minimization of the maximum train delay as the objective function of the problem and investigate the evaluation of the conditional value-at-risk (CVaR) of the delay as a risk measure for the deterministic solutions of rtRTMP [4]. We model such solutions using activity networks. For normal scale instances, the CVaR can be computed accurately and quickly using a methodology based on a counting approach [2,3]. In this paper, we investigate what happens when the complexity of the instances under study increases to the point where the computation of CVaR by this state-of-the-art methodology may not be manageable in real time. Taking into account how the rtRTMP can be modeled as a Job Shop Scheduling Problem (JSSP), we consider classical blocking JSSP instances enriched with typical rtRTMP constraints such as release, due dates, and sequence-dependent setup times [5]. We study the case where the duration of these constraints, as well as the execution and dwell times, may be uncertain, and only the range of possible duration values for each constraint is known in advance. We propose a machine learning-based approach to quickly estimate the CVaR based on specific features of the activity network. Computational experiments validate the proposed approach and the accuracy of our estimates.

*Keywords*: Train delay, CVaR, Dwell times, Uncertainty, Activity Networks, Risk Assessment

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**Learning from reliability and maintainability for simulating generation and propagation of trains' delays**

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*Abstract* The success of railway transport process needs the regular operation of all components: infrastructure elements have to function with regulari-ty during different periods of the travel time and the vehicle for the entire travel time. The analyses on disruptions generating irregularities, such as delays, need to know reliability and maintainability of the single components to forecast disruptive events and their consequences. The approach to the problem can be by means of purely stochastic models, based on the analysis of failures and their spatial and temporal distributions, or by means of simulation models, possibly including stochastic procedures, replaying the real operation and including the failure events on its components. Simulation models of traffic operation are today largely available but they all need tests on different operational contexts, in order to reach a better correspondence with the reality. In particular, the mechanism of generation and propagation of delays in the real operation is complex and the normal schematization includes primary delays, normally generated by technical disruptions or inadequate human behaviours, and secondary delays, normally generated by traffic conflicts due to the deviations from the timetable produced by primary delays. In this context, learning from typical reliability and maintainability attitudes of infrastructures and vehicles components, is possibly the most appropriate process to build a predictive mechanism capable to forecast generation and propagation of disruptions in typical Artificial Intelligence applications to machine learning. The present research analyses the potential role of the various components of infrastructures and vehicles in delays generation and propagation, starting from their reliability and maintainability profiles.

*Keywords:* Transport, Railway, Operation

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# Workshop AI4RAILS
# Freight, maintenance and disruptions
### Chair: Nikola Bešinović

## Storage Space Allocation Problem of Containers at Rail-Road Transshipment Terminal for Loading Double-Stack Trains

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*Abstract* This research introduces a novel approach to the storage space allocation problem for containers at rail-truck transshipment terminals, aiming to optimize double-stack train loading. Contrary to traditional methods which assign containers to trains post-truck arrival, this methodology assigns each container to a specific train beforehand, thus streamlining terminal operations. A mathematical model incorporating safety regulations and operational constraints is presented, which significantly reduces retrieval and loading time when implemented via problem-specific heuristics. Preliminary results indicate near-full train utilization, leading to more efficient operations. The study calls for a paradigm shift from solely focusing on train utilization to considering revenue management, suggesting that the optimal solution may not always maximize train utilization. Future research directions include creating a revenue maximization model, investigating effects of irregular truck arrivals, exploring innovative container storage methods, studying supply chain collaboration benefits, and evaluating the environmental impact of proposed strategies. This research contributes to enhancing terminal operations efficiency, potentially improving overall supply chain performance and sustainability.

*Keywords:* Railway and Air traffic problems, Practice of OR, Logistics

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# Optimising locations of urban consolidation center for sustainable urban logistics using agent-based modelling

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*Abstract* The Courier, Express and Parcel (CEP) sector in Germany has a volume of 4 billion consignments per year and is expected to increase further. These developments affect cities through increasing negative impacts of CEP traffic on infrastructures and inhabitants. Urban consolidation centres (UCC) are used to increase efficiency on the last mile, to reduce these negative impacts and to enable neighbourhood-based logistics [1]. Identifying the most suitable UCC location in urban areas while considering the stakeholder objectives requires further research.

In this research, we investigate the problem of facility location problems for UCCs. We use a two-step approach by combining agent-based modelling (ABM) [2] with a mathematical optimization (MO) formulation for facility location problem. In this approach, ABM allows to accurately replicate the behaviour of the freight carrier in route choice, traffic assignment and location selection. Also, we model the interaction with other road users and the impact of freight policies on location selection. The MO model determines the ideal location taking into account the main objectives of the urban logistics stakeholders. including minimising last mile costs for carriers or minimising environmental impacts from the perspective of authorities or residents [1].

We demonstrate the model performance on a delivery district in Berlin and carry out a sensitivity analysis by varying the carrier behaviour in location choice and introducing freight policies such as road pricing. We use Open Street Map data for the buildings and the road network and. Open data from the German Federal Association of Parcel and Express Logistics [3] is used to generate freight flows.

The model enables to find the optimal location for UCCs considering the behaviour of freight carriers, the urban form of the delivery area, land availability and the impact on stakeholders of urban logistics.

*Keywords:* agent-based modelling, facility location problem, sustainable urban logistics

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## Reinforcement Learning-based railway rolling stock rostering

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*Abstract* The study itself is to explore the minimum costs of rolling stocks rostering in terms of the usage of rolling stock, considering the maintenance activities. Rolling Stock Management (RSM) is one of the main cost sources for Rail Undertakings. A key problem in railway planning requires covering a given set of services and maintenance works with a minimum amount of rolling stock units as the primary objective. Additional objectives are to minimize the number of empty runs and kilometres travelled by each train between two maintenance operations of the same type. The rostering and maintenance optimization problem are formulated as a travelling salesman problem (TSP) with additional constraints that involves scheduling tasks related to train services and empty rides. The maintenance tasks can only be done at a limited number of dedicated sites (i.e., main stations/junctions in the route). In this case, each train service represented as a node in the graph, there are four different kinds of arcs between nodes: 1) paired train services do not requires travel (no maintenance and no rostering), 2) the empty rides without maintenance tasks (pure rostering), 3) the empty rides with maintenance tasks (a maintenance delivered in any of the inter-mediate major station). 4) the maintenance tasks without empty rides (a maintenance conducted within the station). We propose a novel Deep Reinforcement Learning framework for solving the rostering TSP with customised reward functions and environment. Compared to a conventional TSP, multiple arcs are created between a pair of nodes to reflect the requirements of our problem. Preliminary experiment results based on real-world scenarios from TransPennine Express show the effectiveness of this approach as a proof-of-concept test.

*Keywords:* Deep Reinforcement Learning, Rolling Stock Rostering, Maintenance Scheduling

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**Optimize car-to-train assignment in a train marshalling yard via graph neural network and deep reinforcement learning**

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*Abstract* The car-to-train assignment problem is an important problem in railway marshalling yards. An optimized car-to-train assignment plan would significantly reduce the average car dwell time and thus enhance the efficiency of railway freight transportation. However, existing works face challenges in dealing with the uncertainty, dynamics, and flexibility of train traffic in the railway marshalling yard, such as the varying entity movement time and the required flexible utilization of classification tracks. In this paper, a deep reinforcement learning method is proposed to optimize car-to-train assignment by adjusting train hump sequences and allocating railcars to classification tracks. A tripartite graph, including nodes of arrival trains, departure trains, and classification tracks, is designed for presenting states of the problem instances. The proposed state representation also integrates train operation procedures and car distributions in the marshalling yard. A Graph Isomorphism Network(GIN) based architecture is applied to conduct node embeddings and capture the complex relationship among all nodes. The Proximal Policy Optimization(PPO) algorithm which employs an actor-critic structure is used to train size-agnostic policy networks. Moreover, a discrete event based simulation model is developed to simulate the train operations and relevant constraints in the marshalling yard and serves as the environment for reinforcement learning. The experiment results show that our method is able to obtain high-quality car-to-train assignment plans with shortened car dwell time. Furthermore, the trained policy network can be generalized to solve unseen instances.

*Keywords:* train marshalling yard, car-to-train assignment, hump sequencing, clas-

sification track utilization, graph neural networks, deep reinforcement learning

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**Detecting metro service disruptions and predicting their network-wide domino effects using large-scale vehicle location data**

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*Abstract* Metros are crucial for efficient urban transportation, offering high-frequency services and accommodating large numbers of passengers. However, these extensive urban metro systems are susceptible to disruptions, leading to longer travel times, perceived delays, missed connections, and decreased passenger satisfaction. To enhance the reliability of metro operations, operators require comprehensive data on disruptions, and the resulting network-wide domino effects [1]. This in-formation is vital for effective disruption management, enabling operators to develop efficient recovery plans, as well as providing real-time service disruption information to the passengers [2].

Using large-scale vehicle location data, this paper proposes a frame-work to detect metro service disruptions (i.e., primary delays), and predict their propagation effects on the entire network (i.e., secondary delays). The framework involves overlaying the real-time vehicle locations (using vehicle location data) onto the scheduled train paths (obtained by transforming the static GTFS data into GPS-like data), thereby identifying deviations from the scheduled train paths. Additionally, a graph modelling framework is proposed to represent the interdependencies between trains and stations in the metro network. In this model, running time, dwell time, and headways are depicted as edges, while stations are represented as nodes. Subsequently, when a delay is observed at the station level, backward and forward pass algorithms are employed to identify the time-stamped position of the primary delays and establish associations between these primary delays and their network-wide consequences (i.e., secondary delays). The obtained primary-secondary dataset will be enriched by computing time-table slacks using vehicle location data, along with other features. Lastly, a deep learning model is trained to predict network-wide secondary delays upon the detection of any disruptions in metro service.

*Keywords:* metro system, disruption detection, secondary delay prediction

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# Workshop AI4RAILS
# Infrastructure
## Chair: Andrea D'Ariano

### A Deep Learning Based Generative Model for Detecting Traffic Lights in High Speed Railways

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*Abstract* With the development of autonomous trains that are operated without human labor in high-speed railways, the real-time detection of traffic lights (TLs) and obstacles, including vehicles, falling rocks, and the infrastructure that collapses near the railroad, has received increased attention. Although existing studies have proposed different deep learning-based models, the key issue is the need for real-world obstacle data along the rail tracks since the accidents caused by these obstacles seldom happen in practice. In this paper, we propose a Generative Adversarial Network (GAN) framework for the real-time detection of TLs and obstacles in front of the high-speed train. Our GAN framework employs two connected deep-learning networks. The first network adopts a pix2pix scheme to automatically generate the few-shot data, i.e., obstacles, and our second network aims to detect these objects. In particular, we also use a CARAFE module to get a faster response. We conduct experiments and compare our GAN with a few benchmarks on real-world data. The results are that our GAN significantly outperforms the standard YOLO results in the accuracy of detecting objects. In our work, we apply pix2pix [1], which is a kind of GAN with some revision on the network architecture. It gets a great lift for TL detection by equipping GAN datasets, especially regarding decision rate and accuracy, and the average improvement of detection rate in red TLs, green TLs, and obstacles is 22.19%, 13.17%, and 152.97% with GAN modules, respectively. The results show that our GAN framework significantly outperforms the standard deep learning network (without GAN) regarding the accuracy of detecting obstacles.

*Keywords:* GAN, railway, detection, signal

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# Artificial intelligence techniques to detect rail defects from ultrasonic and eddy current data for automated railway infrastructure monitoring and maintenance

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*Abstract* In recent years, rail transportation has become one of the most important modes of travel. As the total number of passengers increases, how to ensure safe railway operation has become a dominant issue that has attracted public attention. Accidents and severe damage can occur if the faults on the tracks are not repaired [1]. Artificial intelligence has been advancing railway maintenance and monitoring tasks for the last few years. One promising application of AI in this domain is the detection of railway defects using ultrasonic and eddy current data [2]. Cur-rent methodologies for rail defect analysis are traditional methods based on visual inspection from video and images from cameras and different sensors like eddy-current and ultrasonic sensors separately [3] [4]. Therefore, this research aims to develop a well-structured efficient deep-learning method for detecting railway defects from ultrasonic and eddy current data together. The ultrasonic and eddy current data will be used in this research which contains information from 16 ET probes, 8 UT Probes, and the local reference from both rails. Ultra-sonic testing utilizes high-frequency sound waves to detect and locate internal defects in railway components whereas eddy current testing is a non-contact technique that uses electromagnetic fields to detect surface cracks and other defects in railway components [5]. The methodology includes data processing, labelling, and using conventional neural networks to develop the model. The key findings from this research will be the well-established model that can identify the rail defect from both ultrasonic and eddy current sensor data together in different scenarios and longitude, which can improve automated railway infrastructure monitoring and maintenance by applying these methods to defect identification.

*Keywords:* Rail defects, Ultrasonic sensor, Eddy current sensor, CNN

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**Machine learning approach for railway wheel impact load alert prediction for highly imbalanced data**

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*Abstract* In this paper, we present a regression and classification approach to the problem provided by the organizers of INFORMS, Railway Application Section, Problem Solving Competition 2017. The problem is to predict whether the force exerted by the wheel on the rail track is beyond the given threshold value, when a currently empty rail car would be loaded in the next trip. In the regression approach, we predict the value of peak force exerted by wheel and label the result as 1 if the predicted peak force is greater than the threshold value else 0. The false positives values obtained using this approach are very high for multiple regressors used. Higher false positive rate adversely impacts model reliability and acceptance among the practitioners. It also results in loss of time and money for the users. Thus, instead of predicting the value of peak force, we predict whether the peak force exerted by wheels is above the threshold value (label 1) or not (label 0) by labeling the input data output as o and 1. As the resultant input data is highly imbalanced, we apply Cost Sensitive learning techniques and various sampling techniques like Random Oversampling, Random Undersampling, Synthetic Minority Oversampling Technique (SMOTE) to reduce the false positive rate using multiple classifiers. The standards steps like filtering, pre-sampling, cross validation and hyper parameter tuning are used to improve the results. Random Forest classifier with SMOTE turned out to be the best among all classifiers with accuracy of 91.73%, false negative rate of 13.88% and false positive rate of 8.24%. Compared to the respective values of 85.2%, 0.7% and 72.4% for best regressor (XGBoost) and 94.47%, 29.87% and 5.4% for best classifier (Random Forest) without cost sensitive learning.

*Keywords:* Wheel Impact Load Detectors, kips, classification, cost sensitive learning, SMOTE

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**Artificial Intelligence for Railway Track Geometry Fault Detection and Prediction**

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*Abstract* Railway engineers must be able to identify and predict track problems to ensure safe train operations. Track geometry is a key aspect. Routine inspections with Track Recording Vehicles are costly. A popular research question is whether unattended systems on board in-service trains may reduce costs by relying on few low-cost off-the-shelf sensors. Vertical rail irregularity detection may be achieved by a smart use of accelerometers only. Lateral irregularities (rail alignment) are harder to detect. The Assets4Rail project contributed by demonstrating the measurement of the lateral displacement of the wheel in relation to the rail (LDWR) through Computer Vision. As a follow-up, two ongoing research projects address the use of Artificial Intelligence (AI) for the detection and prediction of track irregularities, alignment in particular. In the "detection project", simulation results for both straight and curved track sections were utilised to train and evaluate a supervised machine-learning model for alignment detection. The best models were regression ones, particularly Random Forest. LDWR was shown to be a more important feature in detection than lateral axlebox acceleration. The results suggested: a) further experimental tests with LDWR and alternative detection methods; b) the investigation of future accuracy versus frequency scenarios for in-service measurements to achieve lower-cost detection and prediction; c) a logical follow-up in a second "prediction project" exploring the use of AI to improve predictions of irregularity evolution. In this paper, the findings of the "detection project" are summarised and logically connected to a "prediction project" description developed within the Italian Centre for Sustainable Mobility (MOST). The novel accuracy/frequency scenarios are presented on the basis of, respectively, the findings of the "detection project" and operational assumptions related to different rail service types (high-speed, regional, metro etc.).

*Keywords:* Track geometry, Alignment measurement, on-board sensor systems, Artificial Intelligence, Predictive maintenance

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**From Roads to Rails: Bridging the Gap in Signal Recognition Through Computer Vision for Railway Systems**

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*Abstract* In this paper, we present a comprehensive review of traffic signal recognition through computer vision (CV) and its potential applications within the railway domain. This methodology is well-established in the automotive industry (i.e., self-driving cars) [1] where several specific methods have been developed [2], but little is written on signal recognition for autonomous trains or as Advanced Driver Assistance Systems (ADAS) for railways [3][4]. The objective of this study is to examine the state-of-the-art of CV techniques, the challenges, and possible solutions for accurate and efficient signal detection and classification; and how these techniques can be incorporated into the railway sector. In this study we discuss the importance of signal recognition in ensuring the safety, efficiency, and reliability of semi-supervised and autonomous railway operations. We analyse the key components of CV systems utilized for signal recognition in terms of their suitability for railway signal detection. The points of discussion include: physical components, such as image sensors, cameras, LIDAR and others present in the literature; the different methodologies employed for signal preprocessing (e.g. noise reduction, image enhancement, and image segmentation techniques); feature extraction methodologies (both traditional and deep learning-based approaches); classification algorithms employed for recognizing railway signals (including support vector machines, random forests, convolutional neural networks, and recurrent neural networks among others). Finally, we explore the advantages and challenges of utilizing these existing technologies for signal recognition in railway environments. Some points of discussion include the potential benefits of incorporating artificial vision techniques, and how these technologies can be integrated with the existing railway infrastructure and onboard systems, all of which are discussed in detail within this review.

*Keywords:* signal recognition, railways, autonomous railways, computer vision, ADAS

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# Plenary Lecture
# Chair: Nikola Bešinovic

## Hybrid algorithms for train shunting and servicing at railway hubs

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*Abstract* To support trains executing the railway timetable, they need to be cleaned, undergo security checks, and be parked in an order that matches their departures according to the timetable. When shunting yards are nearing their capacity, deciding on the order of these activities becomes so computationally challenging that state-of-the-art mixed-integer linear programming solvers fail to produce solutions for average-sized railway hubs. In this talk a number of alternative models and algorithms are explored to address this computational challenge, inspired from successes with for example search algorithms, decision diagrams, multi-agent path planning, and pebble motion. Underlying this is a more general lesson about what to include in a model, what to decide upon later, and how to make such modeling decisions.

# Workshop AI4RAILS
# Scheduling & rescheduling
### Chair: Zhiyuan Lin

## Modelling and Efficient Two-stage Optimization of Metro Timetable Rescheduling and Passenger Flow Control Strategy after Random Line Disruption

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*Abstract* When a metro system is affected by power failure, medical emergencies, and weather/natural disasters, this can cause delays or even paralyze all trains, while passengers quickly gather at stations. In order to minimise deviations from the original timetable and waiting times for passengers outside the station, this paper proposes a joint optimisation method for train rescheduling and passenger flow control in the case of partial disruptions to the metro line. In the model, dynamic equations are described for the evolution of train stopping times and the number of passengers on the platform for each train. Train services use different recovery actions such as cancellations, short turns, alternate train directions, etc. and manage the number of entering passengers by controlling the speed at which they enter the station. In addition, a novel two-stage disruption management control method is designed to improve computational efficiency. In the first stage, a Sup-port Vector Machine (SVM) is used to process the dataset generated by the disruption simulation prior to rescheduling control, inputting in-formation about the environment of random line disruptions to predict the optimal train control strategy. In the second stage, the original MILP problem is solved by fixing some binary variables according to the solution of the

first stage. The method simplifies the process of evaluating and searching for potentially optimal solutions, and existing commercial solution software can provide feasible control operations for lines and stations within an efficient calculation time. Finally, numerical experiments based on real data from the Xi'an Metro are conducted to validate the effectiveness of our method. The proposed two-stage approach meets the real-time requirements and reduces the number of stranded passengers on the platform and the waiting time for passengers outside the station, compared to using only heuristic algorithms or commercial solving software.

*Keywords:* Urban rail transit, Disruption, Rescheduling, Passenger flow control, SVM

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## A Train Rescheduling Approach based on Deep Q-network and Supervised Learning

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*Abstract* Train rescheduling has been viewed as an extremely difficult and challenging problem due to its complicated factors to be considered and ambiguous adjustment target. We introduce a new approach to dis-patch trains that applies deep neural networks based on supervised learning and reinforcement learning. The deep networks are first trained by supervised learning from human train dispatchers' operation record with features selected to describe railway static, time-series, and spatiotemporal order. After the training period of imitating human operation, networks obtain certain dispatching prior knowledge and can make appropriate dispatching decisions like experienced dispatchers according to current state of the railway system when disturbance occurs. In order to further improve the quality of dispatching decision, the networks are then trained by reinforcement learning from outcomes of itself adjustments where the reward function makes a trade-off between different objectives of dispatching goals, such as minimizing total train delay, increased delay and passenger delay. In practice, it is to convert and embed the pre-trained networks into the framework of deep q-network so as to improve the efficiency of experience reply mechanism, which makes up for the inherent defects of reinforcement learning at the early period of learning process. Our method makes a combination between process oriented rescheduling and result oriented rescheduling, which is superior to the conventional method, and it expects to make high-quality rescheduling decisions in real-time railway traffic management.

*Keywords:* train rescheduling, deep q-network, deep neural network

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# A Reinforcement Learning Approach to Solving Very Short-Term Train Rescheduling Problems in Railway Network

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*Abstract* The operation of a railway system could be complicated due to various unexpected hazards such as technical failures, bad weather, high passenger volume, etc. which may disrupt the entire system [1][2]. When the railway system is unable to recover from these disturbances through its designed resilience, it becomes necessary to adjust the operational timetable [3]. This paper focuses on the Very Short Term Rescheduling (VSTR) problem, which involves the rescheduling of trains due to emergency engineering activities occurring 24 to 48 hours before the timetable being executed [4]. The authors propose a novel Q-learning algorithm to solve the VSTR problem in a large-scale rail-way network, taking into account the disruptive impact of hazards. The algorithm interacts with a simplified virtual railway environment in meso-scopic level and uses an infrastructure-oriented agent-modelling approach to organize intelligent agents according to the physical layout of rail tracks around stations and junctions. Computational experiments were conducted to test the performance of the proposed Q-learning algorithm on a British rail network, which demonstrated its ability to overcome the limitations of existing approaches and enable better scalability.[1]

*Keywords:* Reinforcement learning, Q learning, Train rescheduling, Very short term rescheduling

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## Reinforcement Learning Based Robust Railway Timetabling to Resolve Robustness Vulnerabilities

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*Abstract* Railway timetables have an important role in efficient and punctual railway operations. In particular, the robustness of the timetable has a direct impact on the traffic's punctuality. To evaluate the robustness of a timetable, simulation is commonly used. A simulation study may indicate that some trains are too sensitive against minor delays, which may lead to that they fall out of their planned channel of operations (defined by their surrounding trains). We define this as robustness vulnerabilities of the timetable. The work explores reinforcement learning (RL) as a method to resolve timetable robustness vulnerabilities. We formulate a RL-based model for the robust railway timetabling problem and will explore different RL algorithms and compare with time-tables generated using optimization-based methods from our previous work [1, 2]. The models are evaluated using microscopic RailSys simulation for the traffic in the westbound direction of the Swedish Western Main Line. The results are expected to provide better support for robust railway timetabling in practice.

*Keywords:* Scheduling, Robust timetabling, Railroad, Reinforcement learning, Punctuality, Simulation, Train timetabling

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**A consensus algorithm for decentralised real-time railway traffic management**

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*Abstract* The real-time Railway Traffic Management Problem (rtRTMP) involves the efficient management of train movements while minimising the propagation of delay caused by unexpected events. In contrast with most of the optimization algorithms available in the literature [1], the SORTEDMOBILITY project [2] proposes a decentralised approach in which trains are intelligent agents able to self-organise by means of a consensus process. This is an iterative procedure through which the agents progressively converge to an agreement on the best traffic management strategy without any central control. In this work, we describe and assess the algorithm at the core of SORTEDMOBILITY that we have designed being inspired by the literature on consensus processes in multi-agent systems [3-4]. In the proposed approach, each agent formulates hypotheses (HPs) of traffic evolution and assigns them a utility value. The HPs formulated by two distinct agents can be compatible or not. Our algorithm starts with the agents selecting their HP with the highest utility. At each iteration, agents can decide either to retain their current HP or to switch to another one in their set. They aim to select the HP with the highest utility while being compatible with the HPs currently selected by all neighbours. When this compatibility is achieved by all the agents or a maximum number of iterations is reached, the algorithm stops. The achievement of consensus corresponds to a solution of the rtRTMP, as the HPs represent actionable plans to solve traffic perturbations. To evaluate the performance of the consensus algorithm, we run ex-periments on a large dataset describing abstract rtRTMP instances. We compare the consensus solutions against the optimal ones, computed through a centralised approach based on linear integer programming. Consensus converges to the optimum in about 80% of the cases and to a near-optimum around 18% of the times, proving it can deal with complex—although abstract—rtRTMP instances.

*Keywords:* railway traffic management, consensus algorithm, optimization

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# Workshop AI4RAILS
# Control, autonomous driving and traffic/passenger management
### Chair: Zhengliang Ma

## Research on Simulation and Prediction of Passenger Flow in Multi-agent Regional Rail Transit Based on Machine Learning

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*Abstract* Chinese metropolises are building multi-layer rail transit net-works[1] to satisfy the rapid growth of passenger travel demand. Here, the multi-layer rail transit network includes the high-speed railway net-work, the intercity railway network, the regional railway network, and the metro network, among which the regional railway network is in the beginning stage of construction, while the other three have existed and performed well in providing services to passengers. To optimize the line planning of new regional railway lines, it is important to know the passenger demand of the new lines in advance, and to understand the impact of the new lines on the existing railway networks. This study firstly builds a passenger demand prediction method to predict the passenger demand of new regional lines. Multi-source data[2], i.e. the historical passenger travel data and Google API data, are collected. A machine learning method[3] is built to predict the passenger demand of the new regional lines. Then, a simulation platform is developed to simulate the train and passenger movements within the multi-layer network (including new lines). The simulation is developed based on the multi-agent simulation[4] framework, in which each train and passenger is represented by an agent, so that their different characteristics (different trains have different line plans, timetables; different passengers have different origin/destination stations, transfer stations, travel behaviours, etc.) are simulated. The simulation platform is used to verify the proposed passenger demand prediction method, and to analyse the impact of new lines on the passenger flow of existing railway networks.

*Keywords:* multi-agent simulation, machine learning, passenger flow forecasting

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# Use of Hybrid Methods for the Enhancement of Real-Time Railway Traffic Control (Dispatching)

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*Abstract* The execution of scheduled railway operations is characterized by continuous monitoring and systematic adjustment of the existing schedule to the occurrence of stochastic events. The adjustment of the schedule can be referred to as the "Conflict Detection & Conflict Resolution" (CDCR) process. Caused by propagating conflicts between plan adjustments and the initially planned schedule, CDCR is a highly complex process. Due to complexity, a series of decision-support tools mostly relying on heuristic methods have been developed to assist dispatchers in real-time. This article aims to identify strategic enhancement potentials for improving existing schedule adjustment approach-es by integrating different methods (e.g., machine learning methods). A decomposition method is utilized to identify the processes during schedule adjustment that could benefit from applying hybrid methodologies, resulting in a much more efficient and effective search space exploration. At the outset, the processes of generating a set of conflict resolution alternatives and selecting the best-fitting alternative to the actual operating situation have been early identified as potential processes that would benefit from incorporating hybrid methods (e.g., machine learning and heuristic methods). This study utilizes an actual decision-support tool applied within a real scenario to derive concrete evidence regarding the extent to which hybrid methods can be integrated and used to solve complex problems within the real-time adjustment of railway schedules by means of their actual implementation in an existing process. The knowledge and experience gained from the experimental research, acting as a proof of concept, are then translated into general guidelines for further use in improving existing approach-es used in decision-support tools for the CDCR.

*Keywords:* Rescheduling, Schedule Adjustment, Conflict-Detection, Conflict-Resolution, Machine Learning, Heuristic Methods

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# Digitale Schiene Deutschland develops an AI-based capacity and traffic management system using Deep Reinforcement Learning

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*Abstract* The sector initiative Digitale Schiene Deutschland[1] recognizes that digitalization, automation, and artificial intelligence (AI) are crucial in increasing and optimizing the capacity utilization of Germany's 33,000 km rail network. Planning and controlling more than 40,000 local, long-distance, and freight train journeys a day on this network in an automated way poses large-scale optimization problems that need to be solved in short time.

Within Digitale Schiene Deutschland, a Capacity & Traffic Manage-ment System (CTMS) is developed that creates together with further new technologies second-by-second schedules for train movements and infrastructure control. A prototype CTMS is based on Multi-Agent Reinforcement Learning (MARL), where train agents interact with a realistic railway simulation. The simulation environment was designed to represent the future digitalized railway system.

The MARL-based CTMS prototype has shown promising results in creating microscopic timetables and effectively responding to disturb-ances in simulated operational scenarios on sections of the German railway network. To successfully deploy this technology, fundamental challenges need to be addressed: (1) the system must be scalable to the entire German rail network. (2) The system must be able to handle the complexity and variability of real-world conditions. The first challenge is inherently addressed by the MARL approach that combines local decision making with joint global optimization goals. The second chal-lenge relates to the genuine problem of generalization. In conclusion, the MARL approach has demonstrated its potential to become a game changer for crucial functions of railway planning and control.

*Keywords:* Traffic Management System (TMS), Multi-Agent Reinforcement Learning, Deep Reinforcement Learning

*References*
[1] `https://digitale-schiene-deutschland.de/en`

## REPNet: Railway Environment Perception Unified Network

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*Abstract* Environment monitoring of a train is very complex perception tasks to model and a to embed. It is a combination of several artificial intelligence well-known challenges such as object detection of static (level crossing, railway elements, etc.) and dynamic elements (pedestrians, animals, cars, etc.), semantic segmentation (railway tracks, ballast areas, railway area delimitations), classification (presence of anomalies, weather, area type, etc.) and several more depending on the complexity of the target system and the train's operating environment. While most neural networks approaches are composed of an encoderdecoder to solve one of these challenges, we propose a unified deep neural network that outputs multiple predictions based on a single image input. It is composed of a robust feature extractor based on a transformer network to form a robust latent space of features. These feature maps feed multiple independent prediction heads composed of task-dependant neural network. We propose RailNet, a network of 3 prediction tasks: box/class prediction, pixel-wise lane segmentation and weather classification trained with a railway panoptic driving dataset-keeping in mind that more prediction tasks are being added to the overall network. Such an architecture allows an end-to-end training of multiple models and take computational advantages of a single heavy backbone. To improve training performances, we also introduce a unique averaged loss function for each decoder network. For results analysis purposes, an ablation study of each prediction head and combinations of them was made. The unified RailNet model with 3 prediction tasks achieves 86.2 mean Average Precision for object detection, 72.1 mean Intersection over Union for railway lane and ballasts zone segmentation, and 94.11% Recall for weather classification. The overall model scales up to 113 million parameters, which makes the inference run at 18.47 Hz on a Quadro RTX 8000 GPU.

*Keywords:* Deep Neural Networks, Multi-task Learning, Autonomous Driving, Railway Environment

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## xDeepChoice: A fully Interpretable Deep Choice Model for Interactive Attributes

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*Abstract* Although deep learning-based choice models have demonstrated superior accuracy, they have faced criticism for their lack of interpretability when compared to the conventional multinomial logit (MNL) model. In response, this paper presents a novel deep learning-based choice modeling framework that addresses this concern. The proposed framework preserves the interpretability of the MNL models while incorporating attribute interactions through a neural Choquet integral structure. By maintaining full differentiability as a deep learning network, the proposed model enhances interpretability, which is typically diminished in deep learning frameworks. The proposed model is evaluated on a real-world transportation mode choice dataset. The results demonstrate that the model performs on par with existing deep learning-based choice models while significantly outperforming the MNL model. Furthermore, the proposed model effectively uncovers both the individual influence of each attribute on choice behavior (as the MNL model does) and the collective impact resulting from the interactions among attributes, which exemplifies the model's remarkable interpretability.

*Keywords:* deep learning, discrete choice model, model explainability

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# Healthcare Management
## Chair: Raffaele Cerulli

### Designing reconfigurable solutions for the Kidney Exchange Problem

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*Abstract* For people suffering from kidney failure, receiving a transplant increases the possibility of living a longer and healthier life without needing dialysis. Although patients often come with willing living donors, they frequently have incompatible blood or tissue types, which actually prohibit the transplants. In this scenario, kidney paired donation programs, organized in many countries, seek to arrange feasible transplants among pools of incompatible recipient-donor pairs, by having them exchange donors. The underlying optimization problem, known as Kidney Exchange Problem (Biro et al., 2021), consists of identifying the most suitable set of disjoint cycles, of bounded length, in a directed graph, whose nodes and arcs represent recipient-donor pairs and compatibilities, respectively. Taking into account eventual cancellations and the associated consequences is crucial while planning transplants. Indeed, if some of the matched pairs no longer participate in the program, part of the affected transplants may still be rearranged, according to specific recourse policies (Carvalho et al., 2021). In this talk, we discuss recourse policies applicable upon the occurrence of post-decision failures, with a focus on the internal re-arrangement of the failed cycles. In particular, we introduce the notion of reconfigurability and devise a method, based on integer linear programming, to identify reconfigurable solutions. Computational experiments are performed to assess how the obtained solutions differ from those yielded by the state-of-the-art strategies.

*Keywords:* Kidney Exchange Problem, Reconfigurability, Integer Linear Programming

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## A Parallel ALNS for a multi-objective multi-actor nurse routing problem including fairness

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*Abstract* The healthcare industry faces a significant challenge in balancing the diverse goals of various stakeholders, including nurses, patients, and territorial centers responsible for providing assistance services. In this work, we address this challenge in the context of home healthcare by formulating and solving it as a multi-objective problem. We consider one objective for each stakeholder, building on extensive analysis conducted in [1], and solve the problem assuming these objectives are hierarchically ordered. For nurses and patients, we consider several objective functions related to fairness. To handle large-scale instances, we propose a parallel Adaptive Large Neighborhood Search (pALNS) algorithm with customized destroy and repair operators for multi-objective multi-actor problems. Additionally, we introduce a matheuristic as an improvement procedure to further enhance the performance of the algorithm. A distinctive feature of pALNS is its ability to identify, given an objective for each stakeholder, the best solution for all possible hierarchical orders of such objectives. Our results demonstrate that the proposed approach outperforms a commercial Mixed Integer Programming solver in terms of efficiency and effectiveness.

*Keywords:* nurse routing, parallel alns, multi-objective multi-actor optimization

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**Clinical Decision Support System and Situation Awareness: Fuzzy Map and Machine Learning**

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*Abstract* The diagnostic process can be a daunting task for clinicians due to the vast amount of information they must process. This information overload can also lead to information tunnelling [1], where clinicians may focus on a specific set of data, inadvertently overlooking crucial details that could affect the diagnosis, leading to adverse patient outcomes. To tackle these challenges, we propose a clinical decision support system (CDSS) based on situation awareness (SA) that integrates both data-driven and goal-driven approaches [2]. This hybrid CDSS combines fuzzy map methods and machine learning algorithms to produce a more accurate diagnostic process. By taking into account various clinical variables and their levels of uncertainty, the system generates a comprehensive representation of the patient's condition that is less susceptible to information tunnelling. Recognizing the patient's situation is essential because it enables clinicians to make informed decisions that are tailored to each individual's unique characteristics. The machine learning algorithms in the proposed CDSS analyze and classify this patient representation, identifying possible diagnostic paths and recommendations [3]. One of the main advantages of the hybrid data-driven and goal-driven CDSS is its ability to heighten clinicians' awareness of the patient's condition and potential solutions. The integrated recommendation system presents the doctor with a range of options, empowering them to make more informed and deliberate decisions compared to a clinician who does not utilize the system with the recommendation module enabled.

*Keywords:* clinical decision support system, situation awareness, artificial intelligence

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# Vehicle Routing I
## Chair: Renata Mansini

### Strengthened Integer Programming Formulations for the Fleet Quickest Routing Problem on Grids

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*Abstract* This paper is concerned with the problem of finding collisionfree, nonstop Manhattan paths for a set of vehicles that move on a grid, each from a node on the bottom row to the top of the destination column; in particular, we are interested in minimising the number of rows that allow such routing. This problem is known as the Fleet Quickest Routing Problem on Grids. We propose an Integer Linear Programming formulation, introduce some valid inequalities and present a reduced-size model, based on the analysis of vehicle movements on the grid. Computational tests, performed on random benchmarks, show the impact of inequalities on the proposed formulation and that reducing the size of the formulation results in better performances for some classes of instances.

*Keywords:* Collision-free routing, Grid graphs, Integer Linear Programming, Valid inequalities

**Optimizing a multi-period election logistics problem with time-dependent profits**

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*Abstract* Designing an effective election campaign plan for a political party is a challenging and multi-faceted task. The process involves coordinating various stakeholders to create a routing and scheduling plan for the party representatives. We study a new variant of the recently introduced Roaming Salesman Problem (RSP) (see [1]), where a predefined number of political representatives need to visit a set of cities during a planning horizon to maximize collected rewards (profits) while complying with strict time and budget constraints. A city yields a reward when a representative holds an activity on it. Moreover, a location can host multiple activities and can be included in the reward collection of one or more representatives. In the case of a city hosting multiple activities, the associated rewards are time-dependent and vary based on the day of the event and the recency of previous activities. Daily visits do not have a predefined structure, so on the same day, it is possible to have open tours (starting and ending locations do not coincide) for some representatives and closed ones for others. We define a compact Mixed Integer Linear Programming (MILP) formulation for the problem complemented with effective valid inequalities. Since commercial solvers can obtain optimal solutions only for small-sized instances, we develop a Learning-based Granular Variable Neighborhood Search able to provide high-quality solutions in a short amount of CPU time, even for real-world instances. The adaptive nature allows the algorithm to dynamically adjust the neighborhood structure based on the progress of the search, leading to increased efficiency and effectiveness. Valuable managerial insights into critical aspects of election logistics are also provided.

*Keywords:* Multiple roaming salesman problem, Time-dependent profits, Granular Variable Neighborhood Search, Election logistics

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## A Generalized Close-Enough Traveling Salesman Problem for RFID Meter Reading

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*Abstract* The close enough travelling salesman problem (CETSP)[1,2] is a variation of the classic travelling salesman problem (TSP), where the salesman does not need to visit every city exactly but only needs to get close enough to it. The closeness of a city is measured by a threshold distance that is given for each city. The goal is to find the shortest tour that satisfies the closeness requirement for all cities. The CETSP has practical applications in scenarios where the exact location of the destinations is not important and where the cost of getting close enough is lower than the cost of visiting them precisely. One such scenario is the RFID meter reading, where a vehicle equipped with an RFID reader (usually a drone) has to collect data from a set of meters that have RFID tags. In this work, we introduce a new variant of the CETSP specifically designed to address the problem of reading RFID meters. We present a generalization of the CETSP that can account more accurately for the position of the meters to be read and the power of their signal. The main contribution of the work is to define the problem and study some theoretical properties. Additionally, in this work, using a model of second-order cone programming, a method capable of solving the problem is proposed. The algorithm developed will be tested on multiple test instances explicitly created.

*Keywords:* Close-enough TSP, Conic programming, RFID meter reading

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## A New Matheuristic Column Generation Approach for the Multi Vehicle Inventory Routing Problem

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*Abstract* The Multi Vehicle Inventory Routing Problem (MIRP) considers an integrated system in which a supplier must satisfy deterministic demands of a set of customers over a finite and discrete time horizon. A limited inventory capacity is available at the customers and a deterministic amount of product is available at the supplier in each period to fulfill the customer demands with a homogeneous fleet of vehicles. The supplier decides when to re-supply the customers, the quantities of product to deliver and the routes to serve the customers. The aim is to find the best supplying policy minimizing the total inventory and routing cost, while ensuring that no stock-out occurs at the customers and the vehicle capacity is respected. MIRP attracted much attentions in the last decades due to its wide applicability to different fields in which both inventory and routing aspects are dealt with together (see [1], for a survey on inventory routing problems). In our work, we develop a matheuristic algorithm based on a mathematical formulation where we associate a variable with each route and period. The size of this set of variables is clearly exponential; so, we devise a column generation approach in which we heuristically generate part of these variables within an iterated local search procedure. At each iteration of the algorithm, we alternate a first phase in which new variables are generated and some old variables are deactivated, and a second phase in which the model is solved by means of a general-purpose solver. Once a local optimum is reached, we call an auxiliary procedure enlarging the set of columns, so as to find a new starting solution. We compare our approach with the state-of-the-art algorithm proposed in [2] on the benchmark instances introduced in [3] and [4]. The analysis of computational results proves that our algorithm outperforms the method proposed in [2] on most of the considered classes of instances, and it updates the value of the best known solution in several cases.

*Keywords:* Inventory-routing, Column generation, Matheuristic

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# Large Scale Optimization
**Chair: Laura Palagi**

## On the use of the SYMMBK algorithm for computing negative curvature directions within Newton-Krylov methods for large scale optimization

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*Abstract* In this paper, we consider the issue of computing negative curvature directions, for nonconvex functions, within Newton-Krylov methods for large scale unconstrained optimization. This issue has been widely investigated in the literature, and different approaches have been proposed. We focus on the well known SYMMBK method proposed for solving large scale symmetric possibly indefinite linear systems [1, 2, 3, 4], and show how to exploit it to yield an effective negative curvature direction. The distinguishing feature of our proposal is that the computation of such negative curvature direction is iteratively carried out, without storing no more than a couple of additional vectors. The results of a preliminary numerical experience are reported showing the reliability of the novel approach we propose.

*Keywords:* Large scale unconstrained optimization, Newton-Krylov methods, Negative curvature directions, Second order critical points

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## Forecasting and modeling the dynamics of large-scale energy networks under the supply and demand balance constraint

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*Abstract* With the emergence of "Big Data" the analysis of large data sets of high-dimensional energy time series in network structures have become feasible. However, building large-scale data-driven and computationally efficient models to accurately capture the underlying spatial and temporal dynamics and forecast the multivariate time series data remains a great challenge. Additional constraints make the problem more challenging to solve with conventional methods. For example, to ensure the security of supply, energy networks require the demand and supply to be balanced. This paper introduces a novel large-scale Hierarchical Network Regression model with Relaxed Balance constraint (HNR-RB) to investigate the network dynamics and predict multistep-ahead flows in the natural gas transmission network, where the total in- and out-flows of the network have to be balanced over a period of time. We concurrently address three main challenges: high dimensionality of networks with more than 100 nodes, unknown network dynamics, and constraint of balanced supply and demand in the network. The effectiveness of the proposed model is demonstrated through a real-world case study of forecasting demand and supply in a large-scale natural gas transmission network. The results demonstrate that HNR-RB outperforms alternative models for short- and mid-term horizons.

*Keywords:* Energy forecasting, Dynamic network modeling, Mathematical optimization

## Block Decomposition Minibatch Algorithms for large-scale nonconvex finite sum optimization

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*Abstract* We consider minimizing the sum of a large number of smooth and possibly non-convex functions, which is a typical problem encountered when training deep neural networks on huge datasets. By drawing inspiration from the Controlled Minibatch Algorithm (CMA) scheme proposed by Liuzzi et al. (2022), we first define mini-batch algorithmic schemes, which embed a random reshuffling gradient method in an ease controlling scheme based on watchdog techniques and derivative free line search. We derive a method that requires seldom computation of the objective function. which is needed only when light watchdog rules are not satisfied. Convergence still holds under mild and standard assumptions. We further embed the mini-batch scheme in the block variable decomposition framework originally proposed by Palagi et al. (2021) for the Incremental Gradient method when applied to deep Neural networks that present a natural decomposition among layers' weights. We perform numerical testing on different deep networks architectures on large datasets. The tests are showing promising results in terms of efficiency, with respect to state-of-the-art optimization methods for ML, in particular when dealing with ultra-deep architectures.

*Keywords:* mini batch gradient algorithms, decompostion algorithms, non convex optimization

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# Invited Session
# Combinatorial Optimization Problems in Maritime and Multimodal Logistics
### Chair: Anna Sciomachen

## A new classification schema for literature reviews on the applications of machine learning and optimization methods in maritime terminals: a focus on the seaside area

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*Abstract* Maritime terminals play a crucial role in the supply chain networks, transporting containerized cargo from sea to hinterland and vice versa. With the impact of naval gigantism, maritime terminals have experienced a significant increase in daily throughput, resulting in new challenges to enhance operational efficiency. There is a necessity for updated reviews on new methods applied to maritime terminal operations. The idea of this paper is to furnish a new classification schema for organizing literature reviews on machine learning and optimization applied to maritime terminals. An example of the proposed schema for revising papers related to operations performed in the seaside area of a terminal is presented.

*Keywords:* literature review, machine learning, operations research, port terminal, seaside area

## Energy consumption and operational performance in container ports

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*Abstract* As an interface of maritime shipping and land transportation, container ports play an important role in the global supply chain. Although the maritime industry has experienced decades of sustained growth of throughput and overall expansion, energy management has not become a particularly urgent issue until recently. The energy consumption in container ports accounts for a significant proportion in the maritime shipping sector and contributes to air quality, human health and climate change problems at local, regional and global levels. Port operations highly involve energy-intensive activities and play a vital part in developing a reliable, sustainable and resilient infrastructure that can support future economic development. Research to date has mainly focused on the understanding of the energy consumption and emissions in the land transportation and developed frameworks to improve energy utilisation ([1], [2], [3]). There are limited attempts at energy-saving perspectives on port operations at macro level, such as green port policy, green management practice, impact and evaluation of carbon dioxide emissions ([4]). Research at operational level remains scarce. Container movement in the ports involves different types of handling equipment, such as quay cranes, yard cranes, straddle carriers, reach stackers, etc, all of which greatly contributes the energy consumption in ports. This research examines the integrated scheduling problem of the handling equipment and yard space allocation with the consideration of energy consumption during container handling process. The energy consumed in different stages of processes is investigated, including loaded and unloaded travelling and waiting, which is incorporated into optimisation analysis and the trade-off between operational efficiency and energy consumption.

*Keywords:* container operations, energy consumption, container port

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## A scheduling model for the gate appointment problem in an Italian port

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*Abstract* In recent years, container terminals in ports worldwide are facing complex logistical challenges due to the rapid expansion of global trade [1]. One major challenge is handling an increasing volume of freight. To address this, many terminals have implemented advanced technology and optimized their operations to reduce congestion.

Due to such rapid growth, the terminal managers deal with problems related to the high volume of road transport involved in the transfer of containers. Therefore, to avoid congestion, it is crucial to optimize the movements of trucks that perform pickup and delivery operations. To address this, many terminals have implemented truck appointment systems (TASs) to help coordinate external truck flows and optimizing their schedules [2][3].

In the "TIRS-UIP - Transizione Industriale e Resilienza delle Società post Covid-19 - Urban Intelligence over Ports" project, we studied the terminal operations of the Italian port of La Spezia. More in detail, we focused on the scheduling of the external trucks into the container terminal. Currently, there is no predetermined schedule for the arrival of trucks and the consequent congestion inside the port during the peak arrival/departure times is transmitted to the external parking area, and, consequently, to the surrounding neighbourhoods. The aim of this study is to determine the optimal truck schedule in order to mitigate the congestion and minimize the maximum turnaround times in the container terminal. To address this problem, we propose a two phase approach: the first one regards the offline appointment schedule, so as to match the planned schedule for container pickup and delivery time windows with the preferences of the truck companies. In the second phase, a scheduling problem is solved, to take into account the possible deviations from the planned schedule of truck arrivals and container availability. For both problems, an ILP model is proposed and

computational tests are performed.

*Keywords:* Traffic port management, Scheduling, Truck appointment System

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# A mathematical programming shortest path framework for multimodal sustainable logistics cooperation

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*Abstract* The aim of the proposed research project is to develop an integrated framework to be used in the novel paradigm of cooperative logistics that provides support to supply chains moving towards the Sustainable Development Goals expressed by the United Nations 2030 Agenda [1]. The present work proposes an efficient mathematical programming model and solution procedures associated with it aimed at providing support to fill the current lack of cooperation among shippers and logistics service providers to reach effective freight movements through the optimal use of transportation modes by increasing the performance, cargo consolidation, and asset sharing. The design of the model is based on finding the shortest routes in a multimodal freight transportation environment with multiple possible minimization goals [2]. Instances of case studies are translated and parameterized for a Mixed Integer Linear Programming Model (MILP) and then solved by CPLEX. The results of extensive computational experimentation related to different origin-destination multimodal routes are presented and thoroughly discussed to highlight the advantages and the correctness of the proposed model and related solution method.

*Keywords:* Multimodal Logistic Networks, Environmental Sustainability, Shortest Paths, Mixed Integer Linear Programming

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## The liner shipping stowage planning problem: analysis of a MIP model and matheuristic based approaches

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*Abstract* Determining the stowage plan for each port included in the circular route of a containership is a planning problem that the Ship Coordinator (SC) of a line faces every day [1]. In particular, SC has to establish where to stow a given set of containers in order to load the transport demand, satisfy some structural and operational constraints and minimize the ship berthing time. The time spent by the ship in the ports is minimized if the defined stowage plan avoids re-handles, balances the workload of the quayside cranes working in parallel and reduces the opening/closing of the hatches needed to move the containers to/from the hold. This problem has been defined in the literature as Master Planning (MP) [2] or Multi Port Master Bay Planning Problem (MP-MBPP) [3, 4]. To face this problem, we propose a new Mixed Integer Programming formulation (MIP), which includes accurate stability conditions. Standard, reefer, open top and high cube containers are considered. Successively, we analyse matheuristic approaches based on the proposed formulation that are customized to take into account specific aspects of the problem at hand. In particular, we consider a matheuristic that iterates the solution of partially fixed MIP models, performing in this way a randomized large neighbourhood search. In addition, we analyse alternative strategies for applying the kernel search (KS) method [5] to the problem. The proposed MIP model has been used to solve a real multiport planning problems for a 4500 TEUs containership. Moreover, the same instances have been solved thanks to the proposed heuristic approaches. A deeper experimental campaign has been performed on randomly generated instances, assuming three ships of different size (7800, 10000 and 18000 TEU).

*Keywords:* Containership stowage planning, Mixed integer programming, Matheuristics

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## Operations-time-space network for modelling Port Rail Shunting Scheduling Problems

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*Abstract* The modal switch between maritime and rail transportation occurs in the rail-sea yard within the port area, where trains are transferred from the railway network and the maritime terminals and vice versa [1]. The manager operating in the rail-sea yard, the so-called shunting manager, has to define the schedule of all activities necessary for transferring trains from the railway network station to the terminals and vice versa, respecting the time limits imposed by the railway network schedule and by the ships one, and the limits due to the finite resources available in the port area. This problem, known as the Port Rail Shunting Scheduling Problem (PRSSP), has been modelled thanks to an operations-time-space network representing the rail station and the terminals (either the origin or the destination of the trains) and the operations that might be performed on the trains in each zone of the port [2]. This work describes how it is possible to use this operations-time-space network to model port areas characterized by different infrastructures and different capacity constraints. Some focus on specificities of real port systems in Italy are shown. The PRSSP has been solved thanks to different methods: besides a mathematical model, two heuristic approaches based on a constructive heuristic combined with a local search and a simulated annealing have been tested. Preliminary results are reported.

*Keywords:* Port Rail Scheduling, Network flow model, Heuristic approach

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# Data Analysis and Imaging

**Chair: Claudio Sterle**

## 3D-Printing Impacts on Türkiye's Defense Industry: An Implementation of SWOT and DEMATEL Methods

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*Abstract* Nation-states have many reasons to produce armaments, but traditionally the strongest motivation has been classically realist and security-oriented: the need to provide for a secure source of military materiel necessary to deter threats and to defend one's national territory [1]. One of the most important expectations is that the defence industry, like every other sector, should make maximum use of domestic technology for establishing an independent national defence. Supporting national defence with imported defence systems has many limitations and risks because the terms of arms trade agreements between countries may easily be influenced by the political climate of the signatories [2]. 3D printing as an emerging technology is widely used in many sectors including maritime, aero-space, and automotive. It should come as no surprise then, that it is also being increasingly adopted by the defence sector worldwide [3]. However, how this adaptation will be achieved is directly related to the deficiencies, current situation and expectations of the sector. In this regard, this study focuses on the effects of 3D printing technology on Türkiye's defence industry. For this purpose, a three-stage methodology was followed. In the first stage, the positive and negative effects of 3D printers on the defence industry were determined by analysing the literature and consulting experts in the sector. In the second stage, the SWOT analysis of Türkiye's defence industry was examined utilising the annual strategic reports of the relevant ministry (The Ministry of National Defence of Türkiye). In the last stage, the effects of 3D printers on the outputs obtained at the end of SWOT were prioritised and impact analysis was carried out with the DEMATEL approach [4]. The opinions needed during the study were obtained from defence industry companies in Türkiye such as ASELSAN, ROKETSAN and TEI and academicians working in this field.

*Keywords:* Defence industry, 3D printing, SWOT, DEMATEL

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## On the Bayes risk induced by alternative design priors for sample size choice

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*Abstract* In a decision-theoretic framework, criteria for selecting the optimal sample size for an experiment can be based on the Bayes risk of a decision function, i.e. the expected value of the risk function with respect to a prior distribution that describes a design scenario. In the presence of uncertainty on such scenario, an entire class of parametric distributions can be taken into account. The resulting robust optimal sample size is the one yielding a sufficiently small value for the largest risk over the class. In this article we illustrate this robust sample size determination approach for a one-sided testing problem on a normal mean, that is the typical set-up of a superiority clinical trial with continuous endpoints.

*Keywords:* clinical trials, decision theory, robustness, testing

## An Efficient Approach for Pancreas Segmentation in Computer Tomography Scans

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*Abstract* Pancreatic cancer presents a significant challenge in detection and treatment, with a shallow five-year survival rate. The small size and variable shape of the pancreas make it challenging to identify the presence of cancer in its early stages. To address this problem, we propose a novel method for the semantic segmentation of the pancreas in Computer Tomography (CT) scans, utilizing Convolutional Neural Networks (CNNs). Our approach involves training an encoder-decoder neural network to segment precisely the pancreas in CT images. We conducted experiments on

a publicly available dataset, achieving results comparable to state-of-the-art methods based on the average Dice score. Furthermore, we evaluated the impact of different backbone models, providing valuable insights for future optimization. Our findings demonstrate that our approach effectively segments the pancreas in CT scans, potentially improving early detection and treatment planning for pancreatic cancer. This success validates the necessity of developing computer-aided diagnosis tools based on deep learning methods for pancreatic cancer, which are essential to enhancing patient outcomes. In summary, our work provides a solid foundation for developing computer-aided diagnosis tools for pancreatic cancer. Using CNNs for semantic segmentation of the pancreas in CT scans is a promising approach that could significantly improve the early detection and treatment of this deadly disease.

*Keywords:* pancreas segmentation, Convolutional Neural Network, clinical decision support

# Invited Session
# Stream AIRO thematic section on Stochastic Programming
# Stochastic Optimization in Energy, Green Logistics and Finance
**Chair: Patrizia Beraldi**

## The Online Inventory Routing Problem

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*Abstract* In real-time fleet management, input is unknown and revealed incrementally during the design or execution of the vehicle plans (routes). Consequently, the plans are defined in an ongoing fashion. The applications require a significant investment in Information and Communication Technology (ICT) infrastructures. Many important problems must be solved in real-time. Among them, [1] cite the inventory routing problem (IRP), i.e., the delivery problem tackled within the Vendor-Managed Inventory (VMI) systems. More specifically, an IRP is a combinatorial optimization problem arising in situations where customers transfer the responsibility for inventory replenishment to the vendor. Then, the vendor must decide when to visit each customer over a specified time horizon, how much to deliver and how to sequence customers in one or more routes. Here we deal with a multi-vehicle IRP in which a fleet of vehicles has to serve real-time (or online) requests, i.e., demands which are revealed over time and unpredictable accurately in advance. In the following we refer to this variant as Online Inventory Routing Problem (O-IRP). The O-IRP can be encountered in emergency settings, like in the blood supply chain where a collection center monitors the demands at hospitals and determines the optimal distribution scheme.

For the O-IRP we propose an online optimization approach that makes decisions without full knowledge of the problem instance.

Several authors deal with IRPs where real-time information comes from specific ICT infrastructures. For instance, in the study of [2], a mobile device, internet of ve-

hicle, and Google Map are integrated into an online module to handle the real traffic situation and immediate customer requests. However, to the best of our knowledge, online optimization approaches to IRPs are missing in the scientific literature. The definition of online optimization algorithms with a specified competitive ratio represents our main contribution.

*Keywords:* Inventory routing problem, real time demands, online algorithms

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## A Metaheuristic for the Logistics Capacity Planning Problem with Supplier Selection Under Uncertainty

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*Abstract* A shipper must secure contracts with suppliers offering transport capacity to ship items for its customers in the next operation season (e.g., six, or twelve months). Making such a plan is a crucial task in city logistics and long-haul transport, and in both contexts, the plan is defined before operations start when some data is not available yet. Demand can only be estimated, and suppliers may fail to provide the contracted capacity. The shipper can buy additional capacity in the spot market for a higher cost when it discovers that the contracted capacity is not enough to fulfill all demand. We model this setting by a two-stage stochastic programming formulation for what we defined as the Logistics Capacity Planning Problem with Supplier Selection Under Uncertainty. First-stage decisions regard the selection of contracts with suppliers and the number of bins to secure from them. Second-stage decisions comprise capacity acquisition from the spot market and the item-to-bin assignment during operations. We propose a metaheuristic based on the Adaptive Large Neighborhood Search (ALNS), a Destroy and Rebuild (D&R) heuristic inspired by [2] and [3], and the Progressive Hedging (PH) algorithm [4]. The basic idea is to aggregate the bin offers of each supplier in a meta bin, i.e., a unit comprising all bins of the same type of supplier. Starting from an initial solution the metaheuristic alternates an ALNS with intensification and diversification phases in which a subset of the selected meta bins is removed, and other meta bins are added at each iteration. Different destroy and rebuild policies determine which meta bins to remove and which to add in each phase of the metaheuristic. Solutions are computed with a PH variant of [4] that solves the bin packing problem resulting from considering only the selected meta bins. We present computation results showing the efficiency of our metaheuristic compared to that of a commercial solver and some managerial insights.

*Keywords:* Logistics capacity planning, Stochastic programming, Adaptive Large Neighborhood Search, Progressive Hedging

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## Multistage stochastic dominance: an application to pension fund management

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*Abstract* A pension fund manager typically decides the allocation of the pension fund assets looking for a long-term sustainability. Many Asset and Liability Management models in the form of multistage stochastic programming problem have been proposed to help the pension fund manager to define the optimal allocation given a multi-objective function. The recent literature proposes univariate stochastic dominance constraints to guarantee that the optimal strategy is able to stochastically dominate a benchmark portfolio. In this work we extend previous results (i) considering alternative types of multivariate stochastic dominance that appear more suitable in a multistage framework, (ii) proposing a way to measure the economic cost of introducing stochastic dominance constraints, (iii) proposing a sort of augmented stochastic dominance through a safety margin. Numerical results show the difference between the alternative ways to interpret and apply the multivariate stochastic dominance. These results are evaluated thanks to the proposed economic cost of the stochastic dominance constraints and either in presence or not of a safety margin.

*Keywords:* Stochastic programming, Stochastic dominance, Portfolio selection, Sensitivity analysis, Asset and Liability Management, Pension fund

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**The congested partial set covering location problem with uncertain customer demand**

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*Abstract* Congestion, arising from a sudden increase in the demand of users assigned to a service facility, impacts the performance and efficiency of many communication and service networks. We study the congested facility location problem with partial coverage under the assumption of uncertain customer demand. By seeking a more balanced solution, we can prevent facilities from being overloaded, thereby minimizing diseconomies of scale and ensuring better resource allocation. In the deterministic problem setting, congestion at facilities is typically modeled by a convex quadratic term in the objective function [1,2], so that the resulting problem is a mixed-integer convex quadratic program which can be reformulated using perspective constraints. To ensure a reliable and efficient network design that is robust against demand fluctuations, we treat data-uncertainty through the concept of Γ-robustness as introduced in [3]. First, we present a perspective reformulation of the congested facility location with Γ-robustness, which enables us to reformulate the problem as a mixed-integer second-order cone program. Then, we propose to solve the resulting model using a Benders decomposition approach. We highlight the advantages and disadvantages of the two proposed approaches through experiments on (adapted) instances from existing literature.

*Keywords:* Congested facility location; Robust optimization; Benders decomposition; Perspective reformulation

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## Optimal participation of wind power generators in continuous intraday markets

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*Abstract* The structure of electricity markets in Europe is immersed in a transformation process to efficiently integrate a large amount of stochastic renewable energy. Flexible mechanisms, in terms of both hardware and market rules, are required to ensure the economic, technical and environmental sustainability of electric energy systems. Short-term markets such as intraday markets are a clue for wind and solar photovoltaic producers since the prediction of their power generation is more trustable just a few hours ahead of the actual energy supply. In this work, we tackle the problem of a wind power generator that participates in the continuous intraday market, taking into account the uncertainty of the wind power availability and the probability of acceptance of its offers in the continuous market. Specifically, a multistage stochastic programming problem is proposed to determine the optimal energy bids in different trading periods previous to the delivery period, so that the deviation between the energy offered and the actual generation is as low as possible. The model is tested with real data from the Spanish power system. The scenarios of wind power, electricity prices, and probability of acceptance of energy offers in the continuous intraday market have been generated using historical data of the Spanish market.

*Keywords:* continuous intraday market, stochastic programming, wind power generation

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**Green Electricity Retailer: A stochastic Bi Level Approach for the Optimal Sizing of a Renewable-Based Energy System**

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*Abstract* The presentation discusses a bi-level approach designed to support retailers in making investment decisions regarding renewable-based systems for clean electricity generation to sell to potentially affiliated end-users. The proposed model considers the strategic nature of the problem and combines capacity sizing decisions for installed technologies along with pricing decisions regarding electricity tariffs. The interaction between the retailer and end-users is modelled using a Stackelberg game framework. The retailer acting as a leader decides first by setting electricity tariffs. The follower reacts to the communicated prices by establishing the best procurement plan in terms of amount of electricity to purchase from the retailer and from competitors so to minimize the electricity bill. The follower's reaction to the prices is fed back to the retailer and impacts the actual profit which is computed as difference between the revenue generated from selling electricity and the total cost of investment, operation and management. To address the uncertainty in wholesale energy prices, renewable resource availability, and electricity requests, the upper-level problem is formulated as a two-stage stochastic programming model. First-stage decisions refer to the sizing of installed technologies and electricity tariffs, whereas second stage decisions refer to the operation and management of the designed system. The model also integrates a safety measure, namely the Conditional Value at Risk, to control the average profit that can be achieved in a given percentage of worst case situations, so as to provide a contingency against unforeseen changes in market conditions, renewable resource availability and/or electricity demand. A tailored approach that exploits the specific problem structure is designed to solve the proposed formulation and widely tested on a realistic case study. The numerical results demonstrate the efficiency of the proposed approach and validate the significance of explicitly dealing with the uncertainty and the importance of incorporating a safety measure.

*Keywords:* Electricity retailer, Bi-level optimization, Stochastic programming

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# Invited Session
# Health Care Planning
## Chair: Elena Tanfani/Giuliana Carello

### Multi-Neighborhood Simulated Annealing for Nurse Rostering

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*Abstract* We consider the Nurse Rostering problem, in the real-world formulation proposed by Curtois and Qu (2014). For this formulation, we propose a local search approach based on a combination of four neighborhoods guided by a Simulated Annealing metaheuristic, and we test it on the publicly available dataset. This research is still ongoing and the preliminary results show that we are able to obtain results in line with the state-of-the-art ones on a few instances (notably the largest ones), but currently fail to reach the optimal solutions.

*Keywords:* Nurse Rostering, Workforce Scheduling, Simulated Annealing, Local Search

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## A linear programming model to evaluate the Covid-19 vaccination campaign in Italy

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*Abstract* Coronavirus pandemic is probably the most challenging crisis ever that the entire world has to face globally. At April 26, 2023, the cumulative number of confirmed cases are more than 764 millions in the entire World, 248 in Europe, and 25 in Italy [1]. A global vaccination campaign started from the beginning of January 2021. At April 26, 2023, 70% of the world population has received at least one dose of a COVID-19 vaccine [1], the 86.2% in Italy, the 75.1% and 70.2% in EU and Europe, respectively. Only the 29.7% in low income countries. In our talk we present a linear programming model to evaluate the vaccination campaign in Italy exploiting the available institutional open data [2]. Our model is capable to consider the different policies adopted in Italy in accordance with the different authorizations (both in time horizon and age groups) for each available vaccine. Our model is based on the hub&spoke organisational model adopted in Italy in which the spokes are the 19 regions and the 2 autonomous provinces. It considers an unlimited number of boosters after completing the first vaccination cycle, and recovered people that uses less doses. The objective is to maximize the number of vaccinated people by age group, giving priority to older and less vaccinated ones. The interesting and original feature of our model is to embed the vaccinations tendency of the realized campaign in Italy in order to replicate the real inoculation curve of the first vaccination cycle. Thus, we modelled a mechanism that is capable of slowing down the vaccination rate in one age group once the number of people vaccinated in that age group reached a certain threshold. We discuss how to validate the model on the actual scenario deriving also some insights on the applied policies, and other scenarios obtained varying the distribution rules and the different vaccination rates per region in such a way to evaluate their impact both at the national and regional level.

*Keywords:* Healthcare, Linear Programming, Covid-19

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## Use of Machine Learning techniques in predicting the course of relapsing-remitting MS in individual patients

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*Abstract* The course of multiple sclerosis (MS) is highly variable, ranging from nearly benign to highly disabling. The disease usually evolves over 10 to 20 years from a relapsing remitting form (RR-MS) to a secondary progressive form (SP-MS), with little or no response to therapies. Based on the promising results obtained from recent studies using machine learning (ML) algorithms to predict the course of multiple sclerosis (MS), we aim to derive a robust and accurate prognostic tool to personalize the treatment of the disease and reduce the associated social and economic costs. From data in the Italian National Registry (NR), we intend to use ML methods such as Random Forest, XG Boost and Support Vector Machine, as well as data mining techniques, to analyze clinical data and identify models that can predict progression from relapsing-remitting (RR) to secondary progressive (SP) form of MS over a clinically meaningful time interval (720 days). In this first phase we will present preliminary results that will serve as benchmarks for later use of more sophisticated techniques.[2]

*Keywords:* Multiple Sclerosis, Machine Learning, prediction

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## Multi-phase scheduling of 3D-printed devices for medicine

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*Abstract* 3D-printed anatomical models and medical devices for medical use support surgery planning, surgeons' training, and other important activities [1,2,3]. Nowadays, outsourced companies supply 3D-printed devices to hospitals, while only a few services have been in-sourced within the hospital worldwide. However, this configuration will be exploited more and more in the future because it involves physicians more directly in the process, thus reducing production times and costs.

Efficient additive manufacturing organizations require solving combinatorial optimization problems [4,5]. In particular, properly managing in-hospital 3D factories is a complex task, due to the requirements to be considered when scheduling the operations. Typically, an order for a 3D-printed device involves four production phases: two pre-processing phases (segmentation of the patient-specific medical images and design of the device), the 3D printing itself, and a post-processing phase (cleaning and finishing). Furthermore, each order requires a specific set of materials on the printer and changing materials could be wasteful (expensive) and time-consuming.

We developed a multi-phase scheduler suited for in-hospital 3D factories to maximize production and minimize its cost. This scheduler considers the production of devices with different due dates, priorities, activities' duration, and material consumption. Although the main purpose is the selection of orders to be executed, the same production can lead to different material consumption, depending on the assignment of orders to printers and their sequencing.

To this aim, we introduce a hierarchical multiobjective integer linear programming model and a matheuristic approach able to solve the multi-phase scheduling problem for real-size instances. The effectiveness of the proposed method is demonstrated through a computational analysis using real instances from the 3D4Med Clinical 3D Printing Laboratory of IRCCS Policlinico San Matteo, Pavia, Italy.

*Keywords:* 3D printing, additive manufacturing, multi-phase scheduling, matheuristics

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**The Location, dimensioning and districting problem of Community Houses in Lombardy, Italy**

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*Abstract* Community Houses (CHs) are new entities in the Italian Healthcare Service, envisaged to provide proximity care to citizens. CHs are part of the Italian National Recovery and Resilience Plan, within the NextGenerationEU scheme [1]. In this work, we focus on the location, districting, and dimensioning of CHs in Lombardy, Italy. We propose a tool that provides a systematic approach to their planning. It is based on a Mixed Integer Linear Programming (MILP) model that considers various factors such as demand, accessibility, and equity to identify the optimal location, dimensioning, and districting of CHs. The tool uses a data-driven approach that leverages on information on healthcare service provision, enriched with demographic and geographic data. The tool is meant to provide stakeholders with a decision-support platform, enabling them to understand the trade-offs between different options and make informed decisions. The tool was tested on real data from a representative area, the Province of Brescia. It was chosen because it spans a variety of typically Italian environments, including urban, rural, and alpine ones. The results validated the adequacy of the proposed approach.

*Keywords:* Community Health Care, Facility location and dimensioning, Health care systems

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## A two-objective simulation-based optimization approach for the ambulance diversion problem in an Emergency Department network

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*Abstract* We focus on a strategy that can be adopted by Emergency Departments (EDs) aiming at obtaining an improvement of the services provided: the so-called Ambulance Diversion (AD). It can be carried out when an ED is overloaded and consists of redirecting incoming by ambulance patients to neighboring (less crowded) EDs. Properly implemented, AD should result in relieving overcrowding and reducing delays of patient treatment, ensuring safety and rescue of life-threatening patients. From an operational point of view, AD corresponds to a resource pooling policy among EDs in a network. We propose a novel model for dealing with AD problem based on the Simulation-based Optimization (SBO) approach. In particular, we formulate it as a bi-objective SBO problem where the target is the minimization of two conflicting objectives: the non-value added time spent by patients (waiting times and possible transportation times due to AD) and overall costs incurred by the ED network. The optimal allocation of resources at each ED of the network is also considered. A discrete event simulation model is used for reproducing the network operation, where each ED is represented by an input-throughput-output simulation model. In order to assess the reliability of the proposed approach, a real case study consisting of six large EDs in the Lazio region of Italy is considered, analyzing the effects of the adoption of different diversion policies.

*Keywords:* Emergency Department overcrowding, Ambulance Diversion, Discrete Event Simulation, Simulation-based Optimization

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## A Benders decomposition approach for planning home blood donations

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*Abstract* The availability of a sufficient blood supply is crucial for ensuring high-quality and fully-functional health services. Unfortunately, blood and its components are highly perishable: this forbids long term conservation and requires continuous donations by unpaid volunteers.

We consider the problem of planning blood donation services, where the donors are reached at home. The scope is to minimize the penalty for the unserved donors, while guaranteeing that a budget constraint is respected and that the preferences of the donors for the appointments are met. The donors availability is subject to uncertainty, which is modeled using a set of scenarios.

A Benders decomposition approach to solve the problem is developed. The proposed algorithm is tested on real-life instances coming from the Milan department of the Associazione Volontari Italiani Sangue (AVIS).

*Keywords:* home blood donations, donors preferences, Benders decomposition, data uncertainty, scenarios

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**Optimal design of a vaccination clinic: the trade-off between costs and QoS**

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*Abstract* Vaccination clinics are an essential tool to fight pandemics and can be set up temporarily in hospitals. Though typically hosted in permanent institutions, they need to be sized for effective use of resources (mainly space and staff) while maintaining an acceptable level of service, embodied by the waiting time for patients. In this paper, we employ an in-house developed simulation tool to size vaccination clinics and show how trade-offs can be achieved in the search for the optimal solution. We analyse two cases of low and high attendance and show that properly implementing batch processing can help reduce staffing levels (namely, the number of nurses) without sacrificing the level of service.

*Keywords:* health, vaccination, clinics, hospitals, pandemics

# Operations Research for Finance, Pricing and Investment Planning

**Chair: Claudio Gambella**

## Italian Retail Fuel Prices Asymmetric Reactions

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*Abstract* Some analyses of the relationship between crude oil and retail fuel prices show asymmetry [1]. It means that output prices (retail fuel prices) react more sensitively to increases in the input price (crude oil prices) than decreases. The oligopolistic coordination theory, the production and inventory cost of adjustment, the search theory [2], and the theory of strategic interactions can explain such asymmetry [4]. However, the results of such research depend on applying different methods, data samples and frequencies [3]. Using a cointegration model, threshold model, and an approach based on linear exponential adjustment cost function employing specification estimates by generalized methods of moments, we checked whether retail Italian fuel prices react to crude oil price changes asymmetrically. The specification of the latter approach allows us to estimate a price bias caused by asymmetries. Our results, too, vary according to the methods used. Firstly, a cointegrating relationship between gasoline and oil prices or between diesel and oil prices was not confirmed. However, adding a trend to these two relationships made it possible to find cointegrating relationships. Likewise, one cointegrating relationship exists between the three prices, even without a trend. Threshold autoregressive models confirm the conclusions obtained from the cointegration model about long-run relationships, and at the same time, no asymmetry was confirmed. Momentum threshold autoregressive models state the same conclusions except for the relationship between gasoline and oil prices, where asymmetry is confirmed in addition to cointegration. According to the latter approach, we confirmed the asymmetries. The corresponding estimated gasoline price bias is €0.246 per 1000 litres, and the diesel price bias is €0.218 per 1000 litres.

*Keywords:* rockets and feathers, asymmetric price transmission, econometric analyses

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## The Effect of Market Power on the Optimal Investment Mix of Green Technologies in Electricity Markets

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*Abstract* To meet carbon reduction targets, there will need to be investment in a range of different green technologies in electricity markets across the world. For instance, investment in wind energy, solar PV, and battery storage. In this work, we consider what the optimal investment mix for these technologies will be from the perspective of both generating firms and consumers. To do so, we develop a game theory optimisation problem where several generating firms maximise their profits while various consumer groups minimise their demand. All players modelled make hourly operational decisions in addition to long-term investment decisions. The generating firms may exert market power. That is, they may strategically choose their generation decisions so as to increase the market price and thus enhance their profits. The model takes the form of a stochastic mixed complementarity problem [1] and is solved using a Benders Decomposition Algorithm [2]. The uncertainty of wind (both onshore and offshore) and solar PV are the sources of the model's stochasticity. We apply the model to a case study of the Irish electricity system in 2030, which is envisaged to have a significant presence of renewable sources. We consider the optimal investment mix when both market power is both present and absent from the market. Previous similar work either neglected investment decisions [3] or market power [4]. We observe that the presence of market power increases electricity prices which leads to increased generating firms' profits and consumer costs. It also leads to increased investment in renewable technologies and battery storage, which leads to reduced carbon emissions. Furthermore, we consider the effect a Feed-in-Premium (FiP) has on renewable investment and observe a counter-intuitive result whereby the absence of a FiP leads to less investment in renewables from generation companies but, consequently, increased investment in renewables from consumers.

*Keywords:* Green Technologies, Game Theory Optimisation, Market Power

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**FICO Decision Optimizer - Generating predictive models with Action Effect**

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*Abstract* The FICO Decision Optimizer (DO) application [1] is an optimization software package to perform optimal assignment of treatments to a portfolio of customers. DO leverages various optimization algorithms with the goal to empower non-OR professionals with a tool that creates and solves Generalized Assignment Problems. DO considers different kinds of constraints (budget, ratio, . . . ) and allows users to generate highly interpretable decision trees. The DO optimization models depend on structural inputs (values known with certainty, like the composition of the portfolio or customer attributes) and uncertain inputs (predictable target values, such as the impact of treatments on customers). While the DO interface makes it possible to use and edit the predictive models required to produce the uncertain data, developing these Predictive Causal Models [2] usually requires additional tools and knowledge for the Business Analyst. Furthermore, there is inherent historical data bias, because the historical actions are likely to be targeted on certain segments, consequently there may be significant data gaps for some actions. To simplify the user experience, we developed a 2-step Action Effect (AE) approach to predict the impact of the treatment assignment on every customer of the portfolio. We will present the logic behind the quadratic programming models that are solved to create the predictive models. We conclude our presentation with a discussion about the advantages of this methodology over standard unconstrained linear regression [3].

*Keywords:* Finance; Predictive Models; Regression Models

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# Invited Session
# OPTSM – Intelligent Public Transport Management
### Chair: Bisheng He

### Energy-efficient High-speed Train Driving – A Quadratically Constrained Linear Programming-based method

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*Abstract* Among the many challenges which must be faced during the daily operation of high-speed rail, the management of the neutral zones in the catenary during unexpected disturbances remains underinvestigated. This study proposes an energy-efficient method for the Automatic Train Operation of a high-speed train with regenerative braking for passing neutral zones under disturbance. For the first time, different mechanism-based Automatic Passing Neutral Zone systems, including the Magnetic Induction System and Automatic Train Protection, are analysed and modelled as location-based and time-based constraints, respectively. The motion constraints caused by disturbances are described by time windows. Both forced coasting and air brake-allowed passing neutral zone rules are considered in the models. The original model with location-based constraints is a nonlinear model that is transcribed as a quadratically constrained linear model and then solved. The optimality consistency and its establishment condition between the original and transcribed models are analysed based on the Karush-Kuhn-Tucker conditions. The model with time-

based constraints is novelly transformed into an optimal switching point problem. A high-quality solution is obtained effectively and efficiently by iteratively solving a series of subproblems. Comprehensive experiments are conducted based on practical data from a high-speed rail system in China. The benefit of the proposed method is significant compared to Mixed Integer Linear Programming and Artificial Driving Algorithms. Moreover, the impacts of different mechanism-based automatic passing neutral zone systems, operation rules, and a combination of time window settings are analysed in depth.

*Keywords:* High-speed rail, Energy-efficient driving, Intelligent transport systems, Time window, Neutral zone

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**Demand-driven Railway Network Capacity Assessment using Mixed Integer Programming**

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*Abstract* Precise understanding of the interplay between railway network utilization and the corresponding demands is essential to understand network capacity. Hence, demand-driven railway network capacity assessment proves crucial for strategic network planning in times of expected traffic load increases for the railway system. We present the Mixed Integer Programming (MIP) railway network utilization model (MIP-RNUM) to assess the practical network capacity with regard to given demands. It is based on Petri Nets (PN) and combines the benefits of MIP and PN modelling. The PN modelling allows to assess the network's utilization based on the interdependent processes in the network, and particularly the emerging cycles of those processes. Thus, critical process cycles are identified which determine the network utilization.

The developed MIP-RNUM computes the maximum utilization, i.e. practical network capacity, of a certain operational demand scenario (i.e. line plan, transfers and vehicle rotations) in a network. For better model scalability at large and complex instances, we use a row generation solution approach to consider the decisive set of critical process cycles only. The model performance is demonstrated on several instances from the Dutch railway network. The results show the applicability of the MIP-RNUM for network capacity assessment of real-life instances. As such, the MIP-RNUM provides a comprehensive, applicable and extendable solution to the capacity assessment of large and complex railway networks. It thus contributes to the recent efforts to strengthen the railway share in the modal split of European transport.

*Keywords:* Railway Network Capacity, Demand, MIP, Row Generation.

## Flexible routing and resource allocations in rail freight yards

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*Abstract* An increased share of rail freight offers a considerable reduction in greenhouse gas emissions, necessary to align with the future climate goals. The capacity of rail yards need to be considered within the consolidation of rail-based logistics. In particular, scheduling of shunting operations is of particular importance for and directly impacts yard capacity [1, 2]. Freight cars have to be shunted through a yard as efficiently as possible, where their paths depend on manual decisions in consecutive planning stages. Block movements in yards are described in consecutive planning stages by a set of recurring operation chains and expected yard workloads are determined accordingly. However, a more flexible approach to block operation chains is called for, especially in sidings and industrial spurs [3].

In this paper, we introduce a new flexible routing and resource-scheduling model (FRRS) for rail yards. Block process chains [4] are aggregated as paths and can vary depending on yard type, available resources and customer requirements. We consider several available path possibilities for blocks of cars through a yard. The FRRS model minimizes the infrastructure capacity utilization within the yard and provides the most advantageous operation sequence of train processing. Using practical test cases, we test the proposed model against a variety of realistic instances. The research will support planners of yards in decision making on block routings, leading to solutions transcending planning methods based on predefined operation chains.

*Keywords:* Scheduling, Rail Freight, Industrial Railway

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## Optimizing Tram Timetabling for Tramway Network with Signal Coordination at Intersections

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*Abstract* Many cities have constructed tramway network as part of urban public transportation system to alleviate urban congestion and improve efficiency. Tram timetables could reduce the total travel time and boost service levels by determining the arrival and departure times of trams at along stations and intersections, coordinating the relationship with signal lights. Recently, many studies related to the tram timetabling problem only consider a single tramway line and the intersection signals with one phase, which is not suitable for network with multiple lines and signal phases. Tram running conflicts at intersections in actual operations, including approach reservation time and switching time of turnouts, should be concerned due to the network operation.

We propose a novel mixed-integer linear programming model for the tram timetabling problem considering microscopic signalized intersections. The model incorporates a passive signal priority for trams and aims to minimize the total tram travel time, tramway line makespan and negative impact on social vehicles. We introduce the sub-route as a decision variable in the route selection process allowing for dynamic choices on how to pass intersections based on traffic conditions and signal phases. The micro-cells with reservation and release times at intersections are considered together with the time-related constraints, safety regulations and maximum headway. A rolling horizon algorithm is applied to solve our model.

Our model and algorithm are applied to a planned tramway network and satisfy the requirement of network operation. The effectiveness of sub-route is proved through

a comparison of the setting of no-stop, must-stop and stop flexibly via sub-routes. The result shows that the micro-intersections greatly reduce the total travel time and negative impact. Finally, the sensitivity of the maximum headway on the service lines is analysed.

*Keywords:* tram, timetable, tramway network, passive signal priority

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# Invited Session
# OR 4 – Urban Intelligence
### Chair: Giovanni Felici

## Integrating AI and Operations Research to achieve Sustainable Pricing in Urban Logistics and Services

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*Abstract* In production, logistics, and service systems within urban environments, shared resources are often used to serve multiple clients. To ensure business sustainability and profitability in these urban logistics and services, it is crucial to optimize resource allocation over all clients, maintaining competitiveness without reducing net margin and being robust to uncertainties [1]. Recognizing the potential of integrating Artificial Intelligence (AI) into decision-making processes for better business management [2], we propose a framework to enable competitive and sustainable pricing that integrates an operations research (OR) model for optimal resource allocation with a learning model able to estimate the cost of serving a client based on its unique characteristics, and on how it is served together with all other clients. This approach involves solving multiple instances of an OR problem, allocating to each client a fair portion of the overall service cost [3,4], and training a machine learning model that predicts the cost of serving each client based on its characteristics, such as geographical location, delivery time window, and service time in the context of a Vehicle Routing Problem. The aim of this model is to allow vendors to promptly forecast the cost of serving clients, enabling fair and competitive pricing while ensuring business sustainability and profitability.

We assess the validity of this framework with real-world instances of a pick-up and delivery routing problem for reverse logistics (RL) operations. Additionally, we propose a new formulation of a routing problem in RL and a strategy to fairly allocate costs to clients in a reasonable computational time, promoting sustainable pricing practices in urban logistics and services.

*Keywords:* Waste management, machine learning, decision support system

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## From the uncertainty set to the solution and back

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*Abstract* So far, robust optimization have focused on computing solutions resilient to data uncertainty, given an uncertainty set representing the possible realizations of this uncertainty.

In real-life problems it may happen that the lifetime of the implemented solution may be very long, making any estimation used to define the uncertainty set outdated after some time. Moreover, some unexpected phenomena may occur, deeply changing the considered system.

Therefore, we are interested in answering the following question: once a solution of a problem is given, which is the largest uncertainty set that this solution can support? We investigate the complexity of answering the above question, using the cardinality constrained uncertainty model.

*Keywords:* robust optimization, cardinality constrained uncertainty, data uncertainty, computing the uncertainty set

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**Orienteering with classes of PoIs and concave time dependent profits: an application to urban tourist visits**

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*Abstract* Orienteering problems are among the most studied problems in logistics and service engineering [4]. In this work we analyse a specific application to tourist visits of cities, where we take into account "ad hoc" features for the points of interests as well as personal requests of the users. More precisely, in the studied case, tourists want to schedule visits among points of interest of given typology and collect profits following a not decreasing concave utility function. This function models fatigue, which decreases the marginal profit during the visiting time. The formulation considers time windows, a partition of the set of nodes into typology clusters, and scores that depend on the duration of the visit. Moreover, for each cluster, the user can select a minimum and a maximum desired number of points of interest to be visited.

The orienteering problem and its team variant, with time dependent profits, have only recently been studied. In the literature, they are addressed both with exact and approximate approaches [3,5]. In our work, we compare novel approaches based on perspective reformulation [1] and on matheuristics [2], both in synthetic and real case instances. In particular, differently by [3], we propose the use of perspective cuts instead of tangent bounds. A matheuristic based on large neighbourhood search is also developed and compared. Moreover, we describe the application settings where the solution approach is used in an urban intelligence framework, exploited in two cities of Italy.

*Keywods:* orienteering, perspective cuts, matheuristics

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## Optimal Placement of Nature Based Solutions in Urban Greening

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*Abstract* The optimal placement of green areas has become an increasingly important topic in urban planning, as green spaces are recognized for their numerous benefits, including improved air quality, reduced heat island effect, and several positive externalities [1]. In this context, we propose a method for maximizing these benefits through the strategic location of different types of greening such as trees, parks and green walls in urban areas [2, 3]. The impact of greening is estimated over the neighbourhood. We demonstrate the effectiveness of our approach through a case study, where we show significant improvements in terms of all considered environmental effects, including social well-being.

*Keywords:* Greening, Urban Intelligence, Location problems

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## Multi-task learning of convex combinations of forecasting models

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*Abstract* Forecast combination is a popular technique used in the field of time series forecasting, which involves the aggregation of multiple forecasts to produce a single, more accurate one [1]. We propose a multi-task learning methodology based on a deep neural network to automatically learn convex combinations of forecasting methods. Unlike the previous literature, which focuses on obtaining the weights of the base forecasting models by solving either a regression or a classification problem [2], our proposed approach jointly formulates the learning process as a regression and a classification problem. The regression subnetwork aims to learn the weights of the base forecasting methods by minimizing the errors of the combined forecasts, whereas the classification subnetwork selects suitable forecasting methods based on the accuracy and diversity of the ensemble. The overall neural network is trained by optimizing a customized loss function. We empirically demonstrate the effectiveness of our algorithm by testing it on the series of the M4 competition dataset [3].

*Keywords:* forecasting, multi-task learning, neural networks

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# Machine Learning I
**Chair: Gianpaolo Ghiani**

## Reinforcement Learning for Multi-Neighborhood Local Search in Combinatorial Optimization

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*Abstract* In metaheuristics, it is challenging to determine a single best parameter configuration, especially when instances vary considerably in size or problem-specific characteristics, particularly in real-world scenarios. To address this issue in a multi-neighborhood search, we propose the use of reinforcement learning to adjust neighborhood probabilities, focusing on Simulated Annealing as an underlying metaheuristic.

In Simulated Annealing, a move is chosen at random at every iteration, according to probabilities assigned to the neighborhoods. In the traditional setting, these probabilities are determined with an offline tuning procedure and remain unchanged during the search. We assign the same initial probabilities to the neighborhoods, and then, we employ a reinforcement learning strategy at each cooling step to rebalance the weights of the neighborhoods, based on their performance during the last temperature batch. A reward system is used to quantify this performance and assign higher rewards to the neighborhoods contributing the most to improving the objective function. The computational time required for evaluating and performing different moves can vary, however, so neighborhoods consuming more time are penalized, enabling the metaheuristic to adjust its parameter values and to assign higher probabilities to neighborhoods providing better cost-time effectiveness in the specific stage of the search.

To evaluate the effectiveness of our approach, we consider two case studies, namely the examination timetabling problem, proposed by Carter et al. [1], and the sports timetabling problem, from the ITC2021 competition [2]. Both problems have numerous algorithms developed, and multi-neighborhood Simulated Annealing has already achieved state-of-the-art results using offline tuning techniques. Our new Simulated Annealing method, with adaptive multi-neighborhood probabilities, improves upon already competitive results. In addition, it is rather robust with respect to learning hyperparameter configurations, requiring less parameters and much less tuning effort than traditional offline parameter tuning.

*Keywords:* metaheuristics, multi-neighborhood search, reinforcement learning

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**Application of linear algebra in the data mining: a proposal of new matrix decomposition**

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*Abstract* Nowadays in the datafication era, huge amount of data can be collected and then analyzed. Without any loss of generality about the context, large data sets may be analyzed not only by using statistical approach, but may be viewed as large size matrices. The linear algebra approach may be very useful, for example, in the dimensionality reduction, with the advantage that all the statistical information is maintained in the dataset. In this work, a new decomposition for any matrices is presented. Given the interesting characteristics of this new decomposition, its use in the data analysis may be certainly very attractive for the analyst. A little application of this new decomposition is also shown.

*Keywords:* big data, dimensionality reduction, matrix decomposition

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## Ensemble aggregation approaches for functional optimization

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*Abstract* In this work we investigate the use of ensemble methods, consisting in the aggregation of several approximating models, in the context of functional optimization. In fact, while ensemble techniques are routinely employed in the machine learning literature for classification and regression, there is little research on their application to general optimization problems. Here we consider two strategies to aggregate different solutions to a functional optimization problem, based on optimized weighted averaging and aggregation over the minimum, the latter also in approximate version. A theoretical analysis of approximate functional optimization in the context of ensemble aggregation is provided. Then, simulation results are reported to showcase the advantages of ensembles for functional optimization, in terms of better accuracy and improved robustness with respect to single solutions.

*Keywords:* functional optimization, ensemble methods

## Railways Accident Report Text Classification using Natural Language Processing

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*Abstract* Efficiently learning from past railway accidents is paramount in the proactive management of railway safety and accident prevention. Historically, dedicated inquiry committees have meticulously analyzed evidence, track measurements, and statements from employees and eyewitnesses, generating extensive text-based accident investigation reports. However, due to a paucity of effective tools for mining and analyzing this valuable textual data, the potential of these reports for guiding preventive strategies has been underutilized. In response to this challenge, we propose a study to compare ML model based on Natural Language Processing (NLP) techniques. Trained on a vast corpus of historical railway accident text data, our study performed an in-depth analysis of these reports, understanding their underlying features, and predicting accident causes and the respective responsible departments. The primary objective of this study is to demonstrate the potential of artificial intelligence in processing and learning from past accident data. We strive to create a unique tool that analyses the outcomes of previous investigations and aids in informed decision-making at policy acceptance levels. Our proposed system, by identifying problem areas, has significant potential to reinforce railway safety management protocols. This innovative use of NLP promises a new frontier in enhancing the safety standards of the railway industry.

*Keywords:* Natural Language Processing, Railway Accident Analysis, Safety Management

## Randomized regression trees: a model variant and a decomposition training algorithm

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*Abstract* Decision trees are widely used for classification and regression tasks arising in a variety of application fields. In [3] Blanquero et al. recently proposed a continuous nonlinear optimization formulation to train multivariate regression trees with a soft decision rule at each branch node, which can account for sparsity and fairness. For any given input vector, the prediction is defined as the summation of the leaf nodes outputs (linear regressions over the input features) weighted by the probability that the input vector falls into the corresponding leaf node. We propose and investigate a variant of the above tree model where, for every input vector, we have a linear prediction for every leaf node with the associated probability, and the actual prediction is given by the leaf node reached by following from the root the branches with the highest probability. Our formulation is well-suited not only to decomposition but also to impose fairness constraints. The decomposition training algorithm we present includes an ad-hoc initialization strategy and a heuristic for the reassignment of the input vectors along the branching nodes of the tree. Under mild assumptions, we also establish asymptotic convergence guarantees. The results obtained on 15 datasets from the UCI and KEEL repositories indicate that our model variant and decomposition algorithm yield trees with higher accuracy than the formulation in [3], and lead to significant speed-up in training time and similar accuracy compared with the discrete optimization approach described by Bertsimas and Dunn in [1,2].

*Keywords:* Machine learning, randomized regression trees, decomposition algorithm

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## Setup time prediction using machine learning algorithms

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*Abstract* In real-world manufacturing environments, setup times (STs) are often affected by various and unpredictable factors, such as crew experience, machine breakdowns, lack of personnel, complex and non-fixed procedures, and so on (see Allahverdi [1]). However, the vast majority of scheduling studies assume STs to be a fixed input that takes a deterministic value, which is normally calculated using simplistic average-based methods that do not fully capture the complexity of reality. Such oversimplification is not capable of reflecting the actual conditions on the ground, and it can lead to the development of inefficient schedules. Indeed, practitioners often cite the lack of uncertainty and dynamic elements in scheduling models as a major obstacle to bridging the gap between scheduling theory and practice (see Sabucuoglu and Goren [5]). To address this gap in the literature, we propose a general-purpose machine learning (ML) framework for predicting STs that can be easily integrated into scheduling algorithms to improve their accuracy. Our framework utilizes the knowledge extraction capability of ML algorithms to identify and select relevant features to enhance the accuracy of ST predictions. In detail, we use ML regression algorithms to predict uncertain STs dependent on machines and job sequences and we apply them on a real-world scheduling application arising in the colour printing industry (see Iori et. al. [1], [2], and [3]). Using a real-world industrial database, we trained several ML models. We began with a broad set of features and refined them by analysing their inter-dependencies and using a feature selection method based on feature importance scores. We conducted extensive computational experiments that demonstrate the effectiveness of our proposed ML framework. The versatility of the proposed approach enables an easy application to similar tasks in a multitude of scheduling scenarios, making the obtained results particularly significant and valuable.

*Keywords:* Uncertain machine-dependent and job sequence-dependent setup times,

Setup time prediction, Machine learning algorithms

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## Training SVMs with a limited number of support vectors

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*Abstract* We consider the problem of training Support Vector Machines with mathematical programs which impose a budget on the number of support vectors composing the final classifier or regressor.

We present motivations and a range of applications for these types of models, comparing some alternative formulations for enforcing such a budget. More in detail, we focus on the Wolfe dual of the training problem. We either enrich its objective function by suitable (nonlinear) penalty terms, keeping only continuous variables, or introduce binary variables, keeping the dual objective function unchanged.

We experiment our models on both synthetic datasets and real-world ones from the literature, discussing the computational impact of introducing budget constraints during training, and the trade-off between parsimony and quality in testing which can be achieved.

*Keywords:* support vector machines, mixed integer programming, Wolfe duality

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## Learned Upper Bounds for the Time-Dependent Travelling Salesman Problem

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*Abstract* Fleet management plays a central role in several application contexts such as distribution planning, mail delivery, garbage collection, salt gritting, field service routing. Since road congestion has a big impact on driving times, fleet management can be enhanced by taking into account data on current traffic conditions. Today, most carriers gather high-quality historical traffic data by using global position system information. These data serve as an input for defining time-dependent travel times, i.e. travel times changing according to traffic conditions throughout the day. Given a fixed-size fleet of vehicles and a graph with arc traversal times varying over time, Time-Dependent Vehicle Routing Problems aim to select the best routes while minimizing the travelling costs. The basic version with only one route is usually referred to as the Time-Dependent Travelling Salesman Problem. The main goal of this work is to define tight upper bounds for this problem by reusing the information gained when solving instances with similar features. This is customary in distribution management, where vehicle routes have to be generated over and over again with similar input data. To this aim, the authors devise an upper bounding technique based on the solution of a classical (and simpler) time-independent Asymmetric Travelling Salesman Problem, where the constant arc costs are suitably defined by the combined use of a Linear Program and a mix of unsupervised and supervised Machine Learning techniques. The effectiveness of this approach has been assessed through a computational campaign on the real travel time functions of two European cities: Paris and London. The overall average gap between the proposed heuristic and the best-known solutions is about 0.001%. For 31 instances, new best solutions have been obtained.

*Keywords:* Travelling Salesman Problem, Time-dependent Vehicle Routing, Machine Learning

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# Invited Session
# OPTSM – Recent Advances in Public Transport and Fair Mobility
### Chair: Valentina Cacchiani

## Multi-day fair collaboration in demand-responsive transportation

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*Abstract* Transportation operations, of people and goods, are well known to be responsible for a large share of the air pollutants. Alongside, technological developments are modifying in different directions the way we move and transport goods. One of these directions aims at reducing the number of kilometres travelled by road vehicles and/or at increasing the used capacity of a vehicle through demand-responsive transportation. In fact, companies that offer demand-responsive transportation services have the opportunity to reduce their costs and increase their revenues through collaboration, while at the same time reducing the environmental impact of their operations (see [1][2] for a comprehensive literature review). In this talk, the case of companies, offering a shared taxi service, that are involved in horizontal collaboration is presented along with mixed integer programming models for the optimization of their daily routes. The goal of the coalition is to optimize the transportation operations in such a way that no company is penalized, in terms of customers served and/or working time. To this aim, models in [3] embed constraints aimed at balancing the workload exchange of each company with others. These balancing constraints bound the workload exchange in terms of travelled time and/or served customers to be less than thresholds agreed in advance by the companies. An optimization model for a multi-day planning horizon will also be presented that includes constraints aimed at guaranteeing a level of fairness to all companies that can be controlled day-by-day and/or over the planning horizon. Finally, an Adaptive Large Neighbourhood Search heuristic is then presented for its solution. The computational experiments show that, although presented models constraint the optimization space, they both (daily and multi-day) still guarantee substantial savings with respect to the non-collaborative setting and can guarantee the sustainability in the long term of the collaboration initiative.

*Keywords:* Combinatorial Optimization, Sustainable Transportation, Dial-a-ride

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## Trends in Passenger Transportations and Modular Buses Optimization

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*Abstract* The growing number and complexity of modern megalopolises pose colossal challenges to urban mobility. Nowadays, transport planners can take advantage of the progress in information technologies and optimisation methods to design modern services that integrate and coordinate different means of transport. We give an overview of recent contributions from the operational research literature on urban passenger transportation, with special emphasis on integrated and coordinated services. The relevant contributions are classified according to the dimensions of flexibility and integration of the transport service studied. For each of the application areas identified, some trends and open research directions emerge [1]. In particular, we focus on the potential advantages of modular buses with respect to fixed-capacity buses. Modular buses are still at a prototypical level (see, e.g., [2]), and the literature on these vehicles is scarce (see, e.g., [3], [4]). We develop an optimization model to minimize the total number of modules flowing in a given network of bus lines. The model assumes that for a set of origin-destination pairs located at the stops of the bus network, a rate of transport demand is given and must be satisfied. Buses are formed by one or more connected identical modules. Modules can be attached/detached at the endpoints of a line and at intersections of lines. Empty modules can be transferred among different endpoints and intersections if needed. The model establishes the rate of departure of modules from each endpoint and intersection along each line and the rate of transfer of empty modules among endpoints and intersections that allow to satisfy the demand of transport using a minimum number of modules. Some preliminary experiments show the validity of the model and the saving in total transport capacity that can be obtained from a modular system with respect to a fixed-capacity system.

*Keywords:* Flexible transport, Modular vehicle, Customized bus

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## A Monte Carlo Tree Search algorithm for train scheduling

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*Abstract* In real time train scheduling (sometimes also called train dispatching) one has to compute a new conflict-free disposition timetable every few seconds based on the current position of all trains. Existing approaches [1] mostly focus on mathematical programming formulations (which tend to be slow but may have guarantees on the quality of the solution) and custom heuristics (which are fast but have no guarantees on the quality of the solution). An algorithmic framework that has received a lot of attention recently (mainly due its application to games like Chess and Go) is Monte Carlo Tree Search (MCTS). This algorithm builds on-the-fly a search-tree of promising decisions based on random sampling and the expected outcome of future decisions. It is mainly used as a heuristic to quickly produce feasible solutions for complex decision problems, but it can also be used to improve these solutions (or even prove optimality) by spending more time exploring the search-tree. Therefore, it perfectly fits the application of train dispatching, where one would want to make sure that a new good solution is available every few seconds (even if not proven optimal) and possibly better solutions can be chased if more time is available. MCTS also fits well with the so-called lazy conflict resolution, a technique used in state-of-the-art train dispatching algorithms that iteratively considers only train conflicts that appear in the incumbent solutions [2]. Here we present a MCTS algorithm that exploits lazy conflict resolution to consider only relevant dispatching decisions, and we compare it with a state-of-the-art exact dispatching algorithm on a busy line in Norway.

*Keywords:* Train scheduling, Mixed-Integer Linear Programming, Monte Carlo Tree Search

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## Metaheuristics for large-scale mixed-fleet multi-terminal electric bus scheduling

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*Abstract* The transportation sector is a significant contributor to CO2 emissions, accounting for 25% of all emissions. To reduce greenhouse gas emissions, the electrification of transportation has gained attention from policy, planning, and research, all working together to achieve sustainable transportation [1]. Public Transport presents a promising market for Electric Vehicle adoption. Following the works presented by Rinaldi et al. [2] and Picarelli et al. [3], this study addresses the Multi-Terminal Mixed-Fleet Electric Bus Scheduling Problem by comparing several heuristics and metaheuristics to tackle scalability issues in urban-sized instances. The study presents two Chain-Trip Builder (CTB) heuristics for generating feasible solutions and two metaheuristics, a Simulated Annealing and a Genetic Algorithm, for implementing local search and improving initial solutions. The objective of the two CTBs is to generate the initial solution by creating chain of trips and events (i.e. deadheading and full charge) for each electric or hybrid bus activated. The Simulated Annealing exploits a move that permutes time windows of trips between two consecutive charging events of the starting solution, while the Genetic Algorithm focuses on the crossover between parent solutions, trying to repair infeasible solutions by using repair rules. The study compares the performance of each metaheuristic using increasing instance sizes from the shuttle network of Luxembourg city, which includes up to 1084 trips, 11 terminals, and full-day services. Results show a significant reduction in operating costs (i.e. cost per mileage and charging costs) and overheads (i.e. fleet size) compared to the benchmark from the Time-Decomposed MILP model proposed by Picarelli et al. Additionally, the study highlights an optimal trade-off in the mixing

of the bus fleet, suggesting that a full-electric fleet could not be the best solution.

*Keywords:* Electric bus, Urban mobility, Fleet management, Simulated annealing, Genetic algorithm

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## Modeling a crowd-shipping service on a public transport system

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*Abstract* The growing popularity of e-commerce and on-demand products has resulted in a significant increase in delivery services. Urban areas are experiencing a surge in last-mile deliveries that negatively impacts on the citizens quality of life by increasing pollution, noise levels, and the risk of accidents. Different measures can be taken to mitigate these negative effects, like encouraging the use of eco-friendly vehicles, implementing delivery time restrictions to reduce traffic congestion during peak hours, establishing delivery hubs outside the city centre to reduce the number of vehicles entering urban areas or promoting new sustainable delivery models such as crowd-shipping. The latter represents an innovative peer-to-peer delivery model that enlists individuals to transport goods during their regular commutes or travel routes [1]. In this paper, we propose a crowd-shipping service integrated into a public transport system (PTS). Every morning parcels are left in selected stations of the PTS's network by a Logistics Service Provider (LSP). Crowd-shippers on their regular journey transfer parcels collecting and dropping them from/to automated lockers having defined capacity and placed at the main stations of the PTS. The problem aims at minimising the total delivery cost incurred by the LSP including the cost paid to crowd-shippers for the transfer service and a backup cost in case parcels are not delivered to their destination while deciding starting and ending station for each parcel and scheduling of the crowd-shippers over time. We introduce a Mixed-Integer Linear Programming model and solve it with a Branch-and-Cut approach. To tackle real-world sized instances, we develop a tailored Adaptive Large Neighborhood Search (ALNS). Interesting managerial insights are also provided.

*Keywords:* Crowd-shipping, Public Transport System, Lockers, Branch-and-Cut, ALNS

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## Train rescheduling after disruptions in a long-distance railway network

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*Abstract* We consider a large-scale long-distance railway network in which a disruption causes the complete blockage of part of the network for a long period. In addition to train reordering and retiming, we evaluate the option of rerouting trains along alternative paths. Although rerouting was not previously employed in large-scale long-distance networks, we show its benefit in reducing passenger delays. We formulate the problem as a Mixed Integer Linear Programming (MILP) model on a space-time network, and propose a heuristic algorithm, based on the Lagrangian relaxation of a subset of constraints in the MILP model. Due to the large number of constraints and to cope with the real-time requirement, the heuristic algorithm employs dynamic constraint-generation. We tested the heuristic algorithm on railway networks of different sizes and on a real-world instance of a railway network in China with 350 trains under several disruption scenarios. The experimental results show that the heuristic algorithm obtains solutions with an average optimality gap of 2.27% in about 300 seconds.

*Keywords:* Real-time train rescheduling, Heuristic algorithm, Lagrangian relaxation

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# Invited Session
# Teaching and Education (TED)
## Chair: Alice Raffaele/Claudio Sterle

### One year of experiences for soft skills development and orientation: PNRR projects and more!

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*Abstract* In the last year, we received many requests for implementing soft skills development and orientation project from high schools operating in the scientific fields and in technological institutes (both informatics, tourism paths). Thanks to PNRR founding, we have the possibility to increase the number of projects to offer in the schools to reduce school dropout, in the high schools and in University courses. A better orientation is one of the key factor for this reduction [1], [2]. This project has been developed within an innovative orientation program supported by UNIGE. The following projects/ideas have been adopted in some Ligurian schools to orient students:

1. A simple way to design a personal future school path: a lot of possibilities from high school to PhD courses describing the work opportunities at the end of each level of education;
2. Applied maths for decision makers in every field: introduction to decision theory, uncertainty, strategies and optimization:
   a. How to use the summer budget for maximizing our satisfaction;
   b. How to design a touristic itinerary to maximise the tourism satisfaction while respecting budget and time constraints: the touristic point of view and the company (i.e. the travel agency) point of view with revenues requirements. Break-even point, utility functions.
3. How to work in group for solving problems:
   a. lab and internships for a project;
   b. the team work presented to high school students;
   c. a comparison among students of different countries - a student conference for orienteering and development of the international interests of our students.

4. OR and applied maths in high school programs: teachers need to better know the maths starting competences required at different university courses. Teacher orientation for student orientation!

These ideas will be described in more details.

*Keywords:* Student Orientation, teacher orientation, school dropout

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## Optimizing food donation delivery for nonprofit company Logica&Co

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*Abstract* The case addresses a (realistic) non-linear integer problem based on nonprofit company management issues. The aim is to define a suitable plan for picking up and delivering food donations from local businesses to soup kitchens in the forthcoming semester. The framework includes tasks for the warehouses' location identification and the riders' and volunteers' management. The target is to maximize the sum of soup kitchens' savings (seen as profits) and the investors' donations, minus the necessary transportation costs. The case has been presented as a competition for students of the Bachelor's program in Management Engineering at Sapienza University of Rome (e.g. [1], [2] and [3] adopted similar approaches).

*Keywords:* group project; active learning; integer programming

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## Teaching OR before University: the ROAR Experience (Part III)

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*Abstract* Ricerca Operativa Applicazioni Reali (ROAR, i.e., Real Applications of Operations Research) is a three-year learning path for secondary school students whose aim is to increase awareness of Operations Research and interest in mathematics. The experimentation of ROAR was carried out from Spring 2021 to Winter 2023 at the scientific high school IIS Antonietti in Iseo (Brescia, Italy) as a project work fitting into a Percorso per le Competenze Trasversali e l'Orientamento (i.e., Path for Transversal Skills and Orientation). We described the experimentation of the first and second units in [1, 2] and [3], respectively. This talk focuses on the third and last unit, which took place with grade-12 students from October 2022 to January 2023. In particular, we show how we presented the Python programming language and the PuLP open-source library [4] to tackle optimization problems. Like the previous units, we applied collaborative learning by dividing students into groups. Differently, in the last final project, we used cooperative learning, and we involved the company Filtrec S.p.A., a manufacturer known worldwide for producing and distributing hydraulic filters [5]. A manager described to us the problem of optimising milk-run routes to visit contractors several times a week. We adapted and simplified the problem based on students' skills. We implemented a first version of the model in the classroom. Then, every group had to formulate and implement a different family of constraints. Once put these together, we obtained and solved the final version by using historical data given by the company. Finally, students wrote a report and held a presentation at Filtrec headquarters in Telgate (Bergamo, Italy), where they also visited the factory and the warehouse. Here we analyse results and feedback received

from students, teachers, and the company. Then, we reflect on this experimentation of ROAR, and we give some insights to replicate a similar experience.

*Keywords:* OR teaching, mathematics education, grade 12, PuLP, case study

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## Teaching of Mathematics through Problem Solving, Modelling and Optimization

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*Abstract* The teaching of mathematics in high school and university and its relationship with problem modelling and solving is at the centre of debate in many countries, with a rich scientific literature. The theme has to be viewed in a broader framework. The definition of educational chain is preliminary given, starting from the content of a discipline and covering teaching strategies, forms of learning, evaluation and assessment. On this basis the mathematical language and the role of mathematics is discussed. Then the experience of OPS4Math (Optimization and Problem Solving for Teaching of Mathematics), a training project developed at Federico II University of Naples and aimed at high school teachers, is described, including motivations and objectives, and implementation phases. Finally, the proposed teaching strategy is presented through a classical optimization problem.

*Keywords*: Problem Solving, Problem Modelling, Teaching of Mathematics, STEM, Educational chain

# Plenary Lecture
## Chair: Paola Festa

### A bilevel approach for compensation and routing decisions in last-mile delivery

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*Abstract* In last-mile delivery logistics, peer-to-peer delivery platforms play an important role in connecting senders, customers, and independent carriers to fulfil delivery requests. As the carriers are not under the platform's control, the platform has to anticipate their reactions, while deciding how to allocate delivery operations. Indeed, carriers' decisions largely affect the platform's revenue. In this work, we model this problem using bilevel programming. At the upper level, the platform assigns delivery orders to the carriers; at the lower level, each carrier maximizes his/her own profit by determining which offered requests to accept. Possibly, the platform can influence carriers' decisions by determining also the compensation paid for each accepted request. The resulting framework is bilevel in nature given that the two sets of actors, the platform and the carriers, are independent and act according to their own objective function. Indeed, the objective function of the platform is maximizing the net revenue of the orders delivered by the carriers, that corresponds to the price paid by the customers minus the compensation offered to the carriers. Instead, each carrier maximizes the net profit given by the compensation obtained from the delivered requests minus the routing cost. This latter problem corresponds to the profitable tour problem. We model the problems described above with two different formulations: the bilevel profitable tour problem with fixed compensation margins and with margin decisions, respectively. For each of them, we propose single-level reformulations and alternative formulations where the lower-level routing variables are projected out. A branch-and-cut algorithm is proposed to solve the bilevel models, with a tailored warm-start heuristic used to speed up the solution process. Extensive computational results are made to compare the proposed formulations and to analyze solution characteristics.

# Operations Research for Energy and Green Logistics I
**Chair: Tiziano Bacci**

## Optimization of Smart Energy Systems: a nonlinear approach

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*Abstract* Smart Energy is the intelligent optimization of energy costs and efficiency, using innovative technology to build and operate a sustainable energy management system. Such a system combines several generation units to produce a given demand for heat, electricity, etc. Typical units are: combined heat and power (CHP) units, absorption chillers, storages, heat pumps and boilers, etc. Unit Commitment (UC) is a key problem in this context. The goal in UC is to determine a schedule for the machines that maximize the operative margin, satisfying a forecasted heat demand coming from a district heating network as well as functional and regulatory constraints deriving from system composition. Usually the UC problem is formulated as a mixed integer linear programming problem, where the machines are supposed to work in parallel. But in this work, we present a particular case that gives rise to a nonlinear version of the short term UC problem, so we formulate and solve a mixed integer nonlinear and nonconvex optimization model. In the system we studied both the temperature and the water flow must be modelled explicitly introducing several nonlinear constraints, that must be satisfied along with all the classical time binding constraints we have in the UC problem. There are several reasons why this plant cannot be modelled using the classical linearization techniques. First, in order to avoid damaging the hydraulic infrastructure, we have to operate the machines in series and progressively heat the water to reach a given target temperature. Moreover, the historical data showed a strong correlation between the electric production of the CHP unit and water temperature and flow rate. Since the machines' production is a relevant component of the objective function, we need to compute it accurately and involve in the model all the variables on which it depend. Further, we present all the challenges we faced modelling this particular system and solving the nonlinear unit commitment problem.

*Keywords:* smart energy, unit commitment, MILP, nonlinear, nonconvex, optimization

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**Optimising Italian electricity and gas sector coupling in a 2030 decarbonized energy system**

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*Abstract* Power-to-X (PtX) technology is the production of hydrogen by electrolysis and, from this, of other gaseous fuels such as biomethane. In decarbonized energy systems, PtX plants can convert excess renewable energy production into gas that can either be injected into the gas grid, stored temporarily, or used to meet gas demand from other sectors, such as transportation. Due to its flexibility, PtX technology is expected to contribute to the integration of large shares of renewable energy into energy systems. Given the relevance of PtX plants for decarbonized energy systems, this paper provides a comprehensive formulation for the operational planning of integrated systems with bidirectional energy conversion. We then focus on the Italian energy system and present results on the challenges for Italy in exploring decarbonization pathways.

*Keywords:* Integrated energy systems, Power-to-X, Energy systems modeling

## Optimization and Simulation for the Daily Operation of Renewable Energy Communities

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*Abstract* Renewable Energy Communities (RECs) are an important building block for the decarbonization of the energy sector. The concept of RECs allows individual consumers to join together in local communities to generate, store, consume and sell renewable energy. A major benefit of this collective approach is a better match between supply and demand profiles, and thus, an increase in local self-consumption. The optimal exploitation of locally produced electricity raises many operational questions. In this context, we introduce a Mixed Integer Linear Program (MILP) that optimizes the energy flows within a REC. It employs the following instruments relevant for local self-consumption: (a) stationary batteries, (b) batteries of electric vehicles and (c) load shifting (i.e. moving the use of electric appliances from one time period to another). To handle the uncertainty of the involved planning parameters, we use a Model Predictive Control (MPC) approach and solve the optimization model in an iterative manner. The introduced planning framework can be applied to generate realistic performance measures of specific community configurations and to evaluate strategic investment decisions.

*Keywords:* mixed integer linear programming, model predictive control, energy communities

**Smart system for waste collection: economic perspective including the impact of the carbon footprint**

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*Abstract* The concept of smart cities is very popular in recent years. Using modern information technologies, the comfort for citizens and efficiency of processes in cities are improved within this concept. The waste collection process is absolutely vital for all residents in a city. Many researchers have shown in their studies that even this process can be managed in a new, more efficient and modern way. This paper builds on the results of the previous study of the authors [1] where a new smart model based on the individual orders of waste collection by residents has been introduced. Unlike the original study where the emphasis was put on the travelled distance only, this work explores the economic viability of the proposed concept from several perspectives: economic (fee policy), environmental (carbon footprint) and user (comfort for citizens). The performance of the proposed model is carefully explored under various regimes during the year (regular season, increased production, e.g., during Christmas time, decreased production, e.g., during the summer holidays). Then, the smart concept is carefully compared with the current state in terms of the costs, including the costs covering the carbon footprint of the process (via emission allowances used in the European Union to cover CO2 emissions). A detailed sensitivity analysis showed that if the system parameters are set appropriately, residents will be motivated to participate in the system not only because of better comfort and environmental friendliness, but also due to the lower costs.

*Keywords:* waste collection, mathematical programming, smart city, carbon footprint

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## Achieving Modal Shift Targets in Freight Transportation: Exact Models and Methods for Optimal Subsidy-to-Mode Allocation

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*Abstract* It is widely acknowledged that freight transportation is a significant contributor to CO2 emissions in Europe, and road transport is responsible for over 72% of greenhouse gas emissions. In response, many countries have implemented incentive schemes to promote inter-modality, encourage environmentally friendly transportation modes such as rail and maritime, and shift freight traffic away from roads. However, these actions are often sporadic and lack a coordinated vision, targeting specific modes rather than a holistic approach.

In this context, this study deals with the problem of defining incentive schemes to rebalance the modal split between road, rail, and maritime modes, with the aim of minimizing their environmental impact. Likewise, this problem can be regarded as defining incentive schemes to maximize the vehicle flows distributed across non-road modes, while satisfying incentive budget constraints.

The problem has been formulated by a mixed-integer linear programming (MILP) model, employing a deterministic modal choice model with threshold values. Moreover, to overcome dimensional drawbacks, a matheuristic approach has been developed. The proposed approaches have been validated using real freight transportation data sets in Italy, demonstrating their applicability in designing more conscious incentive schemes.

*Keywords:* freight transport, optimal incentive allocation, matheuristic approach

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## A study on the linear relaxation of the ramp-up polytope for the single unit commitment problem

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*Abstract* The unit commitment problem (UC) is a well-known problem with applications in the field of electricity production. In this problem it is necessary to decide whether each energy-producing unit should be switched on or off and how much energy each unit should produce in each time of a given time horizon. The goal is to find a solution at minimum cost in such a way as to guarantee the energy demand in each time, while satisfying a set of constraints on the units. Generally, the constraints taken into consideration on each unit are maximum and minimum power output, minimum up and down time constraints, ramp up and ramp down constraints. More specifically, the ramp up constraints ensure that the increase in energy produced between two successive time instants is at most equal to a given parameter.

In general, in the UC there are few constraints which link the units together, while several complex constraints which describe the single unit are included. Traditionally, efficient methods for solving UC are based on Lagrangian relaxation, where many single-unit (1UC) commitment problems need to be solved [1,2]. Based on the Dynamic Programming algorithm in [1], an exact MINLP formulation has been defined for 1UC which has been deployed in formulations to solve UC [3,4]. Following this line of research, here we focus on the ramp-up 1UC polytope [5], which enforces ramp up constraints, but relax shut down ones. In particular, we analyse a new linear relaxation of the ramp-up 1UC polytope and we define new formulations for the complete UC.

*Keywords:* Unit Commitment problem, Ramp Constraints, MIP Formulations

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# Invited Session
# OPTSM – Real-time train rescheduling
### Chair: Paola Pellegrini

## Train Rerouting and Rescheduling in case of Perturbation: focus on Passenger Connections.

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*Abstract* The real-time Railway Traffic Management Problem (rtRTMP) involves re-ordering and re-routing trains in case of perturbation [1]. In stations, trains can typically stop at various platforms. The platforms used by connecting trains may impact the minimum connection time necessary for passengers transfer: walking time to move between trains is shorter if they stop at adjacent platforms than at far away platforms. Indeed, the arrival of the feeder train must precede the departure of the departing one by at least the minimum connection time. A delay of the feeder train may hence propagate to the departing one, unless a sufficient buffer is present. In this study, we extend the Mixed-Integer Linear Programming formulation of the state-of-the-art RECIFE-MILP algorithm for the rtRTMP [2]: we improve the modelling of connections at stations. RECIPE-MILP models railway infrastructures microscopically and allows solving instances considering all possible rerouting options. In the original RECIFE-MILP, a minimum connection time is allocated for each connection. To ensure feasibility, this time must be sufficient to allow passengers to transfer between the two farthest platforms the trains can use. We propose two enhancements to RECIFE-MILP to reduce the minimum connection time while still ensuring feasibility. The first one involves setting a short minimum connection time. We then restrict the set of platforms accessible to the trains to the pairs that are close to one another: these are the ones for which the set minimum connection time is enough for the transfer. The second enhancement considers minimum connection time to be dependent on the pair of platforms used by the connecting trains. We compare the relative performance of the two proposed enhancements with the original RECIFE-MILP considering traffic at the Lille-Flandres station, in France. We observe that

both enhancements are superior to the original algorithm, with the second enhancement being even more so.

*Keywords:* Railway Traffic Management, Train Connections, Station Capacities

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# Real-time optimization for train regulation and stop-skipping adjustment strategy of urban rail transit lines

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*Abstract* This paper addresses the real-time train regulation problem by taking the stop-skipping strategy into account in high-frequency urban rail transit lines. During rush hours, if the train regulation is not adopted properly and rapidly to deal with the frequent disturbances, the delays may further spread and result in a large number of passengers stranded in the stations. The purpose of this paper is to explore the possibility of dynamic train regulation and stop-skipping adjustment strategy to cope with the disturbance management in a real-time manner. By considering the impact of dynamic passenger flows, a nonlinear programming model for train regulation problem is proposed with the objective of minimizing the total train deviation and enhancing the passenger service quality, which is further converted into a mixed-integer quadratic programming model for ease to solve. In addition, the constraints related to the train rolling-stock plan are taken into account to provide a feasible scheme. Based on a customized model predictive control (MPC) method, the proposed model can be solved in a real-time manner, laying a theoretical groundwork for implementation of the train regulation strategy. Computational results based on the real-world data of Beijing Yizhuang metro line illustrate the superiority of the train regulation strategy in comparison with the practical strategy. The robustness of the method is examined through various scenarios of uncertain passenger demands, and the adjustment performance with different prediction horizons is explored to illustrate the added value brought by the updated information of the proposed MPC method.

*Keywords:* train regulation, stop-skipping adjustment, mixed-integer quadratic programming model

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## A multi-task deep reinforcement learning approach for the real-time traffic management of high-speed trains

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*Abstract* Existing approaches for the real-traffic management of high-speed trains focused on a series of scenario-dependent mathematical formulations, which however requires to solve the model under different disruption scenarios. The traditional deep reinforcement learning (DRL) has similar drawbacks that the model has to be trained under each disruption scenarios. In our study, we develop a multi-task DRL approach for the real-time traffic management of high-speed trains. Our approach only constructs and trains one DRL model, which can be used for different disruption scenarios. We also propose a novel MIP formulation to select the optimal tasks for the training of the DRL model. We test our approach on the real-world data of Beijing-Zhangjiakou high-speed railway network.

*Keywords:* Real-time railway traffic management, deep reinforcement learning, high-speed railway

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## A cross-granularity high-speed railway real-time train rescheduling approach

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*Abstract* High-speed railway is of great importance for satisfying the mobility needs in many countries. However, its operation schema, i.e., the timetable, is exceedingly delicate and can be easily disturbed by many things, which often causes serious consequences. At that case, rescheduling trains is necessary to restore traffic situation and minimize total loss of disturbances. In literature, the train operation management model in macro granularity may not be infeasible in details, while that in micro granularity is too complex to be a timely solution. Therefore, the model combining feasibility and timeliness is much important. We propose a cross-granularity space-time network train rescheduling model which can model bottlenecks in details to ensure the feasibility of solution and model the other areas from macroscopic view to ensure the timeliness. By data-driven distinguishing bottlenecks methods, we analyse historical train operation data to find out which locations of railway network are bottlenecks and should be modelled in microscopic level. Then the cross-granularity space-time network model is established to describe any potential rescheduling schemas and optimize the model to find the optimal rescheduling solution, e.g., corresponding optimal train paths. The network model can be automatically generated with respect to given rescheduling strategies as well as parameters and allows dispatcher to retime, reroute and reorder trains to minimize total loss. To solve this model, a priority-based Lagrangian relaxation heuristic algorithm is employed. The approach is tested on Beijing-Shanghai high-speed railway historical real data and perform well in terms of either feasibility or timeliness. We also use Gurobi to calculate as a control group. Compared with Gurobi, our method has a significant advantage in computing time with a slight acceptable quality loss.

*Keywords:* Railway transportation, Train rescheduling, Cross-granularity model

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**Real-time rail traffic optimization with integrated passenger prediction**

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*Abstract* We propose a new approach to real-time rail traffic optimization that integrates dynamic passenger predictions. The aim is to improve the effectiveness of rail transport systems while meeting passenger needs. Approaches minimizing the impact of delays on train operations are widely studied in the literature, however they have seldom been extended to explicitly include passengers (Corman et al., 2017). To address this gap, we design a framework consisting of two modules: a demand prediction module provides information about upcoming origin-destination passenger flows given a planned rail schedule and past observed demand; a traffic control module optimizes rail traffic in real-time by taking into account this dynamic demand information. The demand prediction module relies on a deep learning model using updated train schedules and real-time passenger data as input, and a heuristic for assigning predicted demand to individual trains. In the traffic control module, we include these demand predictions in an existing mixed-integer linear programming-based algorithm for the real-time traffic management: RECIFE-MILP (Pellegrini et al., 2014). Here, the predicted train and passenger paths are used to minimize the weighted sum of train and passenger delays at destination. We model passenger transfers as soft constraints to ensure the minimum time separation between the arrival and departure of the trains involved. When a passenger transfer is not possible due to the decided train timings, a cost proportional to the potential passenger delay derived from the missing transfer is added to the objective function. The proposed work is part of the SORTEDMOBILITY project, which is focused on developing optimized solutions for self-organizing management of public transport operations. In this context, we assess the proposed methodology in terms of its ability to optimize traffic while capturing passenger demand on the Copenhagen suburban rail network.

*Keywords:* Real-time Railway Traffic Management, Passenger Demand Prediction,

Intelligent Transport Systems

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# Logistics and Transportation I
## Chair: Federico Della Croce

### An Improved Formulation for the Assortment Problem

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*Abstract* A fundamental class of decision-making problems faced by firms is about selecting, from a given finite set of products, the best subset of products to offer to customers. This class of optimization problems is known as assortment optimization and has become crucial in many revenue management applications, such as hotels, car rentals, retailing, and e-commerce (see [1]). We investigate the assortment optimization problem with small consideration sets, where customers belong to classes and choose according to the k-product non-parametric ranking-based choice model—i.e., each customer's preference list contains at most k products, and customers purchase the most preferred product among the ones offered in the assortment. This problem is known to be NP-hard even for k=2. To the best of our knowledge, the literature about solution methods for this problem is limited to a few contributions, as seen in [2] and the references therein. By building upon a compact Mixed-Integer Linear Programming model proposed, in the literature, for the full non-parametric ranking-based choice model, we propose an improved compact model that features a very tight continuous relaxation and can be easily solved with a general-purpose solver. An extensive set of computational experiments shows that our improved formulation can find provably optimal assortments of instances with up to 200 products, 100,000 customers classes, and k=5, in a few minutes of runtime on a notebook.

*Keywords:* assortment optimization, mixed-integer linear programming, exact methods

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**A Continuous Time Physical Graph based Formulation to Scheduled Service Network Design**

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*Abstract* Scheduled Service Network Design supports consolidation based freight carriers in setting up a transportation network by selecting the transportation services to operate, with their schedules, and the itineraries of the commodities to move. We propose a new formulation to the problem that represents time in its continuous nature, directly over the physical graph, thus mitigating the drawbacks that a traditional formulation, relying on a time-space network, may have for large scale instances, due to the increase in its dimensions and the consequent intractability in solving the problem exactly. Preliminary numerical experiments comparing the new and traditional formulations on a set of randomly generated instances are performed. Results highlight that the proposed formulation is a valuable tool to solve large scale instances with a long schedule length.

*Keywords:* Scheduled Service Network Design, Freight Transportation, Continuous Time Representation, Integer Linear Programming

## A System for Optimal Dispatching of Autonomous Mobile Warehouse Robots

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*Abstract* Autonomous Mobile Robots (AMRs) are currently introduced into many logistics operations. Their main advantage is their ability to adapt and react dynamically to system state and environment changes [1]. Modern robots utilize multiple sensors to achieve situational awareness and can communicate and negotiate with each other and other systems to achieve collision-free navigation in dynamic environments.

In warehouses, AMRs are used for order picking and restocking [2]. In the specific researched setting, AMRs carry containers from shelves in the picking areas to centralized packing and consolidation areas and from arriving transports back to the shelves. While the AMRs can navigate autonomously, there is still a need for centralized scheduling and dispatching decisions. Optimizing the scheduling and dispatch is complicated by the interdependence with routing and collision avoidance decisions [3]. To resolve this, we propose a two-stage optimization design. In the first stage, tasks are assigned to robots under an optimal and collision-less routing assumption (i.e., using the shortest path). In the second stage, practical routing decisions are taken, and collisions are avoided. A feedback loop returns to the first stage if there is a significant disparity between the practical routing time and the optimal routing assumption.

In this research, we focus on the first stage while providing a working solution for the second stage. The scheduling problem is modelled as a min-max IP vehicle routing problem. The problem is solved using standard IP solvers, and the solution is compared to various heuristics and distributed solutions. Using practical use cases, we show that the model provides significantly better solutions than any heuristic, thus justifying the benefit of a centralized system.

*Keywords:* autonomous mobile robots, dispatching and routing problem, warehouse robots

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## A Branch-and-price algorithm for the redundancy allocation problem

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*Abstract* We study the redundancy allocation problem (RAP) with heterogeneous components under the mixed redundancy strategy. An exact branch-and-price (BP) algorithm is proposed for the problem that solves in less than one CPU second all the benchmark instances reported in the literature. The proposed BP algorithm is also capable of solving other variants of RAP, including RAPs with either an active or a standby strategy, making it possible to investigate the advantages of the mixed strategy over the active and standby strategies.

*Keywords:* Branch-and-price, Reliability optimization, Redundancy allocation

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## The effect of leadership on the supply chain of a perishable product

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*Abstract* Our study examines the impact of supply chain leadership on the performance of the supply chain for perishable products, using the economic order quantity (EOQ) model.

The manufacturer and retailer interact via a wholesale-price contract, and demand depends on the age of the product on the shelf. We found a closed-form solution for the equilibrium under two scenarios, depending on which party announces its price decision first. We also provided bounds for this conditional equilibrium that depend only on the production cost and the reservation price. Our results suggest that supply chain leadership can play a significant role in the performance of the supply chain for perishable products.

When the cycle length is determined cooperatively, the retailer is likely to be the more effective leader in terms of generating higher profits for the channel.

In conclusion, our study provides insights into the factors that influence the success of supply chain coordination efforts for perishable products. Being the leader of the supply chain can be more profitable for each party involved, and consumers benefit from fresher products when the retailer is the leader. Our findings offer practical implications for decision-makers in the supply chain industry, highlighting the importance of cooperative decision-making and supply chain leadership in ensuring the success of the supply chain for perishable products.

*Keywords:* Supply chain, Perishability, EOQ

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**Iterated Inside-Out: a new exact algorithm for the transportation problem**

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*Abstract* We consider the transportation problem (TP), one of the historical network optimization problems in the mathematical and operations research communities. We mention here, among others, the pioneering work by Dantzig [2] who provided the first primal simplex algorithm for TP. Later, at the end of the twentieth century, several polynomial time algorithms were proposed for the minimum cost flow problem, a generalization of TP, namely the primal network simplex algorithm proposed in [4] and the dual network simplex algorithm proposed in [1]. In [3], it is shown that the primal network simplex algorithm is the best performing algorithm for the minimum cost flow problem on dense graphs. In [5], it is indicated that the best performing approaches for TP are those based on the simplex algorithm (in its various expressions: primal, dual, network). We propose here a novel exact algorithm for TP. The algorithm, denoted Iterated Inside-Out, requires in input a basic feasible solution and is composed by two main phases that are iteratively repeated until an optimal basic feasible solution is computed. In the first "inside" phase, the algorithm progressively improves upon a given basic solution by increasing the value of several non-basic variables with negative reduced cost. This phase typically outputs a non-basic feasible solution interior to the constraint set polytope. The second "out" phase moves in the opposite direction by iteratively setting to zero several variables until a new improved basic feasible solution is reached. Extensive computational tests show that the proposed approach strongly outperforms all versions of network and linear programming algorithms available in the commercial solvers Cplex and Gurobi and other exact algorithms available in the literature.

*Keywords:* Transportation problem, exact algorithm, pivoting operation, basic solutions

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# Machine Learning II
**Chair : Alberto Ceselli**

## A kernel-based semiproximal SVM approach for Multiple Instance Learning

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*Abstract* We tackle a binary Multiple Instance Learning (MIL) problem, which consists in discriminating between two types of point sets: positive and negative. Using the MIL terminology, such sets are called bags and the points inside each bag are called instances. The main characteristic of a MIL problem is that, differently from the standard supervised classification, in the learning phase we know only the labels of the bags, whereas the label of each instance inside the bag remains unknown. In particular, we consider the case with two classes of instances (positive and negative) starting from the standard MIL assumption, which states that a bag is positive if it contains at least a positive instance and is negative vice versa. For solving such problems, we propose a kernel version of the recent semiproximal Support Vector Machine algorithm [1], which combines the standard Support Vector Machine technique with the Proximal Support Vector Machine (PSVM) approach, the latter revealed very effective for supervised learning, especially in terms of computational time. Numerical results are presented on some benchmark test problems drawn from the literature.

*Keywords:* Multiple Instance Learning, semiproximal, kernel functions

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## Data Driven Completion Bounds for Elementary Shortest Path Problems

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*Abstract* Resource Constrained Shortest Path Problems (RCSPP) have wide applicability, representing a flexible model for network applications [1]. Furthermore, they frequently arise as subproblems in decomposition based methods, as occurs in column generation for vehicle routing problems [2], where dynamic programming is often used for their optimal resolution. A well known technique for speeding up these algorithms is the so-called completion bounding: for each partial path a check is performed, to understand if any extension may exist, leading to a feasible complete path. In this context, we experiment a data-driven approach using supervised learning models to detect early infeasibility of a partial path. We consider the specific case, where negative resource values are allowed. The RCSPP with monotone increasing resources is weakly NP-Hard, but when resource values can be negative it becomes NP-Hard in the strong sense, rising the need of handling path elementarity in an explicit way. We design features that are not dependent on the instance size and have different computing times. We test different models. We compare the trade-off between computational effort and effectiveness of the model. Preliminary results have shown this attempt to be effective.

*Keywords:* Resource Constrained Shortest Path Problem, Machine Learning, Completion Bounding

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## Convex polyhedral separation with low hyperplane budget

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*Abstract* We consider the following polyhedral approximation problem with budget K: given a set of feasible points belonging to an unknown d-dimensional convex polyhedron and a set of infeasible points belonging to the complement of the same polyhedron, find K hyperplanes that separate all the feasible points from the largest number of infeasible ones.

The problem is of interest both for the pure convex polyhedron approximation and for its application in machine learning. It is a particular case of binary classification with piecewise-linear separation e.g. [1], addressing convexity in explicit way [2-3].

In our work we tackle the problem using models inspired by support vector machines and designing column generation algorithms. We introduce three mathematical programming models having as a common feature binary variables assigning infeasible points to one specific hyperplane. The first one penalizes the violation of each point with respect to its hyperplane. The second one counts the number of misclassified infeasible points. The third one is obtained from the second one by projection. We also exploit Dantzig-Wolfe decomposition to obtain an extended formulation that we optimize by column generation techniques.

We compare computing time and quality of bounds obtained by all our approaches on synthetic datasets of hundreds up to a few thousands of points. We show that key computational differences arise, depending on whether the budget K is sufficient to completely separate the feasible points from the infeasible ones or not.

*Keywords:* polyhedron approximation, binary classification, column generation

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**Binary Kernel Logistic Regression: sparsity and a SMO-type decomposition algorithm**

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*Abstract* Kernel logistic regression (KLR), see e.g. [1], is a type of kernel machine widely used for binary classification tasks. KLR models provide advantageous probabilistic predictions but, differently from other kernel methods like Support Vector Machines (SVMs), they are generally not sparse. To the best of our knowledge, in the literature, a single heuristic approach, namely the Import Vector Machine (IVM) [2], is known to train sparse KLR models. In this work, we propose an exact binary KLR formulation to induce sparsity in the trained model. Taking inspiration from previous SVMs training methods, we devise an SMO-type decomposition algorithm exploiting second-order information (similar to [3] for SVMs) to efficiently train the dual of such sparse KLR formulation. Asymptotic convergence of the decomposition algorithm is shown. Comparative experiments are conducted with respect to IVMs and SVMs on 15 datasets from the UCI and LIBSVM repositories. Results show that the proposed KLR binary classification approach achieves competitive accuracy and sparsity performance while retaining the probabilistic prediction benefit.

*Keywords:* kernel logistic regression, sparsity, decomposition techniques

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## Optimal Logistic Classification Trees

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*Abstract* Nowadays, interpretable machine learning plays an important role in data science expecially in high-stakes decision making [1]. In this context, Classification Trees (CTs) are one of the most common models. Although they are usually built with greedy strategies [2-3], in recent years, thanks to remarkable advances in Mixer-Integer Programming (MIP) solvers, several exact formulations of the learning problem have been developed [4-5]. In this talk, we address the interpretability problem of these models and we propose a new exact MIP formulation for constructing classification trees with multivariate (oblique) splits that exploits logistic regression to separate the points in the feature space. Our formulation numerically proves to be able to induce trees with enhanced interpretability features and competitive generalization capabilities, compared to the state-of-the-art approaches.

*Keywords:* Optimal Classification Trees, Logistic Regression, Interpretability, Mixed-Integer Programming

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## Enhancing sparse regression models with cutting planes

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*Abstract* We consider simultaneous feature selection, outlier detection, and regression problems. The training of these models can be naturally formulated using mathematical programming, but the feature selection and outlier detection tasks raise the need of introducing binary decision variables, thus making the optimization phase more time-consuming.

A standard optimization procedure would employ branch-and-bound, but we explore instead an aggressive use of cutting planes alone. We evaluate which families of cuts are more effective in reducing integrality gaps, and which is the tradeoff between gap reduction and resolution time.

We also evaluate the effect of cutting planes on the quality of the final regression hyperplane during testing, comparing the hyperplanes in fractional solutions at the end of the cutting phase with those of heuristic integer solutions found at the root node of a branch-and-bound tree.

*Keywords:* support vector regression, feature selection, outlier detection, cutting planes

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# Vehicle Routing II

**Chair: Ornella Pisacane**

## Exact Separation of the Rounded Capacity Inequalities for the Capacitated Vehicle Routing Problem

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*Abstract* The family of Rounded Capacity (RC) inequalities is one of the most important sets of valid inequalities for the Capacitated Vehicle Routing Problem (CVRP). This paper considers the problem of separation of violated RC inequalities and develops an exact procedure employing mixed integer linear programming. The developed routine is demonstrated to be very efficient for small and medium sized problem instances. For larger-scale problem instances, an iterative approach for exact separation of RC inequalities is developed, based upon a selective variable pricing strategy. The approach combines column and row generation and allows us to introduce variables only as it is needed, which is essential when dealing with large-scale problem instances. A computational study demonstrates scalability of the proposed separation routines and provides exact RC-based lower bounds to some of the publicly available unsolved CVRP instances. The same computational study provides RC-based lower bounds for very large-scale CVRP instances with more than 3000 locations obtained within appropriate computational time limits.

*Keywords:* Rounded Capacity Inequalities, Capacitated Vehicle Routing, Mixed Integer Programming

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## The Vehicle Routing Problem with Transfers

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*Abstract* The Vehicle Routing Problem (VRP) involves a fleet of vehicles with limited capacity serving a set of customers with known demands while minimizing costs. The VRP with Split Delivery (VRP-SD) is a variant that allows customer demands to be served by multiple vehicles, resulting in significant cost savings. In this work, we focus on the VRP with Transfers (VRP-T), where customer locations can be used as transfer points to exchange loads among vehicles, leading to a potential cost reduction of at least 50%. To solve this problem, we propose a two-index mixed-integer programming model and a direct solution method with advanced start. Our computational results demonstrate that allowing transfers in the VRP leads to substantial cost savings and reduces the number of required vehicles. Furthermore, our findings suggest that transfers are just as effective as split delivery in reducing costs. The VRP-T is applicable in the last-mile distribution situations where the efficiency of last-mile delivery can be improved by allowing transfers.

*Keywords:* Vehicle Routing Problem, Transfers, Temporal Storage, Split deliveries

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## A Variation of the pick-up and Delivery Vehicle Routing on Manned Vehicles with an Application to Warehouse Management

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*Abstract* We propose a solution strategy to a real-world warehouse management problem [1] by adapting the well-known capacitated vehicle routing with pick-ups and deliveries (CVRPPD) formulation [2]. The considered problem is the management of a warehouse with manned vehicles that have to perform a chain of consecutive operations in the allotted time. Every operation consists in picking up a maximum of two pallets from the storehouse zone, to deliver them to the "ready" zone, where the final orders are assembled and ready to leave the warehouse.

The warehouse is represented as a weighted graph, divided into storehouse nodes and ready nodes, connected with arcs that account the warehouse geometry. Each weight represents the crossing time of its associated arc.

We modify the original CVRPPD formulation to accommodate the needs of the warehouse management. In particular, we allow the vehicles to pass through the same arc more than once, check if an arc is not congested with too many vehicles in a given time, force the vehicle to visit all the pick-up nodes in the storehouse before going in the ready zone, and chain the different operations that the vehicle has to perform.

This results in an Integer Linear Programming problem with hundred of thousands of variables even on small instances. To help us find a good solution efficiently, we devise a strategy that consists in creating a directed and weighted "operation graph". The nodes in the operation graph consist in the different operations and the directed arcs indicate if an operation precedes another. The weights on each arc are computed as the cost of the shortest path to perform that operation. We adapt the obtained solution to be feasible in the modified CVRPPD formulation, satisfying the time and the congestion constraints.

There are several strategies to obtain the operation graph solution, and we report some numerical results on a real-world ceramic warehouse, comparing the performance of these strategies.

*Keywords:* Vehicle Routing, Warehouse Optimization, Integer Optimization

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## Location-Sizing and Routing for a Biomethane Production Chain fed by municipal waste: a case study on the Lazio Region

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*Abstract* Biomethane production from municipal waste is a well-developed technology; however, so far the literature has mainly focused on technical issues forgetting about optimizing the supply chain design or confining it to the first strategic echelon ([1,2,3]). The paper addresses a cluster-first location&sizing&route-second approach for the design of a biomethane production chain fed by the Organic Fraction of Municipal Solid Waste (OFMSW). We implement a two-stage iterative algorithm composed by: (i) a Bounded K-mean clustering heuristic with size and weight limitations; and (ii) a formulation based on a two-commodity flow for a multi-depot Location-Sizing Routing Problem with Fixed Clusters. A classification between small OFMSW producers (to be clustered) and large ones is introduced for the first time. Extensive computational experiments on a case study on the Lazio Region demonstrate the cost-effectiveness of the proposed approach, which saves 30% of transportation costs with respect to a location-sizing model.

*Keywords:* Biomethane, Mixed Integer Linear Programming, Location-Routing

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## Synchronized Deliveries with a Bike and a Self-Driving Robot

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*Abstract* Online e-commerce giants are continuously investigating innovative ways to improve their practices in last-mile deliveries. Inspired by the current practices at JD.com, the second largest online retailer in China, we investigate a delivery problem that we call Travelling Salesman Problem with Bike-and-Robot (TSPBR) where a cargo-bike is aided by a self-driving robot to deliver parcels to customers in urban areas. The TSPBR belongs to the category of autonomous robot-driven deliveries, which has drawn significant attention in the literature recently (see, e.g., the survey of Srinivas, Ramachandiran, and Rajendran, 2022). We present two mixed-integer linear programming models and describe a set of valid inequalities to strengthen their linear relaxation. We show that these models can yield optimal solutions of TSPBR instances with up to 60 nodes. To tackle larger instances, we also present a genetic algorithm based on a dynamic programming recursion that efficiently explores large neighbourhoods. We computationally assess this genetic algorithm on instances provided by JD.com and show that high-quality solutions can be found in a few minutes of computing time. Finally, we provide some managerial insights to assess the impact of deploying the bike-and-robot tandem to deliver parcels in the TSPBR setting.

*Keywords:* self-driving robots, last-mile delivery, synchronization, mixed-integer linear programming, genetic algorithm

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**Efficiently solving the electric vehicle routing problem with a realistic energy consumption model**

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*Abstract* Due to the recent concerns on the climate changes, attention is being paid to the road transport, responsible for about 70% of the harmful emissions of the transportation sector. To this purpose, several countries are promoting green vehicles (e.g., electric vehicles (EVs)). However, especially in the mid-haul logistics, where the driving range of medium-duty EVs cannot usually cover the distances [1], EVs may require recharging during their trip. Considering that the recharging stations (RSs) are not currently widespread on the territory, this requires properly planning their routes, including the stops at RSs. Such a decision problem is referred in the literature as Electric Vehicle Routing Problem with Time Windows, E-VRPTW [2]. It aims at routing a fleet of EVs, to serve all customers within their time windows, with possible recharges en-route, minimizing the total travelled distance. Each EV must start from and return to a common depot within a maximum time. We address a new variant of the problem with a realistic Energy Consumption Rate (EVRPTW-ECR), assuming that the energy consumption depends on EV speed and load. Moreover, the EV speed is a decision variable, varying in a given range. The objective function to minimize represents the fixed costs of using EVs, the energy costs and the drivers' wage costs. We model the problem by Mixed Integer Linear Programming (MILP), without cloning the RSs to allow they to be used more than once in the solutions. To this aim, for each pair of customers, we determine a set of feasible and non-dominated stations. Moreover, we design a Randomized Kernel Search based matheuristic (RKS) initialized by a Random k-Degree Search based matheuristic (RkDS) in which a final re-optimization aims at reducing the number of stops at RSs. Finally, we test the RKS on a set of benchmark instances, where it always outperforms the proposed MILP model in terms of both solution quality and computational times.

*Keywords:* Vehicle Routing, Kernel Search, Mixed Integer Linear Programming

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# Optimization on Graphs
**Chair: Francesco Carrabs**

## Networks Construction / Restoration Problems

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*Abstract* We consider a class of network restoration problems (e.g., [1-3]) where there is a transportation network that has been destroyed by a disaster which has led to its nodes being disconnected from each other, and the connectivity needs to be restored. The network is being restored by construction crews (servers) that have fixed construction speeds. It is assumed that the servers' relocation (travel) times within the network are negligible with respect to construction times. In other words, at any time a server can relocate instantaneously to any point of the network that is reachable from its present location. For any pair of nodes, its connection time is the time when the pair becomes connected by an already restored path. In network restoration problems, it is required to find a feasible construction schedule that minimizes some nondecreasing function of connection times of different node pairs (e.g., the total weighted flow time, or the maximum lateness with respect to some due dates, etc.)

The talk will outline some recent results in this area, including computational complexity issues and optimization algorithms.

*Keywords:* Combinatorial optimization, network optimization, network construction

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**Two formulations and valid inequalities for the Capacitated Steiner Tree Problem**

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*Abstract* We examine a variation of the Steiner tree problem that involves sending commodities from a root node to terminal nodes through transshipment nodes with restricted capacity. We present two formulations for this problem. Unlike the first formulation, the second uses the notion of cardinality of terminals assigned to a transshipment node as in [1]. The second formulation is stronger than the first one and we develop two sets of inequalities that leverage the cardinality effect to enhance the lower bound of the optimal solution. We incorporate these inequalities in a branch-and-bound algorithm that yields a branch-and-cut approach. To test our approach, we apply it to a significant number of randomly generated problem instances. Our experiments indicate that the proposed approach can identify the optimal solution for most of the problem instances with limited capacity, and even in cases where the first formulation may be simpler to solve, the proposed cuts still prove useful for larger capacity instances.

*Keywords:* Steiner tree, Branch-and-cut, Combinatorial optimization

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**Comparing different integer linear formulations of the K dissimilar paths problem**

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*Abstract* The need to find alternative paths between two given nodes in a network is a common feature of many network optimization problems. According to the particularities of each problem, the paths may be required to have specific attributes.

In this talk we address the K dissimilar paths problem, in which, for an integer K, we look for a set of K paths, as diverse as possible, between the two nodes. Several works propose different dissimilarity measures between paths as the metric for achieving this purpose. In fact, this problem finds applications in fields as diverse as the design of resilient telecommunication networks, navigation systems and map-based services or the definition of police patrol routes, and often the dissimilarity measure proposed is tailored to meet the requirements of the specific application. Nevertheless, in general, the paths dissimilarity is measured according to the amount of network resources that they share. In this work, we use two strategies to minimize the extension of the superpositions between the K paths: minimizing the number of arc repetitions and minimizing the number of arc overlaps between all pairs of paths. The two approaches are modelled by means of integer linear programming (ILP). Departing from the classical path formulation, we build up our models making use of reformulation techniques known from the literature to achieve more compact and efficient flow-based models. In this process, four formulations are presented and compared. Computational tests performed in random and in grid networks, and applying the CPLEX solver, showed that by using the flow-based models, the run times to deliver the optimal solution decrease significantly without compromising the paths' dissimilarity.

*Keywords:* K alternative paths, Dissimilarity, ILP formulations

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**PathWise: an open-source library for the Resource Constrained Shortest Path Problem**

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*Abstract* In this work, we consider the Resource Constrained Shortest Path Problem (RCSPP)[1], a fundamental and hard combinatorial problem, and propose PathWise, a flexible, open-source library for its resolution.

More in detail, we developed a platform capable of modelling and solving a variety of standard RCSPPs with an off-the-shelf implementation of state-of-the-art algorithms. We designed PathWise with the final user in mind and included easy-to-use interfaces for both beginners and experts: beginners can either use the library standalone or from their favourite programming language, whilst experts can define and implement, due to clear and well-defined hook points, custom solutions to extend the algorithms and functionalities of the library. Finally, we planned and devised components that will allow PathWise to become a platform ready for data-driven and process-driven methodologies.

We provide computational experiments for two classes of instances from the literature that present a single resource constraint, namely the RCSPP on cyclic networks and the RCSPP on large acyclic networks. Furthermore, we also consider the RCSPP when facing ad-hoc cyclic networks with multiple resource constraints. We detail every result for PathWise, when using multiple techniques and under different configurations, and sketch a comparison with state-of-the-art specialized algorithms[2][3]. We show that our library is packed off-the-shelf with methods capable of tackling all classes of problems. This study represents the first step along the journey of devising and implementing a comprehensive open-source library for a large variety of RCSPPs.

*Keywords:* Resource Constrained Shortest Path Problem, Dynamic Programming, Software

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## A Kernel Search algorithm for the Minimum Spanning Tree Problem with Conflicts

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*Abstract* In this talk, we address the Minimum Spanning Tree Problem with Conflicts (MSTC), which is a variant of the well-known Minimum Spanning Tree Problem (MST) characterized by pairwise conflicts among edges. The MSTC consists in finding the minimum conflict-free spanning tree of a graph, i.e., the spanning tree of minimum cost, including no pairs of edges which are in conflict. The MSTC can be used for the design of offshore wind farm networks [1]. These networks are wired using a tree structure avoiding the overlap between cables. This requirement can be added as a conflict between edges of the network.

The MSTC has been proposed in [2] as MST with disjunctive constraints. This type of constraints are defined using the definition of Conflict Graph, whose nodes correspond to the edges of the original graph and the edges reflect the conflicts; the authors also prove that the MSTC is strongly NP-hard.

We address this problem designing an ad-hoc Kernel Search algorithm, which consists in solving iteratively improved restrictions of the problem. We test our approach on benchmarking instances and compare our results to the ones obtained by the heuristic proposed in [3].

*Keywords:* conflicts, matheuristics, spanning tree

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**Kernousel: a matheuristic for the maximum flow problem with conflict constraints based on Carousel Greedy and Kernel Search approaches.**

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*Abstract* The Maximum Flow Problem with additional Conflict constraints (MFPC) is an NP-Hard variant of the classical Maximum Flow Problem in which given pairs of arcs are not allowed to carry positive flow simultaneously. Such restrictions are known in the literature as negative disjunctive constraints or incompatibility constraints or conflict constraints. The problem was first studied by Pferschy and Schauer [4] and by Şuvak et al. [5] that proposed exact approaches for this problem.

In this work, we merge together the Carousel Greedy [3] and the Kernel Search [1][2] approaches to obtain a fast and effective matheuristic, named Kernousel, for MFPC. The idea behind our algorithm is to exploit the information gathered by the Carousel Greedy to build a more accurate kernel set that makes the Kernel Search more effective. To validate the effectiveness and performance of Kernousel, we compared it with the Carousel Greedy, the Kernel Search and the best-known solutions, available in the literature for the problem, on the benchmark instances proposed by Şuvak et al. [5]. The computational tests show the improvements obtained by using these two methods together rather than singularly.

*Keywords:* Carousel Greedy, Kernel Search, Maximum Flow, Conflict Constraints

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# Applications of OR I
## Chair: Lavinia Amorosi

### Exploring integer programming techniques for the hyper-rectangular clustering problem with axis-parallel clusters

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*Abstract* Given a nonempty set of points in the space of an arbitrary (but fixed) dimension, the hyper-rectangular clustering problem with axis-parallel clusters consists in grouping the points into clusters, in such a way that each cluster is determined by a hyper-rectangle in the corresponding space. Up to a certain number of points may be discarded and not included in any cluster, and these points are declared to be outliers. Hyper-rectangular clustering has been proposed as a model for explainable clustering [1], since it is straightforward to describe the obtained clusters by the bounds defining each hyper-rectangle. In this context, if each coordinate corresponds to a relevant parameter in the application generating the given points, then clusters are specified by a lower and an upper bound on each parameter, and this is easier to communicate than a distance-based clustering. Previous works from the literature have taken advantage of this feature of axis-parallel hyper-rectangular clustering [2,4,5]. In this work we are interested in assessing how far standard mixed integer programming techniques can go at solving this kind of problems with optimality. In a previous work [3] we presented a mixed integer programming formulation for this problem, and we explored a large family of valid inequalities that is separable in polynomial time. In this work we continue this study, by presenting a generalization of this family and by evaluating additional separation strategies. We also propose a column-generation-based heuristic for this problem, and we evaluate the practical contribution of this procedure.

*Keywords:* clustering, integer programming, cutting planes column generation

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**Mars Observation Scheduling Problem: optimizing the search for underground water**

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*Abstract* In recent years, the exploration of space beyond Earth has received increasing attention from governmental and private space agencies. The exploration is carried out through space missions, which require a continuous operative effort during their execution. Within this field, our research focuses on MARS EXPRESS, a mission that started in 2003 with the launch of a satellite that since then is orbiting around Mars [1]. The satellite is equipped with several instruments, among which the radar MARSIS, managed by the Italian National Institute of Astrophysics (INAF), which has the purpose of observing Mars's subsurface in order to map the presence of underground water [2].

Our role in this framework is to optimize and automate the generation of feasible schedules for MARSIS observations, with the aim to reach a coverage of the maximal quality of the South Pole of Mars by considering both environmental conditions and instrumental constraints. The resulting optimization problem, called Mars Observation Scheduling Problem (MOSP), is of high difficulty and has been only manually solved until now.

To the best of our knowledge, observation scheduling problems in outer space have been faced only by Paterna et al. [3]. A large number of studies has been produced for Earth Observation Satellites [4], but these are not directly applicable to outer space missions because they have different operational constraints.

In this work, we model MOSP as an Integer Linear Program. Besides, we solve it by means of three constructive heuristics and a matheuristic. We also adopt Machine Learning algorithms to predict the quality of future observations. The algorithms

have been tested on the real data set from INAF, and a combination of matheuristic and gradient boosting obtained the best performance. Different scenarios have been analyzed by attempting several operating configurations of the radar, proving the flexibility and efficiency of the combined algorithm.

*Keywords:* Satellite Observation Scheduling Problem, Matheuristic, Mars Express, Machine Learning

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## Optimal Software Scheduling Decision Using Multi-Attribute Utility Theory

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*Abstract* In the existing literature on software reliability, various authors have developed software reliability models and their related cost models to determine optimal release time. Literature suggests that it is better to segregate the release and testing termination time of the software lifecycle. But all the existing literature in this direction assumes that the cost of providing an update post-software release is negligible. But it looks impractical in a real-life scenario and hence needs to be reconsidered while developing the cost model. This cost of providing patches during the post-release testing phase has an impact on the total software development cost and hence on the software scheduling policy. I have developed a multi-attribute utility function with help of a software cost and reliability model and optimized it to obtain the optimal release, patching and testing termination. A numerical illustration of the proposed model is carried out on a real-life data set.

*Keywords:* Cost model, optimization, Multi-attribute utility theory, Reliability, Patching

**On minimizing the spread of harmful contagions in networks via Benders decomposition**

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*Abstract* The COVID-19 pandemic has been a recent example of the danger of the spread of harmful contagions in networks. The spread of harmful contagions can also occur as computer viruses and malware in computer networks [1] and as spread of fake news in online social networks [2].

In this talk, we present the measure-based spread minimization problem [3], which can be used to model the way how to optimally minimize the spread of harmful contagions in networks. In this problem, we are given a directed graph representing a network, a stochastic diffusion model for the spread in the network, and a set of initially infected nodes from which the spread of the contagion starts in the network according to the diffusion model. We also have a set of labels for the arcs, each of which represents a certain relationship type. Blocking a label means taking a measure that prevents the corresponding contact between every pair of nodes connected via an arc having that label. The goal is to take measures (i.e., remove sets of arcs) in such a way that the spread of the harmful contagion is minimized while respecting a given budget for taking the measures. The problem is related to the spread blocking problems considered in [4].

We present two different mixed-integer programming formulations of our problem: an arc-based formulation and a path-based formulation. Based on these formulations, we develop two branch-and-Benders-cut algorithms. For both formulations the Benders optimality cuts can be generated using a combinatorial procedure rather than solving the dual subproblems using linear programming. Additional improvements such as using scenario-dependent extended seed sets, initial cuts, and a starting heuristic are also considered.

We assess the contribution of various components of the solution algorithms to the performance on the basis of computational results obtained on a set of instances derived from existing ones in the literature.

*Keywords:* network design, integer programming, Benders decomposition

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## Optimizing paths and schedules in crowded events

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*Abstract* In large crowded events, visitors' experiences can be significantly improved by using a planner that, based on its personal preferences, produces a trip for each visitor. Nevertheless, to be effective and provide visitors with the best experience, the trip determined for a visitor cannot neglect those proposed to the other visitors, especially when the capacity of the locations to be visited is limited. This observation calls for the determination of a set of coordinated trips in order to achieve an optimal solution for the global system. By applying a general and graph theoretic representation, we study a setting comprising a set of locations that provide a service, each associated with a capacity and a service time. A set of requests is given. Among other attributes, each request is associated with a set of locations to visit. We assume that a selection of the locations to visit can be made. We also assume that a request queues whenever the capacity available of a location is not sufficient. We study the problem of determining an optimal set of coordinated paths, one for each request, that minimizes a weighted function of the total number of locations not selected and the total time spent queuing. We call Path And Schedule Optimization (PASO) the resulting optimization problem. Based on a time-space network representation, we cast the PASO as a Mixed-Integer linear Program (MIP). Computational experiments are given where the MIP is solved by using a general-purpose solver on a set of randomly generated instances. The experimental analysis shows the potential benefits that can be achieved by using the PASO as a tool to support decision-making.

*Keywords:* Coordinated Approaches, Optimal Paths, Time-Space Networks, Combinatorial Optimization, Mixed-Integer Linear Programming

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## Optimal Drone Routing for Seal Pup Counts

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*Abstract* We introduce the seal pup count using drones problem. Drones, also known as Unmanned Aerial Vehicles (UAVs), are used to fly over a marine archipelago during the birthing season to estimate the number of harbour seal pups. Pup counts are used as an environmental indicator of ecosystem health and as inputs to national wildlife management policies.

We determine minimum cost routes for the UAVs to collect data for the seal pup count, subject to drone battery capacity. The Drone Routing Problem (DRP) can be formulated as a variant of the Capacitated Vehi- cle Routing Problem (CVRP). We demonstrate the DRP on a real case study in the Kosterhavet National Park area in Sweden.

*Keywords:* Drone Routing Problem (DRP), Unmanned Aerial Vehicles (UAV), Ecological Survey, Harbour Seal, MILP, Branch-and-Cut

# Invited Session
# OPTSM – Traffic management and vulnerability
**Chair: Nikola Besinovic**

## Artificial Intelligence for self-organized train re-routing and re-scheduling in real-time

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*Abstract* Effective real-time railway traffic management implies rapid and sound re-routing and re-scheduling decisions to reduce the impact of perturbations. Current approaches typically rely on centralized decision-making by an authority that oversees all the trains in a given control area. An alternative is to treat individual trains as intelligent agents capable of coordinating with one another to determine the best traffic management decisions, without the need for centralized control. This approach may scale more effectively and respond faster to real-time demands. The European project SORTEDMOBILITY [1] proposes an original conceptual design for a self-organizing process where agents (trains) make real-time re-routing and re-scheduling decisions in perturbed-traffic scenarios. The self-organization process is based on decentralized algorithms known as Consensus Protocols [2]. In this research, we present the conceptual design of the SORTEDMOBILITY self-organization process, with particular emphasis on its deployment scenario. We adopt a decentralized consensus algorithm inspired by the Voter Model [3]. Train interactions are modeled with high accuracy (microscopic detail), i.e., down to track-circuits, interlocking and signals. We use a variant of the state-of-the-art RECIFE-MILP algorithm for real-time traffic management [4] to produce re-routing and re-scheduling options on which trains try to reach consensus. We evaluate a preliminary software implementation of this self-organizing process in a realistic setting. This involves simulating traffic in a French control area using the state-of-the-art railway traffic simulator OpenTrack [5]. In the experimental analysis, the proposed self-organization process achieves effective traffic management comparable to the one provided by a centralized approach.

*Keywords:* Railway traffic management, Optimization algorithms, Self-organization, Consensus, Artificial Intelligence

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## How to Identify the Fragility of Train Timetables

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*Abstract* In dense railway traffic, the delay of a single train may propagate through the network, causing a sequence of knock-on delays. During operations, train dispatcher can mitigate such delays by modifying train routes or changing meet/pass points. A more preventive approach consists instead in constructing robust timetables that are better capable of absorbing such delays. Several approaches based on different robustness measures have been proposed in the last decades. However, many of them consider predictions of knock-on delays, not depending on real-time dispatching decisions. An exception is the stream of papers on the concept of recoverable robustness [1,2], which also inspired this work. We introduce the concept of timetable fragility as a way to identify the sections of a train timetable where a primary delay is more likely to generate knock-on delays. Our fragility measure is computed as the price of recoverable robustness, factoring in optimal future dispatching decisions. We define a suitable set of delay scenarios, each containing exactly one primary delay, and compute the optimal dispatching solution for each scenario. The proposed fragility measure can be used by route planners to evaluate the robustness of each section of a timetable and identify the most critical ones. We present computational results on real-life scenarios from a busy railway line in Norway.

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

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volume 9, pages 1-13. Schloss Dagstuhl-Leibniz-Zentrum fuer Informatik, 2008.

# A MILP-Based Railway Conflict Detection and Resolution Model Approximating Moving-Block Signalling

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*Abstract* Railway industry is developing advanced signalling systems like moving block to improve network capacity. In traditional fixed-block systems, safe train separation is determined based on a fixed number of block sections representing worst-case braking distances. In moving-block systems, the train separation is reduced to absolute braking distances. The introduction of moving-block signalling requires a change in operational rules and hence in real-time conflict detection and resolution methods in case of disturbances. Existing conflict detection and resolution models are mainly based on fixed-block signalling and the available models for moving-block signalling do not sufficiently represent the dynamic relation between safe train separation and actual train speeds. To address this gap, we propose a conflict detection and resolution model that approximates moving-block operations. The model enhances the state-of-the-art fixed-block model RECIFE-MILP [1]. The enhancements include a reconsideration of the discretisation of the infrastructure, the introduction of a speed profile alternative and a redefinition of blocking times. With this, the model is able to include speed-dependent occupation times, train separation based on absolute braking distances and continuous braking curve supervision. We present the reformulated MILP (mixed integer linear programming) model and apply it to two French case studies: the Gonesse junction and a part of the Paris-Le Havre line. For various one-hour periods, rescheduling strategies and disturbance scenarios, we compare the optimal solutions of the enhanced and the original RECIFE-MILP model in terms of total train delay and rescheduling decisions. The results show that the enhanced model can propose different rescheduling decisions than the original model, with a better delay recovery exploiting the moving-block system. This research is funded

by the Shift2Rail Joint Undertaking under grant agreement No. 101015416 (PERFORMINGRAIL).

*Keywords:* railway traffic management, conflict detection and resolution, train rescheduling, moving-block signalling, mixed integer linear programming

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**Rescheduling trains in a station with shunting activity considering locomotive resource limitation**

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*Abstract* With the gradual increase in railway demand, train rescheduling has become even more critical to the punctuality and reliability of rail operations. When disruption occurs, the traffic manager can reschedule the timetable by adjusting the arrival and departure time, reassigning the platform, and changing the train order to eliminate and reduce the secondary delay. The station dispatcher needs simultaneously reschedule the shunting plan to avoid conflict with the adjusted train timetable. The operating capacity of shunting yards is often the limiting factor for dispatching. Moreover, the large number of conflicts between shunting movements and other movements in the peak hour might enlengthen the waiting time of the shunting movement thus aggravating the shortage of the shunting locomotives. Therefore, it is very necessary to consider the number of shunting locomotives when scheduling the train arrival, departure, and shunting movements, which has been neglected in previous literature. We define a status set for each train to descript the predefined status at the station according to its operation plan. Based on that, we proposed a time-space-state network representation for describing the sophisticated movements in the station. The associated optimization model is proposed to simultaneously optimize the train schedule and the shunting schedule under the disruption, considering the interconnection and interference of both. A forward-backward rolling time-horizon approach is developed, which is capable of overcoming the disadvantage that a typical rolling time-horizon approach may result in local optimism. We apply the proposed approach to a China railway hub, different solution strategies, sensitivity analysis, and the difference between considering the shunting operations or not are compared, which shows the ability of the approach to automatically compute a feasible, rapid, and robust result for both rescheduling and shunting operations.

*Keywords:* railway rescheduling, train operation optimization, shunting, time-space-state network

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## Model-predictive control of traffic emissions in port-city environment

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*Abstract* In this paper we present a method, based on model predictive control (MPC), to reduce the impact of pollutant emissions in contexts where a port is located within a city. To this purpose, we first introduce a dynamic model of the interactions between truck flows generated by the port and general mobility traffic in the shared urban infrastructure at the port-city interface. In order to keep track of the multiclass and complex nature of the system, the model takes advantage of microsimulation and deep learning for the prediction of road network traffic and related pollutant emissions. Then, we define a MPC control scheme exploiting the proposed model, to be used in real time to maintain the emissions levels below a certain threshold by appropriately adjusting traffic inflows from the port to the city, which represent the controls optimized by the MPC procedure. A simulation case study, involving the port of Genova in north-west Italy, is presented to showcase the ability of the proposed MPC scheme to control emissions in the shared area, also in complex situations such as transitions to mobility rush hours.

*Keywords:* Emissions optimization, port-city traffic, model-predictive control, deep learning

## Vulnerability envelopes for railway transport networks

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*Abstract* In railway networks, multiple disruptions occur causing extreme challenges to both operators and passengers. In these cases, the operators need to significantly cancel and adjust the existing services, while passengers are required to find an alternative, most likely longer, route to their destinations, or even completely cancel their journeys. In railways, various causes from natural (e.g. flood, earthquake, blizzard), and resource failures (e.g. broken switch, signal failure, failed train) to man-made (e.g. malicious attacks), lead to frequent occurrences of multiple simultaneous disruptions. However, the system dynamics and performance during (multiple) disruptions still remains understudied. Network vulnerability represents the performance measured typically against the critical disruption scenario, i.e. a combination of simultaneous disruptions, that harms the passenger traveling the most. Existing optimization-based literature in railway resilience and vulnerability focuses mainly on finding contingency plans [1], locating emergency trains [2], scheduling response multimodal services [3] and determining critical disruptions [4]. In this paper, we explore a concept of a vulnerability envelope to describe an expected performance for any given (reasonable) number of disruptions. To model the given problem, three interdependent networks are combined including infrastructure, train operations and passenger flows. This research extends on [4]. We present the initial results on the Dutch railway network. Based on the vulnerability envelope of the system, the railway operator can directly understand the expected level of deterioration in the network. This could help them to take appropriate response and recovery strategies to minimize the impacts and restore the system as soon as possible.

*Keywords:* railway, vulnerability, MIP, passengers

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# Invited Session
# OPTSM – Integrated Train Timetabling
**Chair: Lingyun Meng**

## Rail Freight Operation Plan for Integrated Dispatching of Railway Bureau and Yards

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*Abstract* The dwell time of freight trains is usually uncertain, and the bureau dispatcher usually has no knowledge of the progress of yard operations until trains are assembled at the departure bowl. The reason for this phenomenon is the complexity of yard operations. A valid yard plan pairs all initially parked blocks at the classification bowl, as well as all trains or blocks that arrive during the day, with compatible departures train. Furthermore, a feasible solution must be assigned to operation in conflict-free and resources-available manner. In a shunting yard, different types of operations bring changes of the train itself. Furthermore, the movement of trains in different statuses within the yard requires the assistance of shunting engines. Finally, the corresponding locomotive is also required for entering or departing the yard. Therefore, the "multi-state" of train and block in the yard need to be defined. In a global network, different types of rail flows move between multiple yards and accomplish status transitions. These rail flows have complex coupling within the yard. To characterize that, we propose a three-layer time-space network to represent adequately consolidation activities proper to railroad transportation, railcars into blocks and blocks into trains, as well as the three types of rail flows movements, namely, railcars, blocks and trains. This research can significantly improve the efficiency of rail freight dispatching, collaborative optimize freight operations of node (yard) and edge (mainline) allows for more efficient use of the capacity in the global railway network. In specific rail freight facilities, the uncertainty and randomness of operations can be described in more detail, bottlenecks of shunting process, and scarcity of resources can be identified. Micro-operations at the yard can be described in a macro perspective. It will also provide a novel and efficient approach to addressing the consolidation and decomposition nature of railways.

*Keywords:* freight, shunting yard, dispatching, space-time network

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## Integrated train timetable with supply-demand interactions

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*Abstract* In traditional railway operations, train timetable and unit assignment are usually separated from pricing and seat allocation, resulting in revenue loss or operating cost increase. In this paper, we present an integrated optimization approach for train timetable, unit assignment, pricing, and seat allocation under endogenous passenger choice. This integration enables us to explicitly model supply-demand interactions and takes superior decisions. Passenger choice is captured by a multinomial logit (MNL) model and a customized expectation maximization (EM) method is developed to estimate passenger preference coefficients based on real booking data. The resulting optimization model is formulated as a mixed-integer nonlinear programming to maximize total expected profit. By taking the equivalent form of the MNL model, we recast the model as a tractable reformulation that allows the usage of a general-purpose solver to solve instances with realistic sizes. Based on the real data from high-speed railway lines in China, two sets of case studies are carried out to validate the effectiveness and efficiency of the proposed approach. This paper makes the following contributions. First, to our knowledge, this is the first study that optimizes the train timetable, unit assignment, pricing, and seat allocation under endogenous passenger choice. The resulting model is formulated as a mixed integer nonlinear programming. Second, we develop a tractable reformulation of the proposed model. By taking the equivalent form of the MNL model, the proposed model is first transformed into a bi-level programming model with a convex lower-level problem. With the Karush-Kuhn-Tucker (KKT) optimal condition of the lower-level problem, the bi-level programming model is further reformulated into a tractable single-level model.

*Keywords:* train timetable, pricing, passenger choice, mixed-integer nonlinear programming

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# Passenger-oriented integrated optimization of the train rescheduling, platforming, and gate reassignment problem for the large-scale station of high-speed railway

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*Abstract* The train platforming and rescheduling problem (TPRP) aims to adjust the train arrival and departure time with the assigned platform to reduce the total delay time and the deviation from scheduled plan. Recently, passenger satisfaction are concerned in TPRP during the disruption. The passenger service section in China complains that the TPRP ignoring the gate's operation rules will increase passenger dissatisfaction. First, the number of gates open at the same time is limited. The opening of the gates must be equipped with corresponding staff to ensure that passengers get on the trains in an orderly, punctual, and safe manner. Furthermore, the adjustment of gates will increase the travel distance of passengers. Hence, the train rescheduling, platforming, and gate reassignment problem should be optimized simultaneously to provide a passenger-oriented service. We propose a novel mixed integer linear programming(MILP) for the integrated optimization of train rescheduling, platforming, and gate reassignment problem(TRPGP) to minimize the total delay of trains. Based on the constraints regarding train platform arrangement, train route selection, train dwell time, and track conflict-free requirements in the TPRP, the constraints related to the operation of gated are guaranteed in our MILP. Assisted by the decision variables of begin and end time of the gated, and the 0-1 sequential indicator decision variables on the assignment of gate, the limitation of operated gates, gates conflict avoidance, the relationship of train departure time and gate begin time are enforced in our TRPGP model. As our MILP is an NP-Hard problem, a Hyper-Heuristic(HH) algorithm is developed. The proposed model and algorithms of TRPGP are verified in the case of the Chengdu East high-speed railway station in China. Compared with TPRP, our MILP can reduce passenger dissatisfaction. The experimental results on different instances reveal the efficiency and scalability of the HH algorithm.

*Keywords:* train platforming and rescheduling problem, gate reassignment, mixed integer linear program, Hyper-Heuristic

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**A new integrated optimization model for high-speed rolling-stock planning and maintenance scheduling**

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*Abstract* In this talk, the problems of rolling-stock planning and the management of maintenance processes of high-speed trains is studied, using a new integrated approach that considers the close link there is between these two problems. It is possible jointly to minimize the number of used asset units, the number of maintenance operations and the number of train movements within the maintenance workshop. This is achieved also by a graph model introduced to avoid deadheading trips and for planning time windows to perform maintenance activities. Moreover, the formulation embeds the computation of the cumulative number of kilometres travelled by the asset units with respect to each maintenance level. Another key issue, included in the formulation, is the modelling of dedicated resources with limited capacity and the computation of train movements among the platforms, as the operational constraints are quite de-structured and very difficult to formalize in a linear model. Nevertheless, the computational results obtained by running the model on different time horizon instances up to three weeks, derived from a real-world case study of an Italian railway company, show that the formulation can be solved to optimality, or deliver very good solutions with a small percentage gap in two hours. This makes the proposed MILP model usable in practice as the planning problem considered refers to time horizons consisting of different numbers of weeks. Moreover, this approach is compared with a two-stage approach, commonly used in practice and in the literature. The results of this comparison show that the rolling-stock planning problem can produce input parameters (time windows) for the scheduling problem for which no feasible schedules exist (owing to the limited capacity of the platforms in the maintenance workshop). In the cases in which a scheduling solution exists, the final percentage gap of the two-stage solution is much higher than that provided by the integrated model.

*Keywords:* high-speed trains; mathematical modelling; rolling-stock planning; scheduling maintenance, optimization

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**Rescheduling metro trains in the over-crowded situation after disruptions with virtual coupling technology**

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*Abstract* This study focuses on the over-crowded situation after disruptions, contributing to fill the gap that applying virtual coupling technology in rescheduling problems in the metro lines. Specifically, both stop-skipping instructions and virtual coupling/decoupling instructions are considered to be sent to the trains in real-time, and a mixed-integer nonlinear programming (MINLP) model is built based on this two kinds of instructions. The proposed model is solved by GUROBI after linearization, and computational results based on a real-world metro line show that by applying virtual coupling technology, the total waiting time of passengers could significantly reduce by nearly 50%. In addition, it is verified that combining virtual coupling technology with the stop-skipping strategy could have an advantage compared with only applying the virtual coupling technology.

*Keywords:* Train Rescheduling, Stop-skipping Strategy, Virtual Coupling

# Optimization model and algorithm of train timetable structure for train timetable resilience enhancement

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*Abstract* For fully meeting the transportation demand, railway network has gradually become density and busy, making a close coupling relationship between trains. However, this leads to the severe delay propagation between trains, when disturbance occurs. As a key factor of the railway system, train timetable resilience gives the train timetable the ability to resist disturbances, so it is important to improve the train timetable resilience to ensure train operation. The key to improve the train timetable resilience is to reduce the propagation of train delay, and the structure of train timetable plays a decisive role in this regard. Vromans et al.(2006) studied the heterogeneity and reliability of train timetable. And Meng et al.(2010) researched the relationship between the structure and dynamic performance of train timetable. When the heterogeneity of train timetable is high and the number of train overtaking is large, the structure of train timetable is complicated, and once the disturbance occurs, it will constitute a complex delay propagation chain between trains. So, it is necessary to improve the train timetable resilience by reasonable optimization of train timetable structure. Therefore, this paper studies the optimization of the train timetable structure based on the improvement of the train timetable resilience. In this paper, we take the maximum train timetable resilience as the objective function, that is, the minimum heterogeneity of train timetable and the minimum number of overtaking, and construct a train timetable structure optimization model, moreover, design a two-stage solution algorithm. Furthermore, we have conducted a case study on the Beijing-Shanghai high-speed railway in China, and the results show that the train timetable structure optimization model and algorithm we proposed is effective. And we further verify by simulation that the train timetable structure optimization method has a significant effect on improving the train timetable resilience.

*Keywords:* Train timetable structure, Train scheduling, Heterogeneity, Resilience, Overtaking

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# Plenary Lecture
## Chair: Giovanni Felici

### The Role of Geometry in Intelligent Cities of Tomorrow

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*Abstract* The ability to predict, test and evaluate different urban management strategies is becoming an important asset to support a sustainable future for our cities, enabled by the technologies shaping the Smart City concept. In this context, modeling and simulation will play a key role in the development of so-called "digital twins" of urban scenarios, including 3-D models of the urban built environment. But what kind of models are needed to represent the geometries that occur in complex urban areas? What kind of geometric models are needed and how should they be designed to support the transition from smart to intelligent urban models? The talk will address this issue by showing approaches to building 3-D digital models and discussing how they intervene in decision-making processes related to urban management.

# Scheduling I
## Chair: Mauro Gaggero

### Compact Optimization Models for the Sub-Tree Scheduling of Wireless Sensor Networks with Partial Coverage

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*Abstract* Given an undirected graph G whose edge weights change over s time slots, the sub-tree scheduling for wireless sensor networks with partial coverage asks to partition G into s non-empty trees such that the total weight of the trees is minimized. In this work we show that the problem, first presented in [1], is NP-hard, exploiting a reduction from the cardinality Steiner tree problem. Then we propose new compact integer linear programs modelling the problem. They are obtained from the non-compact model presented in [2] by replacing an exponential-size family of subtour elimination constraints by one of the following: 1) constraints involving flow variables; 2) constraints involving arborescence variables; 3) MTZ-like constraints. We show that, in all of our formulations, the variables associated with the new constraints can be relaxed to be continuous. Therefore, we test and compare the proposed formulations exploiting various algorithmic frameworks offered by commercial MILP solvers, namely: standard branch-and-cut, branch-and-cut with custom branching priorities and Benders' decomposition. We discuss the performance of these algorithms depending on the sparsity and size of the graphs representing the instance networks. Finally, we compare the performance of our algorithms with that of algorithms presented in the literature.

*Keywords:* Wireless sensor network, Scheduling, Compact integer linear program, Computational complexity

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**Using Self-Supervised Learning to Solve the Job Shop Scheduling Problem**

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*Abstract* The Job Shop Problem (JSP) involves scheduling sequences of operations (jobs) on machines by minimizing the makespan [1]. A JSP instance is often represented with a disjunctive graph, where jobs are given by chains of nodes (operations) connected by directed arcs, and dashed disjunctive edges identify operation pairs to execute on the same machine. Our novel approach tackles the JSP as a sequence of decisions nicely represented by a branch-decision tree. At each decision node, we explore all the possible job selections for scheduling the next operation. We use an encoder-decoder architecture [2], where the Graph Attention Networks [3] encoder creates embeddings for operations from the disjunctive graph, and the decoder generates solutions from embeddings and contextual information by producing at each decision node a probability of selecting each job. We train this model on a small dataset using self-supervision by sampling multiple solutions and refining predictions based on the best one. Our model outperforms Priority Dispatching Rules [1] and Reinforcement Learning [4][5] on benchmark instances, with up to 20% reduction in optimality gaps. It is also efficient in terms of hardware, supervision, and number of training instances.

*Keywords:* Deep Learning, Job Shop Scheduling, Self-Supervised Learning

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## Modeling and solution methods for the ground trolley based automated container terminal system

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*Abstract* In traditional automated container terminals, storage blocks are laid perpendicular to the apron. The Rail Mounted Gantry crane (RMG) frequently moves along a block for pick-ups or drop-offs. To reduce such gantry moves, a new container terminal design is proposed, in which the perpendicular block is equipped with a RMG and a sidekick Ground Trolley (GT). The RMG can handle containers by itself, or utilize the sidekick GT for container delivery. Unlike the traditional crane scheduling problem (CSP), the makespan is not merely determined by the job sequence, but also affected by the GT allocation and the RMG-GT synchronization. This novel optimization problem is defined as the crane scheduling problem with sidekick (CSP-S). Modeling and solution methods catered for the CSP-S will be discussed in this study.

*Keywords:* Automated container terminal, Crane scheduling, Ground trolley collaboration.

## Arc-flow formulations for makespan minimisation on parallel machines with a common server

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*Abstract* In many manufacturing systems, a common server such as a human operator, a robot, or a tool needs to be shared by a number of parallel machines to implement setups or loads. Scheduling problems with a single server occur frequently in automated material handling systems; in flexible manufacturing systems where an automated guided vehicle is used to load jobs on machines [3]. We consider here the problem of scheduling non-preemptively a set of jobs on parallel identical machines with prior setup operations on a single shared server, where the objective is to minimise the makespan. Seminal contributions to the problem mostly consider two machines with equal processing or setup times and provide complexity analyses and solution methods [2,3,5]. The problem with an arbitrary number of machines was first optimally addressed by [4] who provided two mixed integer programming formulations. To solve the problem, we develop an arc-flow formulation with two multigraphs, one for the machines and one for the server, with the same set of nodes representing points in time, and arcs associated with job execution, and with machines or server idleness. The resulting Flow-Flow formulation (FFF) and its tuned version (FFT) are compared with the best existing model in the literature [1] which is based on an improved time-indexed formulation named TIV I, on benchmark instances with up to 200 jobs and 7 machines. Computational results showed that our Flow-Flow models outperformed the relevant literature for instances with 100 jobs and produced optimal solutions to the majority of problems with 150 and 200 jobs for which TIV I failed to even find integer solutions within the standard limited runtime of 3600 s. When non-optimal solutions provided by our models exhibited very low gaps to best bound. We also proved that the optimal solution of the continuous relaxation of our model is never lower than the preemptive lower bound, which is not the case for the

TIV I formulation.

*Keywords:* arc-flow formulation, common server, parallel machine

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**Variable Neighborhood Search for the Just in Time Job Shop Scheduling with sequence dependent setup times**

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*Abstract* In this work we address the Just in Time (JIT) job shop scheduling, extending the problem addressed in [2] by the introduction of sequence-dependent setup times and release dates. The goal of JIT scheduling is to complete jobs as close as possible to their due dates. Thus, JIT models feature a non-regular objective function, encompassing both earliness and tardiness penalties. Earliness captures the holding cost of the finished jobs, while tardiness accounts for the cost of customer compensation for missing the due date or the loss of goodwill. Nevertheless, considering only earliness and tardiness may lead to schedules in which the first operation of several jobs is processed as early as possible and the last ones close to the due date, thus inducing waiting times and storage costs which contradict the JIT philosophy. While this issue can be solved by enforcing operation due dates if set up costs are not considered [2], this cannot be done if they are. Thus, we introduce a term in the objective function which accounts for the flow time (i.e., the difference between the completion time of the last operation and the starting time of the first one). Using the three-field notation of [3] the problem that we face is: $J|r_j, ST_{sd}|w_j^E E_j + w_j^T T_j + w_j^F (C_j - S_j)$. As in [1], to get good solution in a reasonable amount of time we decompose the problem in sequencing (i.e., decide the order for performing the operations) and timing since, if a feasible sequence is provided an optimal schedule for the given sequence can be obtained in polynomial time by solving a linear programming model [4]. Then, we develop a reduced variable neighbourhood search (VNS) to guide the search in the space of sequences. We define the neighborhoods using several different destroy and repair operators, and we compare their performances. We show that repair operators based on mathematical models outperform other ones, and we analyse the performance of two families of destroy operators: One based on random selection, and one leveraging information from the dual variables of the timing problem. Finally, by solving a set of instances ranging from 5 to 50 jobs and 50 to 500 operations, we prove the effectiveness of the proposed VNS algorithm.

*Keywords:* Just in Time Scheduling, Sequence Dependent Setup Times, VNS

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## A Computational Journey in Job Scheduling with Time-of-Use Costs

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*Abstract* We present recent advances on both exact and heuristic algorithms for the bi-objective identical parallel machine scheduling with Time-of-Use costs problem. This problem belongs to the field of energy-efficient scheduling, which has received a large attention during the last years in the literature on sustainable manufacturing. As a novel contribution, we investigate how multithreaded computation is able to improve the performances of the current state-of-the-art approaches over a set of problem instances characterized by different sizes, ranging from small to large.

*Keywords:* scheduling, Time-of-Use costs, mixed-integer linear programming, heuristics, multi-threaded computation

# Stream AIRO thematic section on Stochastic Programming Optimization under Uncertainty
**Chair: Michele Monaci**

## Benders Adaptive-Cuts Method for Two-Stage Stochastic Programs

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*Abstract* Benders decomposition [1] is one of the most applied methods to solve two-stage stochastic problems (TSSP) with a large number of scenarios. The main idea behind the Benders decomposition is to solve a large problem by replacing the values of the second-stage subproblems with individual variables, and progressively forcing those variables to reach the optimal value of the subproblems, dynamically inserting additional valid constraints, known as Benders cuts. Most traditional implementations add a cut for each scenario (multi-cut) or a single-cut that includes all scenarios (see [2], for example). In this paper we present a novel Benders adaptive-cuts method, where the Benders cuts are aggregated according to a partition of the scenarios, which is dynamically refined using the LP-dual information of the subproblems. This scenario aggregation/disaggregation is based on the Generalized Adaptive Partitioning Method (GAPM), which has been successfully applied to TSSPs in [3,5]. We formalize this hybridization of Benders decomposition and the GAPM, by providing sufficient conditions under which an optimal solution of the deterministic equivalent can be obtained in a finite number of iterations. Our new method (see [4]) can be interpreted as a compromise between the Benders single-cuts and multi-cuts methods, drawing on the advantages of both sides, by rendering the initial iterations faster (as for the single-cuts Benders) and ensuring the overall faster convergence (as for the multi-cuts Benders). Computational experiments on three TSSPs validate these statements, showing that the new method outperforms the other implementations of Benders method, as well as other standard methods for solving TSSPs, in particular when the number of scenarios is very large

*Keywords:* Two-stage Stochastic Programming, Benders Decomposition, Adaptive-Partition Method, Electricity Planning, Stochastic Multi-Commodity Flow, Conditional Value-at-Risk, Facility Location

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## The berth allocation problem under uncertainty: a distributionally robust optimization approach

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*Abstract* Port terminals play a critical role in maritime transportation. There are several optimization problems occurring in port terminals, and the berth allocation problem (BAP) is amongst the most important ones. It consists of determining berth positions and berthing times of the vessels taking into account their arrival time, handling time, and length. The first two parameters are highly affected by uncertainty due to many factors such as weather conditions and mechanical failures. Therefore, it is crucial to take uncertainty into account when approaching BAPs [1]. Robust optimization and stochastic programming are the most common approaches used to deal with uncertainty in BAPs, and such uncertainty is frequently represented by a discrete set of scenarios. Here, we study the BAP under a distributionally robust optimization (DRO) approach [2]. We assume that each vessel has an associated deadline to finish its operations, but delays can occur. Therefore, we aim to minimize the worst-case of the expected sum of delays of vessels with respect to a set of possible probability distributions of the handling times. The proposed model is solved by an exact algorithm enhanced with several improvement strategies that drastically reduce the associated running time. The DRO model depends on a risk-parameter that makes it possible to obtain solutions with different degrees of protection against the risk. In particular, the DRO model reduces to a stochastic programming model when the risk-parameter takes value 0 and to a robust optimization model when it takes a sufficiently large value. Extensive computational results comparing DRO, stochastic programming, and robust optimization are also reported.

*Keywords:* distributionally robust optimization, berth allocation, uncertainty

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**Drivers' reservation as a mitigation strategy for occasional drivers' absenteeism in last mile delivery: A two-stage stochastic approach**

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*Abstract* The advent of e-commerce and the exponential increase of its popularity made last mile delivery an extremely challenging issue. Although e-commerce giants like Amazon already have their well-established delivery network, which allows them to keep delivery operational costs low, fulfilling a very large number of orders is still a great challenge for small sized companies, [1]. Maintaining a fleet of owned vehicle, able to handle demand peaks, would be too costly for the company. One of the attractive solutions adopted to reduce delivery cost is to employ Occasional Drivers (ODs), who are freelancers without a fixed contract ODs are usually willing to perform, according to their availability, one or more deliveries in front of a little compensation. Thus, ODs often result to be cheaper compared to corporate drivers because they do not imply any fixed cost. However, since their collaboration with the company is not ruled by a contract, the degree of absenteeism of ODs, who accept to perform some delivery tasks and then do not show, is alarming high, and this can negatively impact the delivery system performance. To mitigate absenteeism effects, we propose a mitigation strategy based on drivers' reservation, according to which we pay drivers for guaranteeing their presence and being exploited to fulfil tasks remained uncovered due to ODs absence. The resulting decision problem can be modelled as Two-Stage Stochastic problem in which at the first stage we decide the assignment of tasks to ODs, and which ODs to reserve, while at the second stage, once ODs absences are revealed, we decide the assignment of uncovered tasks to reserved ODs, in order to minimize the total expected costs (assignment, reservation and penalty costs for rejecting customers) over a set of ODs absence scenarios. To efficiently handle large size instances, we propose a self-learning matheuristic, which can be easily generalized to solve a broad class of stochastic problems sharing a similar structure.

*Keywords:* last mile delivery, stochastic optimization, occasional drivers, matheuristic

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## Solving the Online On-Demand Warehousing Problem

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*Abstract* We investigate an online version of the On-Demand Warehousing Problem (ODWP) proposed by [1], which consists of assigning stocking space, available at suppliers, to customers' requests, with the goal to maximise the total number of requests satisfied. The Online ODW problem can be modeled as an online stochastic reservation and assignment problem, where new requests of customers come online and must be dynamically assigned to suppliers in order to maximize the total number of satisfied requests in the given time horizon. Firstly, we adapt the online stochastic combinatorial optimization (OSCO) framework introduced by [2] to the Online ODWP, and implement expectation, consensus, and regret algorithms. The key idea of the OSCO approach is to generate samples of future requests by evaluating possible allocations for the current request against these samples. Then, we develop two greedy algorithms: the first one follows a first fit strategy, i.e. it selects the first compatible supplier which can satisfy the request; the second one identifies potentially risky assignments based on the remaining capacities of suppliers. This way we penalize assignments that create "capacity holes", which are probably difficult to be filled with future requests. All solution methods are compared on a dataset of realistic instances of different sizes and features, demonstrating their effectiveness with respect to the oracle solutions, which are based on the assumption of perfect information about future requests arrivals.

*Keywords:* on demand warehousing, stochastic optimization, online algorithms

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## Adjustable robust optimization with discrete uncertainty

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*Abstract* We consider optimization problems in which uncertainty may affect some parameters and the decision flow works in two steps: some decisions must be taken here-and-now, whereas some other decisions can be taken later, depending on the former and on the actual value of the parameters. We consider the case in which uncertainty has a discrete support and appears both in the objective function and in the constraints. We show that, in this setting, Adjustable Robust Optimization (ARO) problems can be exactly reformulated as ARO problems with objective uncertainty only. This reformulation is valid with and without the fixed recourse assumption and is not limited to continuous wait-and-see decision variables, unlike most of the existing literature. Additionally, we extend an enumerative algorithm akin to a branch-and-cut scheme for which we study the asymptotic convergence. We discuss how to apply the reformulation on two variants of well-known optimization problems: a Facility Location Problem in which uncertainty may affect the capacity values and a Multiple Knapsack Problem with uncertain weights, and we report extensive computational results demostrating the effectiveness of the approach.

*Keywords:* two-stage robust optimization, discrete uncertainty, branch-and-cut

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# Invited Session
# Optimization Techniques for Hard Problems
### Chair: Veronica Piccialli/Antonio M. Sudoso

## Supervised Discretization of Continuous Features in Machine Learning

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*Abstract* This presentation will focus on a novel combinatorial optimization technique for the supervised discretization of datasets with continuous features. Discretization is essential in many data mining and machine learning applications, as it transforms continuous data into discrete values that are easier to analyze and interpret [1]. However, traditional discretization techniques do not consider the target variable, which can lead to suboptimal results [2]. Our proposed method addresses this limitation by formulating the discretization problem as a combinatorial optimization problem. Our objective is to maximize the compression rate and minimize the inconsistency rate of the discretized dataset [3]. The compression rate measures the reduction in the number of distinct values, while the inconsistency rate measures the proportion of points in the dataset that have different target variables but are discretized into the same interval. The inconsistency rate captures the degree to which the discretization process distorts the underlying relationship between the continuous feature and the target variable, potentially leading to suboptimal model performance; by minimizing the inconsistency rate, our method aims to preserve the discriminatory power of the original continuous feature, while still achieving the benefits of a discrete representation. While this is an early-stage work, we believe that our proposed method has the potential to significantly improve the accuracy and interpretability of machine learning models.

*Keywords:* Machine Learning, Interpretability, Combinatorial Optimization

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**Network Reliability Optimization: Using Convex Envelopes and Spatial Branch-and-Bound**

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*Abstract* Designing a reliable network is an important problem in optimization literature, with many applications in our daily lives and promising future uses. Given a simple undirected graph, edges may fail randomly with a non-homogeneous probability. The reliability of the network is defined as the probability that a specific subset of nodes remains connected. The network reliability optimization problem involves determining which edges to construct within a predefined budget to maximize the reliability of the resulting network. In this presentation, we explore how to use convex envelopes to approximate this non-linear non-convex integer programming problem. We discuss the use of reliability-preserving reductions and classical convex envelopes of bilinear functions, and introduce a new family of convex envelopes for expressions involved in evaluating network reliability. Moreover, we exploit the refinements produced by spatial branch-and-bound to locally strengthen our convex relaxations. For series-parallel networks, this technique allows to obtain the exact optimal solution for networks with up to 100 edges. For general graphs, this approach can significantly reduce the size of the problem, making it suitable for other techniques such as sampling approximations.

*Keywords:* Network Reliability Optimization, Network Design, Convex Envelopes

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## A class of new cutting planes for SDP relaxations of stable set and colouring problems

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*Abstract* Stable set and colouring problems are fundamental combinatorial optimization problems. A standard method in combinatorial optimization is to write a problem as a linear problem with integer variables, and then to consider its relaxation in order to get bounds on the optimal solution. This research focuses on bounds which are obtained by semidefinite relaxations using semidefinite programming. A famous semidefinite relaxation for both stable set and colouring problems is the Lovász theta function. We consider tightening of the Lovász theta function which can be achieved by adding valid inequalities into the formulation. We combine the ideas of some of the existing inequalities and derive new cutting planes for both problems. Finally, we investigate the bounds obtained by adding the proposed inequalities. We compare our bounds with existing relaxations and present computational results.

*Keywords:* Stability number, Chromatic number, semidefinite programming

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## Optimizing Semi-Supervised Support Vector Machines using Semidefinite Programming

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*Abstract* Support vector machines (SVMs) are well-studied supervised learning models for binary classification. They have proven to be powerful machine learning techniques and highly efficient algorithms exist to solve the occurring optimization problems. However, most data in real life is unclassified, leading to semi-supervised support vector machines (S3VMs) instead. State-of-the-art MIP and MINLP solvers can only solve small S3VM instances to optimality. In this talk, we a present a new branch-and-cut approach for S3VMs using semidefinite relaxations. At each branch-and-bound node, we strengthen the bounds by adding RLT cutting planes and applying bound tigthening techniques. We provide numerical results showing that our approach is capable of producing very small duality gaps for real-world instances.

*Keywords:* Semi-supervised support vector machines, Semidefinite programming, Global optimization

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## Fix and Bound: An efficient approach for solving large-scale quadratic programming problems with box constraints

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*Abstract* We propose a branch-and-bound algorithm for solving nonconvex quadratic programming problems with box constraints (BoxQP) [1, 2]. Our approach combines existing tools, such as semidefinite programming (SDP) bounds strengthened through valid inequalities with a new class of optimality-based linear cuts which leads to variable fixing [3]. The most important effect of fixing the value of some variables is the size reduction along the branch-and-bound tree, allowing to compute bounds by solving SDPs of smaller dimension. Extensive computational experiments over large dimensional (up to n=200) test instances show that our method is the state-of-the-art solver on large-scale BoxQPs.

*Keywords:* nonconvex quadratic programming, global optimization, semidefinite programming

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## Dynamic constraint aggregation for solving the minimum sum-of-squares clustering problem

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*Abstract* The minimum sum-of-squares clustering problem (MSSC), also known as k-means clustering, refers to the problem of partitioning n data points into k clusters, with the objective of minimizing the total sum of squared Euclidian distances between each point and the center of its assigned cluster [1, 2]. We propose an efficient algorithm for solving large-scale MSSC instances in two-dimensional Euclidean space, which combines column generation (CG) with dynamic constraint aggregation (DCA) to effectively reduce the number of constraints considered in the CG master problem [3]. DCA reduces degeneracy by utilizing an aggregated restricted master problem obtained from a suitable aggregating partition of the set of data points into disjoint clusters. Our computational results demonstrate that the proposed algorithm significantly outperforms existing CG-based approaches available in the literature.

*Keywords:* column generation, clustering, global optimization

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# Invited Session
# Equilibria, variational models and applications
### Chair: Mauro Passacantando

## Commitment-based strategies for reforestation

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*Abstract* Apart from a few exceptions ([1,2,3]), the environmental economic literature deals separately with pollution control [4] and deforestation [5]. Here, a non-cooperative continuous-time dynamic model is formulated, in which a producer and a deforester both opt for commitment-based strategies. In this setup, and given the benchmark provided by a cooperative solution [3], we investigate the following issues: - whether the forest's restoration should be done by the deforester (as the forest's owner) or outsourced to the producer (the forest's non-owner); - whether non-cooperative strategies for either of the two scenarios above can eliminate history dependency. We show that, in an open-loop Nash equilibrium, the environmental absorption efficiency can be restored indifferently by the deforester or by the producer. Also, compared with the cooperative solution, the possibility of the existence of multiple, history-dependent steady states persists with commitment-based strategies, regardless of whether the restoration efforts of the environmental absorption efficiency are undertaken by the deforester or by the producer. Research supported by Galileo 2019 project IT n. G19-48, FR n. 42089QH. G. Gnecco and M. Sanguineti are members of GNAMPA-INdAM.

*Keywords:* pollution, deforestation, cooperative solution, non-cooperative strategies

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## On the approximation of the Shapley value via machine learning in parametrized transferable utility games

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*Abstract* The Shapley value [1] is a classical solution concept from cooperative game theory. It represents a measure of importance of each player in a transferable utility game. Recently, it has been used to evaluate the importance of each link [2] or node [3] in a network. Nevertheless, its computation is typically time-consuming, especially in the case of large networks. In this talk, we investigate the issue of approximating the Shapley value in a transferable utility game defined on a network that is parametrized by a quantity of interest (e.g., the traffic demand). Smoothness of the Shapley value with respect to the parameter is analysed and exploited to apply machine-learning techniques [4] (e.g., support vector machines, neural networks, etc.) for its approximate computation. The focus is on a case-study in which the Shapley value is actually known, hence a ground truth is available. Finally, the application of the proposed approach to transferable utility games defined on real-world networks is discussed. Research supported by the GNAMPA-INdAM 2023 project "Sviluppo di metodi di machine learning per la stima del valore Shapley e di sue generalizzazioni", code CUP_E53C22001930001. G. Gnecco, M. Passacantando, and M. Sanguineti are members of GNAMPA-INdAM.

*Keywords:* transferable-utility games, Shapley value, approximate computation, machine learning

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## Dealing with Inexactness in Hierarchical Multi-Portfolio Selection

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*Abstract* We address the multi-portfolio selection problem where two decisionmaking levels are considered: account owners and managers play different Nash Equilibrium Problems. We rely on a Tikhonov approach allowing for inexactness to obtain approximate solutions. We corroborate our analysis with numerical results.

*Keywords:* Generalised Nash Equilibrium Problems, Hierarchical Programs, Tikhonov Method, Inexact Equilibria, Multi-Portfolio Selection

## On the equivalence between maximum flow blocker and interdiction problems

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*Abstract* Given a directed graph with capacities and interdiction costs on its arcs, the maximum flow blocker problem (MFBP) asks to find a minimum-cost subset of arcs to be removed from the graph, i.e., interdicted, in such a way that the remaining maximum-flow value does not exceed a given threshold. The MFBP has applications in telecommunication networks and in the monitoring of civil infrastructures, among others. It is closely related to the Maximum Flow Interdiction Problem (MFIP), which asks to find a set of interdicted arcs that respect a given budget, such that the maximum flow value remaining in the graph is minimized. Based on the works of [1] and [2] for the MFIP, we prove that the MFBP and the MFIP are equivalent. In other words, one can transform an instance of the MFBP to one of the MFIP and vice versa. We then derive an integer formulation for the MFBP and obtain some complexity results. Finally, we extend this property to variants of the problem, involving removal of vertices instead of arcs and reduced capacities for the interdicted arcs.

*Keywords:* Combinatorial optimization, blocker, interdiction, bilevel, maximum flow

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## Multi-Periodic Distributional-Robust Stackelberg Game with Environmental Corrective Actions

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*Abstract* In this paper, we build an algorithm to optimize a leader-follower game with environmental corrective actions. Different policies have been studied to reduce human activities' footprint on environmental pollution and climate change. Two of the most common policies are capacity constraints and emissions-correcting taxes. By mandatory capacity constraints, the manufacturer cannot exceed a certain level of capacity. Correcting tax regulation, On the other hand, creates an additional cost for the manufacturer on each unit of production/pollution, meaning that the manufacturer must pay a tax cost for each unit of pollution. In our proposed model, a corrective tax is calculated by the government and is put on the manufacturer to remove the pollution he has produced. Then the players optimize their problem given this tax. In our Stackelberg game, the manufacturer, as the leader of the market, and the retailer, as the follower, aim at maximizing their expected discounted total profits under these two environmental constraints. This channel consists of multi periods where at each period, the manufacturer declares his wholesale price w, and the retailer makes his decisions on retail price r and order quantity q afterward. The demand of our market lacks complete information, and the only available knowledge about demand is the mean and standard deviation since it is either impossible or costly to achieve comprehensive information. As a result, the problem needs to be solved in a distributional-robust structure. A specific case of this approach solves the general case of a multi-period game, where the demand in each period is stochastic and only dependent on the current price and may differ from each other. While in this paper, the demand in each period has been influenced by prices from previous periods, in other words, demand is a function of current and prior retail prices. The players sign a single contract (compared to a periodic contract) which makes a significant difference in the results by utilizing more information and freedom to decide.

*Keywords:* Dynamic Games, Single Contract, Distributional-Robust Demand

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## Game theory models of international agreements on adaptation to climate change

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*Abstract* This note deals with the formation of coalitions of countries to jointly fight the adverse effects of climate change. We propose two game theory models of international agreements and compare them with the situation where each country individually develops new means to adapt to climate change.

*Keywords:* International environmental agreement; Nash equilibrium; variational inequality; shared constraints

# Vehicle Routing III
**Chair: Luigi Di Puglia Pugliese**

## A multidepot vehicle routing problem with time windows and intermediate replenishments

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*Abstract* We tackle a variant of the multidepot vehicle routing problem with intermediate replenishment facilities (MDVRPI) [1], characterized by a heterogenous fleet of vehicles and time windows. To model this problem, we propose two different MILP formulations: in the first one the replenishment facilities are represented by a set of specific nodes, whereas in the second model we use special replenishment arcs. In order to treat larger instances, a set-partitioning model is also proposed, solved by a Branch & Price algorithm in which the pricing subproblem reduces to a variant of the elementary shortest path problem with resource constraints (ESPPRC) [2]. Some preliminary numerical results are presented on a set of benchmark problems.

*Keywords:* Multidepot vehicle routing problem, heterogenous fleet, intermediate replenishments

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## A Framework for Efficient Vehicle Routing Problem Heuristics

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*Abstract* Vehicle Routing Problems (VRPs) are a class of combinatorial optimization problems with a wide range of applications. In the past decades, numerous heuristic and exact approaches have been proposed to solve various VRP variants. However, developing a unifying framework for VRP heuristics is complex due to the balance required between the generality of the approach and the specificity in exploiting problem characteristics. A successful framework proposed by Vidal et al. [1] separated generic and variant-specific components of the algorithm. This separation helped to achieve a good compromise between efficiency and generality. However, the wide adoption of such a framework has been limited, possibly due to the absence of a public library to aid researchers with new heuristics ideas and techniques. In this ongoing work, we aim to extend the Resource Extension Function framework to generalise it to other classes of constraints and objective functions. Additionally, we plan to study and develop a taxonomy of VRP constraints and introduce reflection capabilities to the framework to enable specialised handling of the most costly operations, while still maintaining the generality of the unifying approach. Furthermore, we will apply the same rationale to the algorithmic counterpart and present a framework that can assist in the development of meta-heuristics by decomposing them into basic algorithmic components and providing ways to compose them together.

*Keywords:* VRP, Metaheuristic, C++

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## Optimization of on-demand waste management services

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*Abstract* Various waste management services are offered on demand, meaning that resources are assigned to tasks on a day-by-day basis as opposed to following a predefined long-term calendar. The on-demand approach is becoming more and more attractive also thanks to the spreading of IoT sensors that measure the amount of waste in a container and trigger a service request only when needed. Examples of applications include the disposal of bulky waste using roll-off containers and the emptying of large bins with different waste streams located at large facilities (e.g. hospitals, schools, supermarkets). The challenges of optimizing the operations of on-demand waste collection services are multidimensional. In practice, problems are generally tackled in two phases: (i) capacity planning, informed by demand forecasts on a time horizon of 1-2 weeks, and (ii) daily planning, where actual service orders are assigned to routes, which are in turn assigned to the available vehicles and drivers. Our focus is on the optimization models and algorithms that support the daily planning of an Italian waste management company. Mathematically, on-demand waste collection problems can be modeled as capacitated multi-trip vehicle routing problems with pickups and deliveries, heterogeneous fleet, multiple time windows and a set of compatibility constraints between vehicles, drivers, nodes and types of goods. Additional problem-specific features include the assignment of drivers to shifts which include scheduled breaks and the use of assets such as hooklifts to handle the loading and unloading of goods. Since the problems under consideration are strongly constrained, we adopt a flexible approach based on an Adaptive Large Neighborhood Search metaheuristic and we evaluate the performance of a number of ruin and recreate operators. We conclude by describing the decision support system in which these optimization models and algorithms are embedded. The tool is integrated with the waste management company's information systems and allows a user-friendly interaction with the proposed solutions, thus bridging the gap between applied research and its practical use.

*Keywords:* Vehicle Routing Problem, Waste Collection, ALNS

## Benefits of Cooperative Distribution

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*Abstract* One of the most well-known problems in logistics is the issue of distribution. Many types of distribution can be modelled as circular routing problems, which involve finding the most cost-effective circular route for the distribution of commodities. Various types of Vehicle Routing Problems are discussed in this context. In cases where multiple entities are involved in the delivery of a homogeneous commodity, the possibility of cooperation in the delivery process can be considered. We assume the existence of multiple warehouses (players), each serving its own predetermined customers. If these warehouses can cooperate in serving their customers and this collaboration brings benefits, this behaviour can be analysed using game theory tools. In general, two cases can be studied: transferable pay-off and non-transferable pay-off. In the case of non-transferable pay-off, cooperation is assumed only during the delivery process, not during the division of additional benefits. It is obvious that the case of transferable payoffs allows for broader possibilities of cooperation but assumes additional division of the benefits gained through cooperation. We will present the Shapley value, egalitarian, utilitarian, Nash principles of surplus redistribution, and compare them to non-transferable payoffs. For both cases, we will present new mathematical models of cooperative distribution.

*Keywords:* Vehicle Routing Problems, Game Theory, cooperation

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## A parallel ALNS approach for the Attended Home Delivery Problem with Redelivery Options

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*Abstract* The increasing popularity of attended home deliveries has brought attention to the need for companies to ensure timely services, as missed deliveries can negatively impact customer satisfaction and loyalty as well as delivery costs. To address these issues, we propose an Attended Home Delivery Problem with Redelivery Options (AHDP-RO) based on the knowledge of customers' availability through different profiles identifying the probability of the customer presence for each time slot of the delivery day [1]. When a missed delivery occurs, the courier must apply a redelivery policy based on the customer's preferences (e.g., leaving the package in a safe spot, scheduling a second delivery attempt on the same day, or directing the package to a designated collection point). To optimize the scheduling of deliveries and minimize routing costs, we present a Mixed-Integer Linear Programming formulation in which the cost of a missed delivery is proportional to a penalty determined by the chosen redelivery option and to the probability of not finding the customer at home during the selected time slot. By solving realistic instances, we provide analytical insights into the costs of different redelivery options and the number of time slots to consider. Our study can help logistics companies in optimizing their attended home delivery operations while improving customer satisfaction. Finally, we develop a tailored Adaptive Large Neighborhood Search (ALNS) to tackle the model resolution for real-world dimensions. In particular, the parallelization exploits the ALNS flexibility on choosing destroy and repair operators and the size of the neighborhoods. We assess the algorithm performance with similar approaches taken from the literature [2].

*Keywords:* Attended Home Delivery, Vehicle Routing Problem, Redelivery Options, Customer Availability Profiles, ALNS

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## Truck and drone route optimization for delivering and monitoring task

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*Abstract* We address a variant of the combined truck-drone delivery problem [1, 2], in which beside the delivery task, drones are used as monitoring/surveillance devices [3]. In particular, we consider a single truck equipped with a single drone that have to serve a set of customers located in an urban area. We suppose that the considered area has some zones of interest that should be monitored. Each customer can be served by either the truck or the drone. The drone can take off from the depot or from the truck at customer locations, perform a delivery for a single customer, and come back to the truck. During the delivery, the drone can possibly deviate from the more convenient route in order to fly over a zone of interest. The aim is to serve all customers by either the truck or the drone and to monitor the area of interest at minimum cost. The scientific literature has focused on both routing problems with trucks and drones and the monitoring and surveillance problem of areas of interest with drones [4]. The first problem is modelled as a travelling salesman problem with drone (TSP-D) or vehicle routing problem with drone (VRP-D), whereas the second problem can be modelled as the covering tour problem (CTP)[5]. The addressed problem is a combination of TSP-D and CTP, named TSP-D and monitoring task (TSP-DM). We model the problem as a mixed-integer linear program (MILP) in which the zone of interest is discretized in points of interest. Monitoring all points of interest ensures that the area of interest is monitored. The MILP is implemented in the Java language and solved by CPLEX. The implemented model has been tested on instances generated by the Solomon benchmarks properly modified in order to consider both delivery and monitoring task for the drone. A computational analysis is carried out in order to study the behaviour of the considered delivery and monitoring system in terms of feasibility, effectiveness, and efficiency.

*Keywords:* Parcel delivery, Routing, Covering, Drone

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# Invited Session
# The Optimizer's Guide to the Sustainable World
### Chair: Giusy Macrina/Lorenzo Peirano

## Algorithms for the Pickup and Delivery Problem with Time Windows and Last-in-First-out Loading

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*Abstract* The Pickup and Delivery Problem with Time Windows and Last-in-First-out Loading (PDPTWL) is an important problem arising in transportation. Its goal is to minimize the costs to serve a set of customers, consisting of pickup and delivery locations, using a fleet of vehicles and handling their loads with a LIFO policy.

Exact methods for the PDPTWL are explored in [1] and [2]. In [1], the authors develop three exact branch-price-and-cut algorithms, based on set partitioning formulations. In the first one, the LIFO constraints are managed in the master problem. In the second one, LIFO constraints are managed in the pricing problem. In the third one, a hybrid approach combining the advantages of the former two is proposed. In [2], the authors develop an exact branch-and-cut algorithm based on a relaxed network-flow model with time discretization. In this model, variables are associated with fragments, which are sequences of pickup and delivery requests starting and ending with an empty vehicle, satisfying time, capacity, and pairing constraints.

In our work, we propose algorithms to find tight dual bounds to the PDPTWL by solving the continuous relaxation of a set partitioning formulation of the problem, where variables correspond to (non-necessarily elementary) routes corresponding to sequences of fragments. This set partitioning model is solved with column generation, and state-space relaxation is used to solve the pricing problem. These dual bounds are then used to find an optimal PDPTWL solution through variable enumeration/fixing and branching. Preliminary results are promising and show that the proposed method is competitive with the state-of-the-art solution methods.

*Keywords:* pickup and delivery, column generation, dynamic programming

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## A two-phase approach to evaluate and optimize an interlibrary loan service: the case study of Provincia di Brescia

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*Abstract* The interlibrary loan is a service including the phases of borrowing, lending, and document delivery of items from and to different libraries. These can thus share and exchange their heritage, allowing their users to access several public goods, generally without having to pay. In this work, we present the case study of Rete Bibliotecaria Bresciana Cremonese, i.e., the library network of Provincia di Brescia, a public body in Northern Italy [1]. In the current implementation of their interlibrary loan service, 210 public libraries are divided into eight clusters, each associated with a fixed route scheduled at all its stops. Each library is visited by a courier a few times a week, according to a calendar predetermined by considering historical data and library opening hours. Both routes and calendars are manually designed. The operations of picking up and delivering items in the network are outsourced to a logistics firm selected through a reverse auction. Every year this costs a fixed amount to Provincia di Brescia. Here we illustrate how this service can be evaluated in terms of routing and transportation costs. Given the large number of libraries in the network, we adopt a first-cluster-then-route philosophy, like what is done by Provincia di Brescia. In the first phase, we decide the number of clusters by exploiting the Elbow method [2] and the Average Silhouette method [3]. Then, we cluster the libraries by applying the k-means algorithm [4] or integer linear programming. In the second phase, we use mixed-integer linear programming to model the problem of each cluster as a Vehicle Routing Problem with pickup and delivery, backhauls, and time windows. Computational experiments on the real data of 2019 show that, even by maintaining the same clusters currently in use, huge savings could be obtained in terms of

distances, costs, and vehicles employed. However, we discuss the applicability of our approach. Finally, we provide a few managerial insights [5].

*Keywords:* public sector, clustering, vehicle routing problem, mixed-integer linear programming, case study

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# Multi-Objective Optimization for the Security of Water-Energy-Food Nexus

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*Abstract* Climate change, population growth, and rapid urbanization are seriously threatening the security of water, energy, and food resources, which are fundamental for the human survival and sustainable development. These resources are inextricably interrelated and the term Water-Energy-Food Nexus, or other permutations of the three words, refers to the synergies and trade-offs among the three sectors. Nexus planning and management for the overall security of the system are very complicated, because of conflicting objectives among sectors and, at the same time, unavoidable. For this reason, much of the scientific research, that studies sustainability issues and the nexus system, focuses on multiobjective optimization problems. The present work aims at finding several solutions for a Nexus system, by developing a linear mixed-integer multi-objective problem. The weighted Global Criterion Method was adopted as solution method and real-world Water-Energy-Food Nexus scenarios are used to assess the behaviour of the considered approach.

*Keywords:* Multi-Objective Optimization, Weighted Global Criterion, Method, Water-Energy-Food Nexus, Security Assessment

## Incorporating time-dependent demand patterns in the optimal location of capacitated charging stations

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

*Keywords:* Facility location, Charging stations, Time-dependent optimization, Electric vehicles, Demand patterns

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## The profitability-sustainability trade-off in complex chemical value chains

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*Abstract* Limiting the effects of global warming and climate change is one of the main objectives that the international community has set for the next decades. Therefore, several countries approved laws legally binding them to achieve net-zero targets within the next 25-30 years. One of the major greenhouse gases emitted by human activity is carbon dioxide (CO2) which accounts for more than 75% of the global greenhouse gas emissions. To remain competitive in their markets while reducing their emissions, companies need to re-optimise their entire value chain focusing not only on traditional costs, related to manufacturing and transport, but also on those related to greenhouse gas emissions. In this work, we propose a linear programming model to optimise a deterministic multi-objective value-chain problem aimed at minimising CO2 emissions and maximising a company's total contribution margin. We test the model on a real-world dataset, provided by a multinational chemical company, to determine the main sources of emissions and their geographical distribution. Moreover, we analyse how much emissions can be reduced at a negligible impact on the total contribution margin and describe what are the best strategies to achieve the targeted emissions reduction. This study also introduces the product-specific carbon footprint problem, which aims to analyse the value chain profitability-sustainability trade-off when specific limits on emissions are imposed for each product. A model capable of addressing this problem provides a useful tool for accounting for the emissions associated with each type of product, estimating costs associated with introducing a more sustainable version of the product, and optimising operations accordingly. However, the product-specific emissions constraints introduce non-linearity to the proposed model, making it more challenging to solve. Therefore, this study is valuable from both practical and theoretical perspectives.

*Keywords:* Sustainable value chain, multi-objective optimization, strategic planning

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## A bi-level approach for the vehicle routing problem with private fleet and common carrier

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*Abstract* We address the problem of a delivery company that must serve a set of customers located in an urban area, by managing a fleet of regular vehicles and using an outsourcing delivery service offered by a common carrier. The carrier has his own customers to serve and may accept to perform some additional deliveries, according to his constraints. Since the carrier is not under the direct control of the delivery company, his reaction should be considered. We model the interaction between the delivery company and the carrier by using the Stackelberg game framework with the two decision makers playing the role of leader and follower, respectively ([1],[2]). Hence, we formulate the problem as a bi-level vehicle routing problem with private fleet and common carrier (VRPPC) ([3]), and time windows. At the upper level, the delivery company decides which customers are served by the private fleet, and how many and which customers should be served by the carrier, and the compensation offered to the carrier for performing the deliveries. At the lower level, the carrier decides which customers to serve, and which compensations can be accepted. We design a solution approach that exploits the specific problem structure. Preliminary results carried out on small sized test instances are presented and discussed.

*Keywords:* vehicle routing, common carrier, bi-level optimization

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# Invited Session
# OPTSM – Urban Transport
## Chair: Andrea D'Ariano

### Synchronization of Train Timetables in an Urban Rail Network: A Bi-Objective Optimization Approach

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*Abstract* As urban rail networks in big cities tend to expand, the synchronization of trains has become a key issue for improving the service quality of passengers because most urban rail transit systems in the world involve more than one connected line, and passengers must transfer between these lines. In contrast to most existing studies that focus on a single line, in this study, we focus on synchronized train timetable optimization in an urban rail transit network, considering the dynamic passenger demand with transfers as well as train loading capacity constraints. First, we propose a mixed-integer programming (MIP) formulation for the synchronization of training timetables, in which we consider the optimization of two objectives. The first objective is to minimize the total waiting time of passengers, involving arriving and transfer passengers. Our second objective is a synchronization quality indicator (SQI) with piecewise linear formulation, which we propose to evaluate the transfer convenience of passengers. Subsequently, we propose several linearization techniques to handle the nonlinear constraints in the MIP formulation, and we prove the tightness of our reformulations. To solve large-scale instances more efficiently, we also develop a hybrid adaptive large neighbor search algorithm that is compared with two benchmarks: the commercial solver CPLEX and a metaheuristic. Finally, we focus on a series of real-world instances based on historical data from the Beijing metro network. The results show that our algorithm outperforms both benchmarks, and the synchronized timetable generated by our approach reduces the average waiting time of passengers by 1.5% and improves the connection quality of the Beijing metro by 14.8%.

*Keywords:* Timetable synchronization, urban rail network, bi-objective optimization

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**A Branch-and-Cut Approach for the Scheduling of Train Platoons in Urban Rail Networks**

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*Abstract* With the emerging of virtual coupling technologies, the concept of train platoon, where different vehicles can be flexibly and dynamically grouped or decoupled, has become a hot research topic. In this study, we investigate the scheduling of train platoons for urban rail networks with time-dependent demand to mitigate passenger inconvenience. We propose a mixed-integer linear programming (MILP) model that simultaneously optimizes the train-platoon (de)coupling strategies, arrival/departure times at each station, and the running orders of trains, while considering limited rolling stock resources at the depots and the safety of trains at cross-line zones. To tackle computational challenges in real-world instances, we develop a customized branch-and-cut solution algorithm, based on the analysis of mathematical properties of our MILP model, to generate (near-)optimal solutions more efficiently. In particular, we propose three sets of valid inequalities that are dynamically added to the model to strengthen the linear relaxation bounds at each node. We also design a customized branching rule in the search tree by imposing to branch on the key decision variables regarding the train orders at the cross-line zones. Real-world case studies based on the operational data of Beijing metro network are conducted to verify the effectiveness of our approach. The results demonstrate that our branch-and-cut-based approach evidently outperforms commercial solvers in terms of solution quality and computational efficiency. Compared to the current train schedule with fixed compositions in practice, our approach with flexible coupling strategies can reduce the passenger dissatisfaction by over 15%.

*Keywods:* Transportation, Train scheduling, Flexible coupling, Passenger dissatisfaction, Branch-and-Cut

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# A Mode Choice Model for Sustainable Freight Transport Considering Urban Logistics Stakeholder Perspectives

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*Abstract* In the last 10 years, the volume of consignments in the courier, express and parcel service industry in Germany has doubled to 4 billion consignments per year. These consignments are mainly transported by fossil fuelled road transport. The increased volume is causing rising strain on city infrastructures and has gained public and research relevance. Considering main objectives of urban logistics stakeholders a potential shift to rail in order to reduce congestion and emissions needs to be explored [1].

In this research, we investigate the problem of optimal sustainable mode choice in bi-modal freight networks. It introduces a concept of inner-city hubs, which enable transhipment between small electric vehicles for distribution and long-distance road and rail transport. A network flow model is developed which minimises induced costs by deciding preferred mode between the inner-city hubs. Transport policies such as high-speed freight trains, tolls or reducing energy consumption are implemented [2]. Different objectives of city logistic stakeholders are considered, such as carriers which aim to minimise transport costs or inhabitants, which aim to reduce noise and pollution [3].

We demonstrate the model performance on a German parcel network and carry out a sensitivity analysis by varying parameters such as velocity, transport costs, emission costs, capacities and a factor which measures the impact on the city. We used public data provided by the German Federal Association of Parcel and Express Logistics and derive the flows of consignments between major German cities [4] and considered different types of artificial logistic networks in Germany like point-to-point or hub-and-spoke.

The proposed model enables evaluating the impact of predefined freight policies on mode choice for parcel delivery networks as well as to which extent and under which conditions rail freight traffic can be integrated into a sustainable inner-city supply chain of the future.

*Keywords:* mode choice, MILP, sensitivity analysis

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# Efficient iterative optimization to real-time train regulation in urban rail transit networks combined with Benders decomposition method

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*Abstract* This paper investigates the design of network-level real-time train regulation strategies for urban rail transit systems under frequent disturbances. Specifically, a mixed integer nonlinear programming (MINLP) model is constructed in a rolling horizon framework to improve the punctuality and regularity in train operations, and reduce passenger waiting. To effectively address the complexity of the model and meet requirements of real-time implementation, an efficient iterative optimization (IO) approach combined with generalized Benders decomposition (GBD) is particularly designed, which can effectively treat intractable non-convexity of the formulation and quickly obtain high-quality solutions. Furthermore, two numerical examples on a simple network and a realistic network based on Beijing Subway are given to verify the effectiveness of the proposed approach. The results show that our approach can effectively contribute to the reliability of train regulation for urban rail transit networks, improving the operation efficiency and service quality, and is suitable to real-time application.

*Keywords:* Urban rail transit networks, train regulation, Benders decomposition

# Lagrangian relaxation based speed trajectory optimization for multiple trains under virtual coupling with operational state transition

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*Abstract* The virtual coupling train operation is a promising method to increase the capacity of high-speed railway. When the virtual coupling operation is adopted, the trains can be coupled and decoupled in the running process, making the operation under virtual coupling different from the ordinary fixed block or moving block operation. Due to the difference between the virtual coupling operation and ordinary operation, the optimal speed profile for ordinary operation is unsuited to virtual coupling, which means that it is important to investigate the speed profile optimization problem under virtual coupling. In this paper, a mixed integer nonlinear programming model is proposed to describe the train operation under virtual coupling, where the states of virtual coupling, i.e., moving block running state, coupling state, coupled running state and decoupling state, are denoted by binary variables. By adopting a piecewise-linear method, the nonlinear model is transformed into a mixed integer linear programming model which can be solved by commercial solvers. If two trains are in the coupling state, the distance between them will decrease and constraints of safety distance will be active, which leads to that the problem requires a long time to solve. To enhance the computational efficiency, a Lagrangian relaxation method is proposed to relax the constraints of safety distance. Based on the data of Beijing-Shanghai high-speed railway, numerical experiments are conducted to demonstrate the effectiveness of the proposed methodology in coupling and decoupling scenarios. The results indicate that the proposed model can be used to optimize the speed profile for multiple trains under virtual coupling, and the Lagrangian relaxation method can achieve better performance in terms of computational time and objective function value compared with solving the problem by CPLEX directly in the coupling scenario.

*Keywords:* Trajectory optimization, Virtual coupling, High-speed railway

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## Influence of Weather Features on Short-Term Arrival Delay Prediction in Freight Rail Operations

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*Abstract* Transportation has been a crucial aspect of economic growth and development, and effective supply chain management has become increasingly important in today's globalized economy. Freight rail operations play a vital role in the transportation of freight, offering numerous benefits over other modes of transportation, such as energy efficiency and lower greenhouse gas emissions [1]. However, despite the numerous advantages of rail transportation, one of the major challenges faced by the industry is the unpredictable and frequent arrival delays. Arrival delays can result in significant losses for rail operators and customers, causing disruptions to supply chains and negatively affecting the competitiveness of the rail industry. In recent years, researchers have sought to understand the factors that contribute to arrival delays in rail operations, with a growing body of literature aimed at identifying the key features that impact these delays. While these studies have relied on statistical analysis and traditional econometric models to understand the operational factors such as track maintenance and equipment malfunctions that contribute to delays, there has been limited research that has attempted to use weather data to predict arrival delays in freight rail operations. This is despite the well-known impact of weather conditions on rail operations, which can have significant consequences for the industry [2], [3]. The purpose of this study is to employ machine learning models in short-term arrival delay prediction in freight rail operations that rely solely on weather features. By incorporating weather data as predictor features, this study aims to provide a comprehensive analysis of the impact of weather on arrival delays in freight rail operations. Machine learning algorithms have been widely used in various

fields and have shown promising results in predicting and analysing complex systems [4], [5]. In the context of this study, machine learning models offer the advantage of being able to capture complex relationships between weather and arrival delays in rail operations, providing a more accurate and reliable prediction of arrival delays compared to traditional statistical models [2]. The results of this research are expected to provide valuable insights into the relationship between weather and arrival delays in rail operations. By providing a tool for predicting arrival delays in real-time, this study has the potential to inform decision-making processes in the rail industry and improve supply chain management. The findings of this study will also have important implications for the development of sustainable transportation systems and the mitigation of the impacts of weather conditions on freight rail operations.

*Keywords:* Freight rail operations, arrival delays, weather data, machine learning models, supply chain management

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# Invited Session
# Bilevel Optimization
## Chair: Virginie Lurkin

### A Linesearch Derivative-free Method for Bilevel Minimization Problems

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*Abstract* Bilevel programming refers to a class of problems with a particular nested structure [1,2]. According to this structure, the so-called inner or lower level problem is nested inside the feasible region of the so-called outer or upper-level problem. This results in a particular constrained optimization problem where the decision variables can be partitioned in two vectors, x and y, having different roles. Indeed a point (x, y), in order to be feasible, must satisfy not only the traditional constraints but also the requirement that y is the optimal solution of the inner problem which is parametric in x. In this talk, we consider the case where derivatives are not available and propose a solution method based on a derivative-free linesearch technique [3]. Under common assumptions, we carry out a theoretical analysis of the convergence properties of the proposed derivative-free algorithm. In particular the lower level objective function is assumed to be strictly convex. This means that for each upper level choice x, the set of optimal lower level reactions is a singleton.

Finally, for the proposed approach, we show some preliminary numerical results on a set of benchmark test problems.

*Keywords:* Bilevel optimization, derivative-free methods, nonlinear programming

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**Tackling a class of integer bilevel nonlinear programs with disjunctive cuts based on SOCP**

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*Abstract* We study a class of integer bilevel programs with second-order cone constraints at the upper-level and a convex-quadratic objective function and linear constraints at the lower-level. We develop disjunctive cuts (DCs) to separate bilevel-infeasible solutions using a second-order-cone-based cut-generating procedure. We propose DC separation strategies and consider several approaches for removing redundant disjunctions and normalization. Using these DCs, we propose a branch-and-cut algorithm for the problem class we study, and a cutting-plane method for the problem variant with only binary variables.

We present an extensive computational study on a diverse set of instances. This study demonstrates that the proposed enhancements of our solution approaches are effective for improving the performance. Moreover, both of our approaches outperform a state-of-the-art generic solver for mixed-integer bilevel linear programs that is able to solve a linearized version of our binary instances.

A preliminary version of the results was published as [1] and the full version is [2].

*Keywords:* bilevel optimization, disjunctive cuts, conic optimization, nonlinear programming, mathematical programming

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## Single machine adversarial bilevel scheduling problems

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*Abstract* In this contribution we focus on a particular setting in which two agents are concerned by the scheduling of a set of n jobs. The first agent, called the leader, can take some decisions before providing the jobset to the second agent, called the follower, who then takes the remaining decisions to solve the problem. As an example, the leader could select a subset of n'¡n jobs that the follower has to schedule. Notice that the decisions the agents can take are exclusive: in this example, the follower cannot decide the jobs to schedule and the leader cannot schedule the jobs. This setting falls into the category of bilevel optimization [1]. In such problems it is assumed that the leader and the follower follow their own objectives which can be contradictory, so leading to very hard optimization problems. Recently, many papers on bilevel combinatorial optimization appeared, but very little of hem deal with scheduling problems [2, 3, 4].

We focus on single machine scheduling problems under the adversarial framework where the goal of the leader is to make the follower solution as bad as possible and provide several exact polynomial time algorithms for different objective functions. We focus on problems where the leader can either select a subset of jobs for the follower or modify the data of the instances. We consider basic scheduling criteria like the sum of completion times, the maximum lateness and the number of tardy jobs. Some problems and the corresponding algorithms will be presented at the conference.

*Keywords:* Scheduling, Bilevel Optimization, Single machine

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## Strategic Bidding in Electricity Market with AC Power Flow Market Clearing

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*Abstract* In this work, we study the strategic behavior of producers connected to an alternating current (AC) electricity network, where the market is regulated by an independent system operator (ISO) carrying out the market clearing. We focus on a pay-as-bid AC electricity market in which: each producer provides the ISO with a bid used to derive directly its revenues; the market clearing is performed by taking into account the AC power flow constraints. A similar set up has been considered in [1] but with a market clearing procedure based on the (linear) DC power flow model. Further line losses have been tackled in [2]. This scenario can be modeled as a multi-leader-single-follower game, and solved seeking the Nash equilibrium, which occurs when each producer can find no alternative bid to improve his/her revenues, assuming that the other producers hold their bids constant. In order to do it, we use a diagonalization method, which solves, at each iteration, several single-leader single-follower problems through a tailored cutting plane algorithm. To benchmark our results, we consider also an unrealistic scenario in which all the producers act together (in a sort of cartel), trying to maximize the sum of their profits. We successfully test the approaches on small-scale instances.

*Keywords:* ACOPF, Bilevel Optimization, multi-leader-single-follower problem

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**Choice-based time slots assortment and pricing in attended home delivery**

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*Abstract* The growth of e-commerce has led to an increase in requests for home deliveries, including attended home deliveries that require customers' presence at home. Increasingly, online retailers offer customers a choice of delivery times to meet their schedules. Providing these time slots is convenient for customers, but it also results in a higher level of uncertainty for the retailer. In this talk, I present a slot assortment and pricing problem in which customers' behaviors regarding their slot decision are explicitly taken into account. This model fits within the growing literature on choice-based optimization. We propose a metaheuristic-based solution approach to address this challenge efficiently, emphasizing the importance of reduced solving time. Our method uses metaheuristics to ensure a balance between the quality of solutions and computational efficiency, thereby enhancing its practical applicability in real-world situations.

*Keywords:* Choice-based optimization, Logit model, Logic-based benders decomposition, Logistics

# Invited Session
# Recent Advances in Multiobjective Optimization
### Chair: Pierluigi Mansueto

**On necessary optimality conditions for sets of points in multiobjective optimization**

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*Abstract* Taking inspiration from what is commonly done in single-objective optimization, most local algorithms proposed for multiobjective optimization extend the classical iterative scalar methods producing sequences of points able to converge to single efficient points. Recently, a growing number of local algorithms that build sequences of sets has been devised, following the real nature of multiobjective optimization, where the aim is that of approximating the efficient set. This calls for a new analysis of the necessary optimality conditions for multiobjective optimization. We explore conditions for sets of points that share the same features of the necessary optimality conditions for single-objective optimization. On the one hand, from a theoretical point of view, these conditions define properties that are necessarily satisfied by the efficient set. On the other hand, from an algorithmic point of view, any set that does not satisfy such conditions can be easily improved. We analyse both the unconstrained and the constrained case giving some examples.

*Keywords:* Multiobjective optimization, Optimality Conditions, Nonlinear Programming

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## A Novel Bi-objective Approach for Bayesian Optimization

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*Abstract* Bayesian Optimization methods are among the best choices when dealing with very expensive objective functions in (global) optimization problems [1]. The standard approach of these methods is to choose where to evaluate the function based on the optimization of an "acquisition function", finding a compromise between exploration and exploitation. In particular, exploration is obtained by placing observations where the variance is large, while exploitation is obtained by choosing evaluations where the expected function values are low. In this work, we propose to abandon the idea of mixing these two conflicting objectives and to consider the problem as a bi-objective optimization one. In order to solve it, we employed a recently proposed multi-objective optimization tool, NSMA [2], which seems to be very well suited for this task. Numerical results on standard test functions are extremely promising and a direct comparison with tools available in one of the best known Bayesian Optimization libraries, BoTorch [3], show the validity of the bi-objective approach.

*Keywords:* Bayesian Optimization, Bi-objective Optimization, NSMA, BoTorch

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## A new algorithm for detecting the nondominated set of a triobjective integer program

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*Abstract* We present a new criterion space algorithm for solving tri-objective nonlinear integer programs. The method is guaranteed to determine the complete nondominated set of the problem. At every iteration of the algorithm, specific biobjective integer subproblems are defined and solved using a suitable oracle [1]. As an assumption on objective functions we demand that the distance with respect to each component between points in the image space is bounded from below [1, 2]. This property is exploited to properly define the constraints describing the feasible set of each biobjective subproblem. The nondominated points found at each iteration are used for determining the region of the image space to be explored at the following iteration. Numerical experiments on both linear and nonlinear instances are shown and discussed.

*Keywords:* Multiobjective optimization, Mixed integer optimization, Nonlinear optimization

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## A polynomial-time algorithm for minimizing the maximum lateness and the total time deviation on a fixed sequence

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*Abstract* We consider a scheduling problem, with the minimization of two objectives on a fixed sequence of jobs. The first objective is the maximum lateness and the second one the total absolute time deviation from desired completion times, which is better known as the total earliness and tardiness cost. The maximum lateness models a classical scheduling objective, as the maximum delay of jobs with respect to given due dates. The total absolute time deviation models the requirements of a just-in-time environment, where having a job completed early, as well as late, increases the costs. The problem finds an application in the field of rescheduling problems [1], where an original schedule is disrupted after some event and the goal is to minimize both a scheduling objective and the time deviation from the original completion times.

Since the sequence of jobs is fixed, the problem at hand consists in determining an optimal timing of jobs. Given the jobs sequence, we search for the optimal starting times of jobs that minimize both objectives. A first polynomial-time algorithm is presented for the lexicographical problem of minimizing the maximum lateness as a first objective, and the total absolute time deviation as a second objective. Then, another algorithm computes an optimal solution for the problem, where the maximum lateness is minimized subject to a constraint on the total time deviation. The algorithm is shown to run in polynomial time. To the authors' knowledge, this is a first approach to this bi-objective problem in the literature of timing problems (see for instance [2]).

*Keywords:* Timing, Maximum Lateness, Total Time Deviation, Bi-objective Problem

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### Finding sets of short and dissimilar paths

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*Abstract* Given a network with a source node, a destination node, and an integer K, we address the problem of finding sets of K paths between the source and the destination, in which two criteria are considered: the minimization of the total paths' cost and the maximization of the average dissimilarity between them. The purpose of these objective functions is to provide low-cost sets of paths whose elements are simultaneously fairly different from one another and, thus, can serve as alternative in case needed. Such considerations are relevant in applications that range from transportation to telecommunications, where aspects like the safety or the reliability of the solutions are of concern.

Two approaches are used to measure the dissimilarity of a set of K paths: the extension of the superposition between the paths in terms of the number of times that each arc appears in more than one of them; and the number of pairs of paths in which each arc in the solution appears. The bi-objective problems resulting from these approaches are modelled as integer linear programs based on single commodity and discretized flow formulations. Afterwards, an $\varepsilon$-constraint method is designed to find efficient sets of K paths for each of the two problems.

The resulting $\varepsilon$-constraint algorithms are tested for finding K=10, 20 paths, while considering randomly generated networks with up to 500 nodes and square or rectangular grid networks with up to 225 nodes. The computational results are presented in terms of the run time, the quality of the solutions set, and the dissimilarity of the solutions found by each approach. We show that, in general, the first approach to the paths' dissimilarity is considerably easier to solve than the second, even if the average dissimilarity can be up to 25% lower in that case. These differences are more noticeable for the rectangular grid instances.

*Keywords:* K shortest-dissimilar paths, Integer Linear Programming formulations, Bi-objective optimization

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## Improved front steepest descent for multi-objective optimization

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*Abstract* In this talk, we deal with the Front Steepest Descent (FSD) algorithm for multi-objective optimization proposed in [1]. This method was shown to be far superior than a simple multi-start version of the original (single point) steepest descent algorithm for multi-objective optimization [2]. Yet, we point out that FSD is often incapable, by design, of spanning large portions of the Pareto front. We thus introduce some modifications within the algorithm aimed to overcome this significant limitation. We prove that the asymptotic convergence properties of the algorithm are preserved and numerically show that the proposed method significantly outperforms the original one.

*Keywords:* Multi-objective optimization, Steepest descent, Pareto front

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# Operations Research for Energy and Green Logistics II
**Chair: Maurizio Bruglieri**

## Modeling effective capacity of PV across seasons and hours of day: with an application to Israel's electricity market in 2030

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*Abstract* This paper assesses the appropriate representation of the effective capacity of the PV technology in a model that determines the optimal capacities, generation levels and prices of a wholesale electricity market in which power producers use natural gas (NG) and photovoltaic (PV) technologies. The level of PV's effective capacity during the day hours is approximately similar to the probability function of the normal distribution. It is very low in the morning, grows steadily until it reaches its maximal level during the midday hours, and then continuously declines during the afternoon hours. Applied to Israel's stylized electricity market in 2030, we find that a very simple representation of PV's effective capacity during the day and over the seasons of the year provides a very similar optimal capacity mix to a representation in which PV's effective capacity changes during every hour of the day. We also show that NG and PV are necessary to meet Israel's electricity demand during the day hours, and that NG mitigates daytime price spikes and enhances consumer welfare. Finally, we show, as is expected, that technology improvements to the PV technology reduce the optimal PV capacity and the electricity prices during the day hours.

*Keywords:* Wholesale electricity market, PV capacity utilization, Israel

# Optimization Models for Electric Vehicle Charging Station Location Problems: A Multi-Layered Review

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*Abstract* To prevent worse climate change, environmental-friendly and energy-efficient electric vehicles (EVs) have become the most promising alternative to combustion vehicles. Effective planning and layout of charging stations are needed to improve current charging practices and support the widespread adoption of EVs. The charging station location problem (CSLP) arises to optimize the locations of charging stations, thereby refueling EVs to reach their destinations. This problem has been extensively studied in the literature and numerous optimization models have been proposed: a common classification from the existing literature considers flow-based, node-based, and network equilibrium models, among others. This work provides an overview of CSLP optimization models according to different layers, in particular, it presents additional categorizations which provide interested readers with an efficient way to pursue further research in this area. For example, this work also classifies optimization models according to: charging station types (i.e., slow-charging, fast-charging, battery-swapping and a combination of such stations), travel demand type (i.e., intra-city or inter-city), vehicle type (i.e., private, commercial or public), and control policies (i.e., centralized or decentralized) to account for the interaction between the transportation and power networks. Finally, this review also looks at multiple sources of uncertainties that may arise in the CSLP, taking various dynamic and stochastic elements in the real world into account (e.g., travel demand, network topology, driving range). The ultimate goal of this work is to highlight current research gaps, reflect on limitations in the existing literature, and offer suggestions for future research.

*Keywords:* Energy, Environment and Natural Resources; Electric vehicles; Charging station location problem

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## Transactive energy trading using a Solar Organic Rankine Cycle

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*Abstract* Solar Organic Rankine Cycles (ORC) are power production plants where thermal power is supplied to the cycle using solar irradiation. Given the significant compatibility between the operating temperatures of solar irradiation-based technologies and the temperature needs of the cycle, they can be a promising renewable technology. Moreover, their higher performance compared to steam Rankine cycles in small size applications, makes them interesting within the communities and microgrids context. In this study, we inspect the impact that this technology can have in the peer-to-peer trading application in renewable based community microgrids. Here the consumer becomes a prosumer (functioning as both energy producer and consumer), and engage actively in automated market trade with other prosumers at the distribution system level. Specifically, we concentrate on a microgrid where the solar ORC is combined with a storage system, to fulfil the final consumer's demand. In fact, the combination of these plants with storage systems, is fundamental to increase their predictability and competitiveness with conventional plants, but it is quite challenging from a management perspective. Thus, we develop a methodology based on operations research techniques to use this system at its optimal point. Moreover, we investigate how different technological parameters of the solar ORC may affect the final solution. Finally, we study the value of the solar ORC in the transactive energy trading context under different configurations and scenarios.

*Keywords:* Solar organic Rankine cycles, peer-to-peer energy trading, transactive energy trading, storage systems, microgrids, operations research

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## Risk Measures in Energy Markets

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*Abstract* Energy market players face a litany of risks and sources of uncertainty. It is therefore desirable that stochastic programming models describing and informing their decisions allow for risk-averse behaviour, with players sacrificing the prospect of extreme profits to mitigate against potential losses. Risk measures ranging from Value at Risk (VaR) and Conditional Value at Risk (CVaR) to expected shortfall, convex utility functions, and stochastic dominance constraints have been incorporated into energy market models to achieve this [1,2,4]. This discussion provides an overview of these measures and a review of their implementation in existing energy literature. Alongside this is a discussion of Arrow-Debreu securities and their role in the hedging market [3]. It additionally encompasses a sample optimization problem comparing the distribution of profits caused by these risk measures for a player faced with stochastic costs [1]. Furthermore, a sensitivity analysis of the parameters controlling these risk measures is provided. The discussion aims to illustrate the behaviour of the risk measures and elucidate those situations in which each would be applicable. This is valuable to those seeking to model energy markets credibly, particularly given the increasing uncertainty faced by such markets due to the transition to green and sustainable energy.

*Keywords:* Energy markets; Risk Measures; Optimization

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# A heuristic approach for efficiently routing a fleet of electric vehicles with partial recharges and capacitated recharging stations

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*Abstract* The transportation sector is responsible for 25% of the total harmful emissions in Europe and about 70% of them is due to the road transport [1]. Therefore, it is very significant considering eco-sustainable solutions in this sub-sector. To this aim, in the last years, several transport companies are going to introduce electric vehicles (EVs), in their fleets. However, a medium-duty EV is not able to cover long-medium distances without recharging during its trip [2]. On the other hand, the recharging stations (RSs) are not widespread on the territory and the recharging time is by far higher compared to the refueling time of traditional vehicles, therefore the recharging stops must be carefully planned in advance. In this context, the seminal work [3] introduced the Electric Vehicle Routing Problem with Time Windows with the aim of routing a fleet of EVs, each one starting from the depot and returning to it within a maximum time limit, serving customers on time, with possible stops at RSs, at minimum total travel distance. The EVs are assumed to be always fully recharged at the RSs. We instead address a variant in which partial recharges are also allowed. Moreover, unlike [3], we make the realistic assumption that the RSs have a limited number of fueling pumps and then, when an EV arrives to an RS, it may not find any fueling pump available. Two different scenarios are considered. A private scenario in which we assume that the RSs are owned by the transport company preventing overlap among EVs at the RSs. A public scenario in which, in order to avoid possible queues at the RSs we assume that the RSs can be reserved in advance thus leading to time windows for the availability of the RSs. We model the optimization problem of each scenario as a Mixed Integer Linear Program (MILP). In both the cases, we use the MILP formulation in a matheuristic framework to efficiently address also large-sized instances. Finally, we show some preliminary results on benchmark instances.

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

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# Invited Session
# Recent Advances in Variational Inequalities and Equilibrium Problems I
### Chair: Patrizia Daniele

## Some remarks on Network Games with local average

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*Abstract* We investigate a class of network games with bounded strategy space, where each player's action is influenced by her neighbors' average action. We provide a variational inequality formulation of the model and derive a Katz-Bonacich representation formula for the case where some components of the solution lay on the boundary. 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; Katz-Bonacich centrality measure; price of anarchy

**Lagrange multipliers in Trust and Reputation Systems**

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*Abstract* Virtual communities have experienced an exponential increase with the availability of interactive online sites. These interconnected platforms give the possibility to the community members, generally called agents, to share products, services, information, opinions and recommendations. This paradigm has been implemented in very different domains, as the generalist social networks Facebook and Twitter, the thematic social networks as Linkedin and Researchgate, but also in e-commerce platforms as eBay and Amazon, or in comparison shopping websites as Tripadvisor. In this context, trust-based approaches have been recognized as a valid solution to improve the effectiveness of these communities, making interactions taking place therein much fruitful as possible, limiting or even avoiding malicious or fraudulent behaviors. These mechanisms collect information about past experiences and make public the reputations of community members. Thus, by using reputation information, agents can make more conscious choices. There is a rapidly growing literature of theory and applications in trust and reputation systems. Our contribution is to develop an effective equilibrium model by means of a variational inequality formulation. In particular, first, we provide a definition of equilibrium for trust and reputation systems and we prove that it is equivalent to a variational inequality. Then, we perform a Lagrange analysis and, finally, some examples illustrate the model.

*Keywords:* trust and reputation systems, variational inequalities, Lagrange multipliers

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## A Closed-Loop Network Model for 5G Services with UAVs and Trustworthiness Investments

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*Abstract* In this chapter, we provide a closed-loop supply chain network model for the provision of 5G services. It is based on a three-tiered closed loop network in which, in the forward chain, the users or devices on the ground require services, executed by a fleet of UAVs organized as a FANET, controlled by a fleet of manager UAVs, whose role is to receive service requests and send them to executor UAVs. In the reverse chain, the fleet of executor UAVs, once the requests are performed, provide the services to devices and users on the ground. Through a system optimization perspective, service providers seek to maximize their profit, given by the difference between the revenue associated with the provision of services and the costs due to the transmission and the execution of services. Considering the trustworthiness levels of each UAV belonging to the fleet at the highest level of the network, service providers also seek to minimize the investment costs to increase such levels and the penalty associated with not executed services due to unreliability of the executor UAVs. For the proposed optimization problem, we provide a variational formulation and some numerical simulations are performed.

*Keywords:* Closed-Loop Supply Chain Network, Trustworthiness of 5G Networks, UAVs, Variational Inequality

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**Efficient Last-Mile Delivery using UAVs: A Variational Inequality Approach for Optimizing Supply Chain Management**

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*Abstract* Flow optimization is a critical aspect of supply chain management in the whole delivery process, as it plays a crucial role in improving the efficiency and effectiveness. The use of Unmanned Aerial Vehicles (UAVs), such as drones, in the last mile (that is, the delivery of the products in the last stage of the transport) can result in significant optimization benefits. Indeed, a hybrid delivery system combining traditional trucks and drones may reduce congestion and pollutant emissions in urban areas, costs, including fuel and environmental ones, and improve the timeliness of deliveries. We construct and analyze a supply chain network with five layers: the company (which coordinates and manages the whole process), warehouses, fulfillment centers, delivery stations and customer locations. We propose a nonlinear optimization problem with the aim of maximizing the total profit. The obtained model seeks to determine the optimal quantities of products to buy from third-party sellers and/or to self-produce and the optimal flows for each link of the network, also establishing whether to make last mile delivery with drones and/or with trucks. Our nonlinear optimization model considers some important key features such as the number of available drones, their maximum capacity (that is, the maximum weight they are able to carry) and the maximum distance that each drone can reach, due to its battery life duration. The constrained nonlinear optimization problem is formulated as a Variational Inequality. Existence and uniqueness results for the solution of the variational inequality are provided. Furthermore, the analysis of numerical simulations suggests that using UAVs in the last mile can be an effective and efficient solution, since it can significantly reduce the delivery cost and the environmental emissions. A sensitivity analysis on incentives by National Institutions is also provided to highlight how their values can impact on the environmental aspects and optimal solutions.

*Keywords:* Supply Chain Management, Last-mile, UAVs, Variational Formulation

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# Invited Session
# Topics in Combinatorial Optimization
### Chair: Paolo Toth

### A column generation scheme to solve the vehicle crew rostering problem with staff transportation

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*Abstract* The vehicle crew rostering problem (VCRP) is a well-known problem in the operations research literature. It involves the simultaneous assignment of transportation vehicles of a public transportation company to a set of timetabled trips and crew members to operate the vehicles to form duties. Due to a variety of practical considerations, however, it is required by some transportation companies to provide transportation for their crew members, which is referred to as the staff transportation problem (STP). In this presentation, we consider a variant of the VCRP, in which the VCRP and the STP are integrated, called the vehicle crew rostering problem with staff transportation (VCRPST). We propose a novel column generation scheme for solving instances of the VCRPST. An all-pairs shortest path algorithm is used to generate duties, after which the duties are used to solve a column generation pricing problem. A commercial MIP solver is used to solve the master problem. The model proposed is verified in terms of real-world instances.

*Keywords:* Vehicle routing, crew rostering, staff transportation

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## Lagrangian approaches for QoS scheduling in computer networks

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*Abstract* We study a routing problem arising in computer networks where stringent Quality of Service (QoS) scheduling requirements ask for a routing of the packets with controlled worst-case "end-to-end" delay. With widely used delay formulæ, this is a shortest-path-type problem with a nonlinear constraint depending in a complex way on the reserved rates on the chosen arcs. However, when the minimum reserved rate in the path is fixed, the Lagrangian problem obtained by relaxing the delay constraint presents a special structure and can be solved efficiently. We exploit this property and present an effective method that provides both upper and lower bounds of very good quality in extremely short computing times.

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

**A recycling heuristic capable of generating initial solutions for use in vehicle routing metaheuristics**

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*Abstract* Instances of the vehicle routing problem (VRP) and its variants are notoriously difficult to solve. Moreover, when combining characteristics of multiple VRP variants, the underlying complexities of the variants proliferate. This has led to a variety of metaheuristics being proposed for solving VRP instances with side constraints. Metaheuristics, however, require the generation of an appropriate initial solution (trajectory-based metaheuristics) or a population of initial solutions (population-based metaheuristics), the quality of which affects the performance of the solution approach. When computing VRP solutions for a depot and its assigned customers, historical solutions generated for the same depot may be adapted to form the initial solution or part of the initial population for the metaheuristic employed, thereby effectively recycling historical solutions. In this paper, such a recycling heuristic is proposed. A genetic algorithm is applied to solve instances of the periodic VRP with time-windows (PVRPTW) and the effect of the recycling heuristic on the run time of the metaheuristic is evaluated. It is shown that a decrease in run time of up to 26% may be achieved by employing the recycling heuristic to generate initial solutions, without affecting the quality of the solutions returned.

*Keywords:* Vehicle routing problem, metaheuristics, recycling heuristic

## Approximation of Nonlinear Sum and Product Knapsack Problems

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*Abstract* We consider a very general version of the well-known knapsack problem. Our generalization covers, with few exceptions, all versions of knapsack problems that have been studied in the literature so far and allows for an objective function consisting of sums or products of possibly nonlinear, separable item profits. The knapsack constraint states an upper bound on the sum of possibly nonlinear, separable item weights. Nonlinear, separable knapsack problems were treated in a number of publications, most notably by [1]. For such a general setting a fully polynomial-time approximation scheme (FPTAS) is presented. This provides a considerable extension of the recent approximation of the product knapsack problem [4], but with a completely different technique. Our approach employs a partitioning of the profit range into intervals of geometrically increasing width. This has some relation to the approximation scheme presented in [2].

Our FPTAS is also extended to a multi-objective fully polynomial-time approximation scheme (MFPTAS) for the multi-objective version of the problem. Note that an arbitrary combination of sum and product objectives is allowed in this setting.

As applications of our general algorithms, we obtain the first FPTAS for the recently-introduced 0-1 time-bomb knapsack problem [3] as well as FPTASs for a variety of robust knapsack problems. Moreover, we extend our FPTAS to the minimization version of our general problem, which, in particular, allows us to explicitly state an FPTAS for the classical minimization knapsack problem, which (surprisingly) has been missing in the literature so far. A journal version of this work is accepted for publication in Discrete Optimization.

*Keywords:* Nonlinear knapsack problem, Approximation algorithm, Product knapsack problem

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## A Novel Evolutionary Algorithm for Solving the Quadratic Multiple Knapsack Problem

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*Abstract* The Quadratic Multiple Knapsack Problem (QMKP) is an extension of the Quadratic Knapsack Problem and the Multiple Knapsack Problem, requiring the allocation of items to several knapsacks, each with a designated capacity. The aim is to optimize both the linear profit linked to individual items and the quadratic profit arising from including two items in the same knapsack. Metaheuristic methods have predominantly been employed for instances with over 100 items [1,2], while matheuristic and exact approaches have been used for instances with less than 100 items [3,4]. In this study, we propose an evolutionary technique based on genetic programming to address the QMKP. Our method generates hybrid algorithms integrating heuristic, metaheuristic, and exact components [5]. These algorithms are artificially created using mutation and crossover operators commonly utilized in genetic programming. A comparison with existing methods in the literature showcases the competitive performance of our approach while preserving manageable computational times.

*Keywords:* Automatic Generation of Algorithm, Genetic Programming, Metaheuristics, Integer Programming, Quadratic Multiple Knapsack Problem

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specialized algorithms for the binary knapsack problem. Expert Systems with Applications, 141, 112908. (2020).

**Formulations and Matheuristic Algorithms for the Quadratic Knapsack Problem with Setup**

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*Abstract* The Quadratic Knapsack Problem (QKP) was presented for the first time by Gallo et al. in 1980, and received a considerable attention since then. As in the classical 0-1 Knapsack Problem (KP), we are given a knapsack with integer capacity, and a set of items characterized by a non-negative integer profit and a non-negative integer weight. The distinctive feature of the QKP, underlying the quadratic nature of the problem, is that each pair of items produces an additional pairwise profit if both are selected. The QKP consists of selecting a subset of items, whose overall weight does not exceed the capacity and the total profit is maximized. Another relevant generalization of the KP is the Knapsack Problem with Setup (KPS), introduced in 1994 by Chajakis and Guignard and thoroughly investigated in the literature. In the KPS, the items are partitioned into classes, and the items of a class can only be inserted into the knapsack if the corresponding class is activated. Activating a class involves a non-negative integer activation setup cost and a setup reduction of the capacity. Despite a rich literature on these two problems, their obvious generalization, i.e., the Quadratic Knapsack Problem with Setup (QKPS), was never investigated so far. The purpose of this research is to provide a first study on this problem. We discuss mathematical formulations, deterministic matheuristic algorithms, and computationally evaluate their performance.

*Keywords:* Combinatorial Optimization, Integer Programming, Knapsack Problems, Matheuristic Algorithms

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# Invited Session
# Recent Advances in Variational Inequalities and Equilibrium Problems II
### Chair: Laura Rosa Maria Scrimali

## Multi-provider FANET integrated into 5G ecosystem: a Generalized Nash Equilibrium problem and Variational Formulation

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*Abstract* The 5G technology emerged to meet the challenging requirements of the mobile communication networks evolution and is expected to offer a variety of new services with the goal of providing ubiquitous coverage and computing anywhere, anytime. Relevant challenges are posed by those scenarios in which remote areas are poorly connected or not fully provided with communication structured networks or even when bandwidth low-latency applications that require real-time control and implementation are needed. To provide such innovative services, Unmanned Aerial Vehicles (UAVs) can be used as Computing Elements, giving the possibility to host virtual functions (VFs) and/or provide data processing services and storage, extending traditional wireless networks. In this work, we present a scenario in which the FANET is integrated into the 5G ecosystem with the aim of providing services on

demand requested by end users and/or devices on the ground. In our framework the UAVs that constitute the FANET belong to different providers of services. Managing the request of service flows optimally among the UAVs in order to minimize the overall consumption and maximize the FANET lifetime, the quality-of-service provisioning as well as the providers profit represents the key aspect in our model. We formulate the nonlinear optimization problem as a non-cooperative game in which each player is rational and acts selfishly. In particular, we analyze the Generalized Nash Equilibrium Problem (GNEP), and we provide an equivalent formulation of it by means of Variational Inequality theory, that allows us to meet the optimality conditions for all providers simultaneously. We also detail the theorem demonstrations concerning both the GNE and VI problems equivalence and the alternative Variational Inequality Formulation of the variational equilibrium. Finally, illustrative numerical examples are presented and analyzed to estimate the optimal convergence conditions.

*Keywords:* 5G, Unmanned Aerial Vehicles, Generalized Nash Equilibrium Problem, Variational Formulation

*References*

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## Stackelberg competition for the stream of online contents

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*Abstract* This paper investigates the interactions between content creators and viewers in donation-based live streaming platforms. In these social media systems, creators produce their content, while viewers enjoy the live streaming and decide to donate money to creators. To capture the sequential decision process of the model, we introduce a multi-leader-follower Stackelberg game, in which creators act as the leaders of the game and viewers as the followers. Creators first optimize their performance level and the duration of the streams to maximize their profit. Then, viewers optimize the time spent watching a live stream to maximize their utility. Thus, the first stage of the game models the non-cooperative competition among creators, who make their decisions anticipating viewers' choices. The second stage represents the behaviour of viewers deciding on their content demands. We formulate these games as Nash equilibrium problems, and then as variational inequalities. We analyse the existence and uniqueness of the Stackelberg equilibrium. Finally, we present an illustrative numerical example to verify the proposed model.

*Keywords:* Multi-leader-follower game, Nash equilibrium, Variational inequalities, live streaming platform

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## Heuristic and AI Methods for Solving Generalized Nash Equilibrium Problems

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*Abstract* In this paper, we introduce the Shadow Point function, a novel penalty function for Generalized Nash Equilibrium Problems, similar to the Nikaido-Isoda penalty function. We investigate the use of this function across two heursitic models. The first is an evolutionary-inspired algorithm which utilizes competitive selection and linear regression to motivate generation of new points. The other algorithm involves stochastic gradient descent of the Shadow Point function across mass numbers of agents to find solutions. These algorithms are evaluated on 2 and 3 player games in 2 and 3 dimensions, with both linear and non-linear shared constraints. The success of these algorithms is discussed and compared, and the limitations of the algorithms are explored. We tackle the same problems with an ANN based computation and we discuss the results compared to the above approaches and generalizations.

*Keywords:* Generalized Nash equilibria, heuristics methods, solution set

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# Invited Session
# Stream AIRO thematic section on Stochastic Programming
# Urban logistics and sustainable transportation: optimization under uncertainty and machine learning
**Chair: Francesca Maggioni**

## A Threshold Recourse Policy for the Electric Vehicle Routing Problem with Stochastic Energy Consumption

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*Abstract* The Electric Vehicle Routing Problem (EVRP) aims at routing Electric Vehicles (EVs) while planning their stops at Charging Stations (CSs), due to the limited autonomy of their batteries. The majority of studies on the EVRP and its variants have considered deterministic energy consumption. However, energy consumption is subject to a great deal of uncertainty, which if ignored can lead the EV to run out of battery mid-route. In this paper, we develop a two-stage stochastic programming formulation for the electric vehicle routing problem with stochastic energy consumption. In particular, we propose a threshold recourse policy which entails that the EV will head to a charging station after a certain energy level is reached. We show the added value of the extensive formulation of our model on a set of small instances derived from the deterministic literature.

*Keywords:* Routing, Electric vehicles, Uncertain energy consumption, Stochastic programming

## Generating Informative Scenarios via Active Learning

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*Abstract* Scenario generation is a crucial task in Stochastic Program- ming (SP). It involves a trade-off between keeping the scenario set small while making it representative for the target problem. While most state- of-the-art methods focus on matching the uncertainty of the stochastic process using distribution-driven approaches, problem-driven method- ologies have been proposed in recent years to exploit the structure of the target problem during the scenario generation process. In order to rep- resent uncertainties in a more concise way, we propose a novel approach based on Active Learning that sequentially generates a set of scenarios by including a new promising scenario at each iteration. Searching for the most promising scenario is a black-box global optimization problem, efficiently solved via Bayesian Optimization. Preliminary experimental results are presented on a classical newsvendor problem, providing em- pirical evidence that the proposed method can both identify the smallest and most informative scenario set for the problem. Our method can also efficiently and effectively handle multi-modal and fat-tailed distributions, analogously to the most recent problem-driven methods.

*Keywords:* Stochastic programming, Scenario generation, Bayesian optimization, Machine learning

# Demand and Capacity Management in a Stochastic Dynamic Pickup and Delivery Problem with Crowdsourced resources

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*Abstract* In this study we examine the situation of a consortium of brick-and-mortar businesses operating a e-portal to collect customer orders and provide same-day delivery as a dynamic and stochastic pickupand-delivery problem in which deliveries are performed with a mixed fleet of vehicles composed of dedicated vehicles and crowdsourced resources. Forms of delivery capacity vary with respect to the level of information and control that the dispatcher has on the availability and behavior of the courier. Taking into account the specific nature of the different types of delivery capacity, we present an approximate dynamic programming approach to manage the same-day delivery. We present computational results for different scenarios of demand.

*Keywords:* stochastic dynamic pickup and delivery problem, crowdsourced capacity, approximate dynamic programming

## A rolling horizon heuristic approach for a multi-stage stochastic waste collection problem

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*Abstract* In this talk we present a multi-stage stochastic optimization model for a waste collection inventory routing problem [5]. The decisions are related to the selection of the bins to be visited and the corresponding visiting sequence in a predefined time horizon [3]. The aim is the maximization of the total expected waste collection at lowest transportation cost, considering uncertainty in the waste accumulation rate in the network bins. Stochasticity in waste accumulation is modelled through scenario trees generated via conditional density estimation and dynamic stochastic approximation techniques [4]. The model is solved through a rolling horizon approach [2], providing a worst-case analysis on its performance [1]. Computational experiments are carried out on instances based on real data of a large Portuguese waste collection company. The impact of stochasticity on waste generation is examined through stochastic measures, and the performance of the rolling horizon approach is evaluated. Managerial insights are finally discussed.

*Keywords:* routing, waste collection, multi-stage stochastic programming

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**A stochastic Vehicle Routing Problem with divisible deliveries and pickups for reverse logistics**

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*Abstract* Nowadays, e-commerce companies must efficiently manage both the delivery of ordered goods and the return requests, i.e., they also deal with the so-called Reverse Logistics. More precisely, along with delivery operations, a company must accommodate non-delayable (or mandatory) return requests. At the same time, to increase customer satisfaction and speed up the return of goods to the market, delayable (or optional) return requests can be fulfilled as well. For this reason, in this work we study a stochastic version of the Vehicle Routing Problem with Divisible Deliveries and Pickups [1], where the optional return demand is subject to uncertain positive variations as in realistic scenarios. With the aim of minimizing the total cost, the problem seeks for routing a homogeneous fleet of vehicles to satisfy the mandatory deliveries and pickups and to ensure that at least a minimum percentage of optional pickups is fulfilled as well. To deal with the uncertain environment, we propose different problem formulations based on two-stage Stochastic Programming that differ for the recourse actions available within the second stage, such as the possible modification of the vehicles' loading, routing, or fulfilling decisions [2]. We validate the models over a ground set of instances adapted from the literature, and we present a comparison of the different recourse actions, highlighting their strengths and weaknesses against various operative settings.

*Keywords:* Reverse logistics, Vehicle Routing Problem, Divisible deliveries and pickups, Stochastic Programming

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## A Robust Nonlinear Support Vector Machine Approach for Vehicles Smog Rating Classification

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*Abstract* Nowadays all new vehicles are labelled in terms of their emissions thanks to ad hoc legislation. However, from a practical perspective, it is difficult to rank all of them. This paper considers the problem of classifying vehicles in terms of smog rating emissions by adopting a Machine Learning technique. Specifically, a new Support Vector Machine approach is considered, designed for nonlinear separating decision boundaries. To protect the model against uncertainty arising in the measurement procedure, a robust optimization model with spherical uncertainty sets is formulated. Numerical results are performed on both synthetic and real-world datasets, showing the good performance of the proposed formulation.

*Keywords:* Machine Learning, Support Vector Machine, Robust Optimization, Carbon Emission

# Shared Mobility and Company Cooperation

**Chair: Fabio Mercurio**

## Improving Urban Delivery Logistics with Crowdshipping and Station-Based Bike Sharing for Sustainable Last-Mile Delivery

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*Abstract* Urbanization and online shopping are driving an increased demand for logistics services in cities worldwide with last-mile delivery accounting for about 40% of the total used energy and generated emissions from the e-commerce supply chain. Crowdshipping, which uses individuals to pick up and deliver packages during their regular commutes or trips, has emerged as an innovative solution that can help to address this growing demand in a sustainable manner. In this study we evaluate a mixed delivery system that incorporates both traditional delivery vehicles and crowdshippers using a station-based bike sharing system (SBBSS). By modeling the delivery of parcels from a central depot to lockers and final destinations in a municipality, this work demonstrates how crowdshipping can reduce the impact of urban delivery traffic, decrease energy use and emissions, and provide economic benefits. The optimization model considers limited van capacity, bike availability, delivery priority, and the use of parcel lockers to enable crowdshipping trips. By employing a branch-and-bound algorithm with column generation, we obtain optimal solutions that quantify how incorporating crowdshippers as an enhancement to a vehicle-based delivery system can significantly improve sustainability and efficiency compared to the standard vehicle-only alternative. Followingly, with over half the world's population living in cities and e-commerce growing rapidly, crowdshipping appears to be a promising approach for managing increased delivery demand in a way that benefits both businesses and urban residents.

*Keywords:* Last-mile delivery, Crowdshipping, Branch-and-Price

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## A simulation framework for a station-based bike-sharing system

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*Abstract* Many cities and towns offer to citizens a Bike-Sharing System (BSS). When a company starts the service, multiple decisions have to be taken at strategic, tactical, and operational level. When the service is in place, it is often necessary to adapt these decisions to changed conditions. Starting from the experience gained in the real-case of Bicimia in Brescia, Italy, we present a simulation framework to support decisions in the design or revision of a BSS, including the shifts of the operators, the number of vehicles and their capacity, the sizing of the stations, and the sizing of the fleet of bikes. The simulator includes an optimization algorithm to solve the problem of routing the vehicles performing the relocation of the bikes, as well as their operations at the visited stations. A review of the planning problems arising in bike sharing systems is reported in [1].

*Keywords:* Bike-sharing system, Simulation framework, Station-based, Bike relocation

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## Cooperative locker location games

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*Abstract* More and more people are ordering products online and having their parcels delivered to their homes. This leads to more congestion, which negatively impacts the environment and public health and safety. Carriers can use automated parcel lockers to consolidate and serve their customers to reduce these negative impacts. Unfortunately, the cost of lockers and their maintenance can make parcel locker networks expensive to operate for a single company. As such, it could be beneficial for companies to share the costs of opening lockers as well as revenues obtained from serving customers in a horizontal collaboration. We study this problem through cooperative game theory and investigate how to facilitate such horizontal collaboration to promote the use of parcel lockers in the last-mile delivery.

For this purpose, we introduce a stylized model in which a group of carriers can decide collectively to position parcel lockers. Opening a locker comes at a cost, while serving a customer via close-by lockers generates a customer-specific profit. The carriers collectively decide how many lockers to order and where to position them to maximize profit (i.e., the revenues from serving customers minus the costs of opening lockers). We formulate this problem as an integer linear programming problem and show that it can be solved efficiently when the network has a tree structure.

To facilitate horizontal collaboration, we investigate whether the carriers can stably allocate the profit. For this purpose, we introduce an associated cooperative game and study its corresponding core, i.e., the set of allocations that divide the profit among the carriers such that no group of carriers generates more by working on their own.

We show that the core of our game can be empty (i.e., collaboration is not always possible), and prove that it is non-empty when the integer linear programming problem can be solved efficiently.

In addition, we conduct a number of numerical experiments, indicating that for

most real-life situations, the core is non-empty, i.e., a stable collaboration is possible.

*Keywords:* last-mile logistics; facility location; cooperative game theory

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# Applications of OR II
## Chair: Veronica Dal Sasso

### Strip Packing Problem Relaxations

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*Abstract* In the two-dimensional strip packing problem (SPP), one wants to pack a set of rectangular items into a strip with fixed width such that the height of the resulting packing is minimized. The items must not overlap and be packed with their edges parallel to the borders of the strip. The SPP is a strongly NP-hard problem that is difficult to solve in practice. Indeed, some instances with as few as 20 items cannot be solved to optimality, even by the most competitive approaches. Those competitive approaches include mixed-integer linear programs, branch-and-bound algorithms, branch-and-price algorithms, constraint programming, and decomposition approaches. It has been showed through a large set of computational experiments that decomposition approaches were the most competitive solution techniques. Decomposition algorithms proposed in the literature mostly formulate the master problem either as a parallel processing scheduling problem with contiguity constraints ($P|cont|C_{max}$) or one-dimensional contiguous bin packing problem (1CBP), where the former being more used than the latter. Given a solution produced by the master problem, the slave problem tries to transform it into a feasible solution of the SPP. Even though various sets of computational experiments showed that most of the running time is spent solving the master problem, very few research papers (if any at all) focused on developing efficient techniques to solve $P|cont|C_{max}$. Therefore, this work aims to gather and enhance the existing knowledge about $P|cont|C_{max}$ problem. After reviewing the MILP models that have been proposed in the literature, we study how recent cutting and packing advances such as the so-called "meet-in-the-middle" patterns, "reflect arcs", and "reduced-cost variable fixing" may be used to enhance the performance of these models. We also introduce a new pattern-based approach for solving the $P|cont|C_{max}$. In our work, we compare the performance of the resulting algorithms through a comprehensive empirical study and identify the methods that yield the best results.

*Keywords:* strip packing problem, decomposition algorithm, relaxation

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**An integrated framework for the development of and Eldana saccharina infestation risk index in South African sugarcane production**

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*Abstract* One of the key concerns in the South African sugarcane industry is the yield loss due to crop damage caused by the African stem borer, Eldana saccharina Walker (E. saccharina). A number of mathematical models have been developed to investigate the population dynamics of the pest species, and improved pest control strategies for biological control, the release of sterile insects, and the use of Bt sugarcane. In addition, detailed mechanistic sugarcane growth models are used by the sugarcane industry to predict sugarcane yield, given climatic factors. The life cycle of the pest species is intricately linked with sugarcane growth dynamics and harvesting, however, an integrated framework to link implemented sugarcane growth models in industry and E. saccharina population dynamics models have not been established. Such a framework will provide improved decision support for pest management in a region by having a more integrated view of the sugarcane agroecosystem. In this research, an Eldana Risk Index (ERI) model is proposed as a decision support tool that builds on previous research by integrating sugarcane crop model output and E. saccharina population growth models through seasonally integrated risk profiles. The ERI model's primary structure comprises two main dimensions, assessed daily by combining output data from the sugarcane growth model, Canesim, weather data, and an E. saccharina population growth model adapted from previously developed models. The first dimension focuses on sugarcane and includes temperature, water stress related to cane health, water stress regarding susceptibility to infestation, and damage due to infestation. The second-dimension addresses risk related to E. saccharina, and includes temperature impact on degree day abundance of the pest, desiccation stress, desiccation mortality, and precipitation contribution to desiccation mortality. The ERI model offers a promising interdisciplinary approach for quantifying infestation risks in the sugarcane industry, and provides improved decision support for integrated pest management.

*Keywords:* decision support systems, integrated pest management, Eldana saccharina Walker, sugarcane, agricultural systems modelling

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## Multi-neighborhood local search for the capacitated facility location problem with customer incompatibilities

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*Abstract* The capacitated facility location problem with customer incompatibilities was introduced by Maia et al. (2023) as a variant of the classical multi-source capacitated facility location problem, with the additional constraint that some pairs of customers cannot be served by the same facility. Originally, the problem was proposed as a competition to the participants of the Metaheuristics Summer School (MESS 2020+1) and it is equipped with all the necessary infrastructure to guarantee a fair ground of comparison, such as specifications, training and validation instances, and solution validator. For this problem, Maia et al. (2023) presented a portfolio of metaheuristic techniques: a multi-start iterated local search, a GRASP approach, an evolutionary algorithm, and a multi-start greedy procedure. In this work, we investigate the effectiveness of multi-neighborhood search for this problem. We developed several neighborhood relations and a Simulated Annealing approach to drive the local search. In order to be able to efficiently manage very large instances (i.e., 3000 facilities and 7800 customers), we devise ad-hoc techniques to build the initial solution, to reduce the search space, to explore more promising areas, and to accelerate the evaluation of neighbor solutions. This work is ongoing, but preliminary experiments show that we are able to obtain state-of-the-art results, using the same timeout of previous approaches.

*Keywords:* facility location, metaheuristics, neighborhood search

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## Solving Crop Planning Problems in Sustainable Agriculture

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*Abstract* In this work, the problem of planning the allocation of crops to arable land, taking into account crop rotations principles and diversification strategies promoted by sustainable agriculture initiatives is addressed. Crop planning involves the assignment of crops to plots of land and to seeding periods of a given time horizon, with the goal of maximizing the farmer's profit. In sustainable agriculture, different constraints must be considered, including crop rotation issues and diversification requirements. In fact, monoculture schemes, in which the same crop is assigned to the entire farmland over the whole planning horizon, lead to a series of issues, such as loss of yield and soil fertility, increase of weed and pest diseases. In the literature, crop planning and rotation problems have received considerable attention from the operations management and agricultural economics communities, especially focusing on sustainability [1,2,3]. In this work, we show that the problem is strongly NP-hard, while simpler variants can be polynomially solved as a minimum cost flow problem. Furthermore, a solution approach based on Lagrangian Relaxation has been devised, in which nasty constraints of the general problem are relaxed. The resulting Lagrangian problem is solvable as a minimum cost flow problem, on a graph where paths represent sequences of crops over the years, and the flow reflects the number of plots cultivated with a given sequence. The Lagrangian Dual problem is computed by a subgradient method, where heuristic procedures are also employed in order to find feasible solutions. A computational campaign on real-world instances is presented, in which the quality of the lagrangian bounds is assessed through a comparison with the optimal solutions of Integer Linear Programming models.

*Keywords:* Sustainable Agriculture, Crop Rotation Planning, Lagrangian Relaxation, Heuristics

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## Feasibility Jump: an LP-free Lagrangian MIP heuristic

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*Abstract* We present Feasibility Jump (FJ) [1], a primal heuristic for mixed-integer linear programs (MIP) using stochastic guided local search over a Lagrangian relaxation. The method is incomplete: it does not necessarily produce solutions to all feasible problems, the solutions it produces are not in general optimal, and it cannot detect infeasibility. It does, however, very quickly produce feasible solutions to many hard MIP problem instances. Starting from any variable assignment, Feasibility Jump repeatedly selects a variable and sets its value to min-imize a weighted sum of constraint violations. These weights (which correspond to the Lagrangian multipliers) are adjusted for constraints that remain violated in local minima. Contrary to many other primal heuristics, Feasibility Jump does not require a solution of the continuous relaxation, which can be time-consuming for some problems. We show that this heuristic is effective on a range of problems from the MIPLIB 2017 benchmark set, improving the average time to find a first feasible solution over state-of-the-art commercial solvers. Our entry based on FJ to the MIP 2022 Computational Competition (which challenged participants to write LP-free MIP heuristics) won 1st place. Moreover, an implementation of Feasibility Jump now runs by default on FICO Xpress Solver 9.0, and in the CP-SAT solver of OR-Tools 9.7.

*Keywords*: Mixed-Integer Programming, Heuristics, Lagrangian methods

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## Deadlock prevention and detection: a new 0,1-linear formulation

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*Abstract* Railway traffic management involves the solution of complex problems. At the tactical level, it is necessary to decide which and how many trains should travel on any line. This is done taking into account the capacity of the underlying network, in particular in terms of locations where two crossing trains can meet, given their length. At the operational level, however, delays and unforeseen disruptions may alter the capacity of the network and the amount of traffic, thus increasing the risk of creating deadlocks. When a deadlock occurs, two or more trains cannot reach their destination, and at least one of them must be pushed backwards. As these are time and money consuming events, it is crucial to prevent them or, at least, to identify bound-to-deadlock situations, that is a subset of trains which, even if still far from each other, cannot reach their destination because of congestion on the line. When the trains are operated following a solution to a dispatching problem, deadlock prevention should be naturally ensured. Nevertheless, when sudden disruptions occur, it may be necessary to stop trains in advance, where they do not impede the traffic (the so-called safeplaces), in addition to triggering a deadlock detection task. The majority of deadlocks involve a pair of trains, and an algorithm to efficiently detect them is presented in [2]. Here, we present a new Integer Linear Programming formulation, inspired by the path-and-cycle formulation for train dispatching [3], which can perform the two different tasks: on one hand, it can detect deadlocks involving an unknown number of trains, on the other hand, it can identify suitable location to park trains while waiting for the resolution of a disruption. Computational comparison is performed with a previous approach [4].

*Keywords:* railway traffic management, deadlock detection, deadlock prevention, 0,1-linear programming

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# AIROYoung Dissertation Award 2023
## Chair: AiroYoung Board

### Variational inequality and metaheuristic approaches to model and investigate the agents' strategies

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*Abstract* During my Ph.D. experience, research work led to the development of numerous scientific articles which revolve around the understanding of human mentality and behavior. Modeling reality and its behavior represents one of the most investigated topics of scientific research in the field of operational research. The investigation moved through two main approaches: mathematical models of variational inequalities and metaheuristic algorithms and both are complex decision-making systems. The two approaches, the variational one and the metaheuristic one can both be represented and modeled through networks. In the study of a phenomenon, a mathematical model is developed. It must represent the problem effectively and take into consideration all the agents involved and the relevant aspects. The main contribution of the thesis is threefold. Firstly, to study deterministic models as the dynamics of the popularity of online content, the closed-loop supply chain network for second-hand trading of high-uniqueness products, and the scheduling problem of speech-language pathologists. Secondly, to formulate a two-stage procurement planning model in a random environment during emergencies such as health or natural disasters. Thirdly, to understand the behavior of agents who must escape or group in communities. The thesis contains a rich bibliography of sixty-five relevant publications.

*Keywords:* Variational inequality, Nash equilibrium, Agent behavior, Meta-heuristics

## Optimization-based integration platform for Synchromodal Logistics

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*Abstract* Shipping companies are facing greater volumes of shipments than in the past while also striving to reduce pollution associated with the transport sector, one of the main contributors to global warming. New paradigms try to address the challenges faced in the transport industry as more economically viable and environmentally sustainable solutions are required. Synchromodality, or Synchromodal Logistics, is one of them. Synchromodality is the delivery of efficient and sustainable services through stakeholders' coordination and activities' synchronization, strongly relying on modern technologies. We aim to contribute to some of the many challenges in synchromodality implementation. As the literature lacks a precise definition of all characteristics of this paradigm, our first contribution is a detailed analysis of synchromodality. We discuss the current development status in the literature and from real-case studies of the main enabling technologies for synchromodality, providing future research lines for all of them. Our second contribution is to present the smart steaming concept idea as a plan for delivering more sustainable and effective synchromodal logistics services. We examine the issues in implementing smart steaming, considering environmental regulations and operational restrictions. The third contribution relates to the platform prototype built for the Horizon2020 SYNCHRO-NET project, which integrates various enabling technologies. We present the optimization tool for finding multimodal routes and schedules in both strategic and operational settings. The optimization tool is integrated with the modules developed by the other project partners. The platform was tested over three separate case studies using real data from the industrial partners. The last contribution focuses on the Location-Transshipment Problem, which consists of contracting terminals for transshipment activities. Transshipment operations are crucial as congested terminals are one of the primary causes of shipment delays. We present three variants, one stochastic and two deterministic, including important factors for synchromodality, such as a multi-period setting, uncertainty regarding handling capacities and utilities, and synchronization mechanisms based on early and late delivery penalties. We present a computation analysis derived by solving the models designed for the three variants with a commercial solver, and we propose a few tailor-made variants of the Progressive Hedging algorithm for solving the stochastic model.

*Keywords:* Synchromodality, Optimization-based integration platform, Hub Location Problem

## Adjustable robust optimization with nonlinear recourses

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*Abstract* Over the last century, mathematical optimization has become a prominent tool for decision making with applications in economics, logistics and defence. In the last decades, however, the research community raised more and more attention to the role of uncertainty in the optimization process. In particular, one may question the notion of optimality, and even feasibility, when studying decision problems with unknown or imprecise input parameters. In this talk, we focus on a class of optimization problems which suffer from such uncertainties and feature a two-stage decision process, i.e., in which decisions are made in a sequential order – called stages – and where unknown parameters are revealed throughout the stages. More precisely, we dive into the current state of the art for solving adjustable robust optimization problems. Throughout the presentation, we highlight the contributions made during the speaker's Ph.D thesis, which explore novel algorithmic approaches to address such issues. The rest of the talk is then dedicated to a deeper exposition of a selected topic regarding problems in which costs are uncertain.

*Keywords:* Adjustable, Robust optimization, Decomposition

## Optimization methods for knapsack and tool switching problems

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*Abstract* The thesis deals with two different classes of optimization problems: Knapsack Problems (KPs) and Tool Switching Problems (ToSPs). The thesis begins with an extensive treatment of classical single KPs and their variants. Then, the thesis shifts the focus to multiple, multidimensional, and quadratic KPs, followed by a brief overview of online and multiobjective KPs. The survey is based on over 450 bibliographic references, over 70% of which have been published in the last decade, underscoring the vibrant research interest in the area of KPs, even after more than six decades of intensive research. In the subsequent part of the thesis, motivated by a real-world application in the color printing industry, we deal with different variants of the well-known ToSP. Firstly, we introduce four different variants of ToSP. For each variant, we discuss its complexity and propose a mathematical formulation. The third and fourth variants introduce a novel requirement into ToSP: the tool order constraint. We show that the new problem variants are NP-hard even when the job sequence is given as part of the input. We solve them by using dedicated arc flow models, whose effectiveness is evaluated on several instances that are generated with the aim of covering different scenarios of interest. The thesis continues by addressing a challenging real-world industrial problem in the food packaging industry, which generalizes the fourth introduced variant of ToSP by introducing parallel heterogeneous printer machines, due dates, and other complexities. To tackle this problem, a greedy randomized adaptive search procedure is proposed, incorporating various local search procedures. Computational experiments on real-world instances demonstrate that the algorithm produces high-quality solutions within a limited computing time, outperforming the company solutions by a considerable margin. In the addressed industrial problem setup times are subject to significant uncertainties. Predicting such times is a very difficult task and significantly impacts the quality and efficiency of job scheduling. The last part of the thesis adopts a data-driven approach based on machine learning regression algorithms to enhance setup time evaluations. The proposed algorithms are validated through computational experiments, demonstrating their effectiveness in providing accurate results.

*Keywords:* Knapsack problems, Tool switching problems, Machine learning

# Logistics and Transportation II
**Chair: Maurizio Boccia**

## Optimizing the Automated Parcel Lockers Network for Last-Mile Delivery: A Hybrid Modelling Approach with Agent-Based Modelling and Facility Location Optimization

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*Abstract* This work presents a hybrid modelling approach for designing an optimized network of automated parcel lockers (APLs) in an urban setting as a last-mile delivery scheme [1-2]. We conduct a case study in Pamplona, Spain, to examine the usage patterns of APLs and propose a methodology that combines agent-based modelling [3] and a facility location problem optimization to estimate future demand for APLs and identify optimal locations for these lockers. Our approach considers socio-economic factors, such as population size, e-commerce growth rates, and customer behaviour, to create a simulation-optimization model that minimizes operational and service APL-related costs while improving service quality and customer satisfaction. Our results predict an increase in the number of eShoppers and a five-fold increase in the number of APLs in Pamplona over the next three years. Thus, this study contributes to the field of optimization and decision sciences by offering a novel approach to designing an optimized APL network in an urban setting. Our findings demonstrate the potential benefits of simulation and optimization tools in order to promote the adoption of APLs as an effective last-mile delivery scheme.

*Keywords*: automated parcel lockers, facility location problem, last mile delivery, agent-based modelling

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**A location - network design problem with vehicle selection in city logistics**

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*Abstract* We investigate a location - network design problem arising in the field of city logistics [1], [2]. A fleet of containers must be moved from a port to satellites, where pallets are unpacked from containers, transhipped into different vehicles and moved to their final destinations. We must select satellites and vehicles, assign containers to satellites, determine the paths of the selected vehicles and the flows of pallets. A mixed integer programming formulation is proposed for this problem. We propose an iterative solution method in which the overall problem can be divided at each step into two subproblems: (i) in the first we determine satellites, assign containers to satellites, select and assign vehicles to satellites; (ii) in the second we solve a network design problem with routing constraints to determine the paths of vehicles and pallets from satellites to customers. An adaptive large neighborhood search (ALNS) algorithm is proposed for problem (ii).

*Keywords:* city logistics, location, network design

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## A simulation approach to improve buffer storage performance in ceramic tile logistics

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*Abstract* This study aims to enhance the warehouse logistics performance of an international ceramic tile company headquartered in Italy by identifying an efficient storage policy for the buffer area between the production plant and the logistics department. Considering the lack of homogeneity of the ceramic production process and the requests for uniform-tile orders, the storage policy must divide the products into homogeneous categories and store them accordingly. The current policy adopted by the company classifies tiles based on their technical properties, whereas the newly devised policy classifies them based on their downstream destination. A discrete event simulation was developed using Salabim [1], a recently developed Python-based open-source software that offers a range of attractive features, including comprehensive documentation, object-oriented architecture, and animations. The simulation was run multiple times to gather the values of four performance indicators, and statistical comparative analyses demonstrated that the proposed policy outperformed the current one on all different indicators. Additionally, a sensitivity analysis was conducted to assess the effectiveness of the policies under different scenarios by increasing the production quantity, coherently with the positive market trends observed in the sector [2]. The results revealed that, regardless of the increase in production, the devised policy consistently outperformed the current policy in all scenarios. As a result, the company decided to implement the proposed storage policy, estimating to reduce the costs related to the buffer area emptying process by 17%. Overall, this research contributes to the literature on simulation-based decision-making in material management and this approach can be implemented in different contexts to enhance warehouse performance. Finally, this work provides a functional case study that illustrates the achievable results of Salabim for modeling complex systems.

*Keywords:* discrete event simulation, ceramic tile, warehouse management

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**Profitability of Ultrafast Grocery Retailers**

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*Abstract* Ultrafast grocery retailers are known for delivering products to their customers within a short time frame [1,2]. To achieve this, these retailers establish numerous dark stores in different locations of cities and countries. Due to their fast expansion, many retailers have gone bankrupt (similar to previous ones [3]), and the remaining ones are now focusing on efficiency and profitability as their top priorities. One way for these retailers to increase profitability is by optimizing their delivery radius. This is a challenging problem as the delivery radius affects the number of customers and the revenue generated, as well as the delivery costs. In this study, we investigate the importance of optimizing the delivery radius and how it can impact the profitability of ultrafast grocery retailers. Our analysis reveals that the profit of an ultrafast grocery retailer may not become positive under any delivery radius. Profitability depends not only on profit margins but also on local characteristics such as delivery costs and customer density. We extend our model by considering customers' willingness to wait for longer delivery times. Our numerical examples indicate that while a higher willingness to wait has a positive impact on profit, the optimal delivery radius does not significantly change under different levels of willingness to wait.While these companies typically commit to identical delivery times in different locations, we demonstrate that this policy may reduce their profitability. By examining the profitability of ultrafast grocery retailers, we offer guidance to optimize their operations and increase their chances of success in this competitive market. Moreover, our investigation into the possibility of merging dark stores can provide useful guidance to these retailers considering this option to improve their profitability. Ultimately, our study aims to enhance the understanding of the ultrafast grocery retailer's business model and its potential for long-term sustainability and profitability.

*Keywords:* Ultrafast grocery, retail operations, delivery radius, inventory management, efficiency

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## An ILP-based exact approach for solving the shared satellite-based last-mile delivery problem

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*Abstract* Two-tier logistics systems have become a frequent solution for the last-mile delivery of products to customers. In these logistics systems, products from different providers are consolidated into shared consolidation centers (satellites) for being bundled and transshipped to final customers within the same day; satellites offer also value-added logistics activities like off-site stockholding, inventory management, unpacking, and waste collection upon payment. Vehicles and satellites are characterized by time-varying tariffs over the day, e.g., cheaper rates are charged at certain times of the day or night. Courier companies that operate satellites are challenged for efficient use of the satellites' capacity by planning deliveries to customers with their limited and heterogeneous fleets of vehicles available in a day. The problem of a courier company operating the satellites can be modeled as a variant of the bin packing problem (BPP) with time-dependent costs. Such modeling is first proposed in [4] as the variable costs and size bin packing problem with time-dependent costs (VCSBPP-TD). The variable-sized BPP appeared first in [3] and the variable cost and size BPP in [2]. Except for pure ILP [4], no exact solution methods have been yet proposed for efficiently solving the VCSBPP-TD. To close this gap, we devise a simple ILP-based approach that progressively computes integer solutions for subsets of problem variables up to obtain a complete integer problem solution. The subsets of the problem variables are related to different problem decisions with different granularity. Such a problem structure is effectively exploited by our approach to solve the problem. The approach we devised is quite similar to the exact algorithm of [1] for solving the 0-1 knapsack problem with setups. Numerical results for a set of real-world instances reveal that our approach computes the optimal solution at least ten times faster than the pure ILP model.

*Keywords:* last-mile delivery, bin packing, combinatorial optimization, exact algorithm

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## Truck-Drone Team Logistics: exact and heuristic approach

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*Abstract* In the last years, the attention of the scientific research community towards the usage of drones has continuously increased. The motivations behind this growing research interest can be mainly found in the continuous developments of drone technologies and in the subsequent exploration of new drone applications. Driven by large corporations such as Amazon, Google, UPS and others, great attention has been paid to the usage of drones in the Last-Mile Logistics (LML) that is one of the most important and expensive part of the freight distribution process in a supply chain. In this context, the most promising delivery system consists of a truck and a drone operating in tandem for the parcel delivery to the customers. The Truck-Drone Team Logistics problem (TDTL) is one of the last optimization problem defined for a truck and drone delivery system and it can be seen as a generalization of the Flying Sidekick Traveling Salesman Problem (FS-TSP) defined by Murray and Chu in one of the pioneering work in this field. Both the problems (FS-TSP and TDT) can be seen as a variant of the TSP where routing decisions are integrated with customer-to-drone and customer-to-truck assignment decisions and truck-and-drone synchronization constraints. The objective is the minimization of the time required to serve all the customers, taking into account drone payload capacity and battery power constraints. The TDTL problem differs from the FS-TSP in the maximum number of clients served by the drone in a single sortie: in the FS-TSP the drone can serve just one client for each sortie while in the TDTL problem a drone can serve more than one clients in a single sortie. A new formulation of the TDTL problem is introduced and solved by a branch-and-cut approach able to solve instances up to 20 clients. To deal with medium and large scale instances, a local search heuristic has been developed too. Computational experience on benchmark instances shows the effectiveness of both the approaches.

*Keywords:* logistics, drones, mixed integer linear programming, heuristic

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# Scheduling II

## Chair: Alessandro Agnetis

### Scheduling automated guided vehicles: challenges and opportunities

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*Abstract* Automated Guided Vehicles(AGVs) play a fundamental role in different logistic systems, being widely used for the automatic handling of materials, goods, and containers. The management of AGVs requires the solution of several optimization problems, such as task allocation/scheduling, routing, and path planning, which are often enriched by additional attributes, such as multi-load, battery constraints, and conflict avoidance. Many of these problems are faced in the real-world context of the Italian company E80 Group, one of the world leaders in the production of AGV systems. The literature is huge for all the aforementioned problems, and hence we focus only on the problem of scheduling AGVs, modeled as a Pickup and Delivery Problem (PDP). In particular, we propose a PDP formulation, discuss real-world and literature scheduling applications, and indicate challenges and research opportunities providing a guide for future researches.

*Keywords:* automated guided vehicles, scheduling problem, pickup and delivery, challenges and opportunities

**MIP models for flow shop scheduling with inter-stage flexibility and blocking constraints**

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*Abstract* We investigate a scheduling problem inspired by a material handling problem arising at a production line of an Austrian company building prefabricated house walls. The addressed problem is a permu- tation flow shop with blocking constraint in which some machines are flexible, that is, there are a number of operations that can be processed on any of two successive machines of the system. This situation is usually referred to as multi-task or inter-stage flexibility. We propose four different MIP Models and test their efficiency and effectiveness on a number of randomly generated instances similar to those of the real-life application.

*Keywords:* Flow shop scheduling, Multi-task flexibility, Mixed Integer Programming

**Minimizing makespan and number of preemptions in resource-constrained project scheduling problems with time-varying resources**

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*Abstract* In project scheduling, allowing the possibility of interrupting the execution of activities can play an important role. This leads us to consider the preemptive version of the resource constrained project scheduling problem (preemptive RCPSP) [1,2]. Preemptions may bring benefits in terms of project makespan, but in some cases they also entail undesired effects, such as an increased risk of operational mistakes, or difficulties in re-aligning resources with project execution. Our purpose is to investigate the tradeoff between the total number of interruptions across a project and the makespan. In particular, we want to investigate the problem in a context in which the resource profile varies over time, which typically may create the need for activity preemption.

In order to solve this bicriteria problem, new ILP formulations are proposed to minimize the number of preemptions with a constraint on project makespan. By applying the ILP formulations to a sample of benchmark instances we are able to obtain the whole set of Pareto optimal solutions. This allows to assess how many Pareto optimal solutions arise and how much the makespan benefits from activity preemption.

The time-varying resource profile over time is inspired by a real case study from software development in which the resources correspond to distinct company departments and they are not constant over time because the same staff may be temporarily involved in other projects.

In our experiments, we consider different scenarios concerning how resources vary over time, characterized by parameters such as resource variation intensity with respect to the baseline, variation frequency and variation length. The results show that a limited number of preemptions is needed to achieve significant benefits, and in most cases the corresponding schedules can be exactly computed with a limited computational effort.

*Keywords:* RCPSP, preemption, ILP formulations

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# Nonlinear Optimization
## Chair: Manlio Gaudioso

### Optimizing Advertising Investments: A Case Study in the Central and Eastern Europe (CEE) Region

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*Abstract* Evaluating communication strategies is critical for the success of marketing initiatives in companies. Specifically, it is necessary to assess the profitability and sustainability of advertising investments. However, revenues are affected by several factors such as seasonality, trends, pricing, distribution, media, and competitor activities, and the impact of each variable must be accounted for. To address this issue, this paper proposes an algorithm that selects relevant variables and incorporates the specific behaviour of media investments, such as lagged effects and diminishing returns to scale. This algorithm integrates the strengths of genetic algorithms and nonlinear optimization techniques. It applies them to the anonymized data of a firm operating in the Central and Eastern Europe (CEE) region. The resulting model achieves a coefficient of determination exceeding 80%, allowing for meaningful conclusions about media communication's effectiveness. Additionally, the return on investment for individual campaigns is calculated, and response curves are estimated. Marketers can use the insights gained from this analysis to develop their communication strategy for the following period.

*Keywords:* Communication Strategy Optimization, Long-Term Effect of Advertisement, Time Series Analysis, Data-Driven Marketing, Non-Linear Optimization

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## Selecting the stepsizes in Polyak's Momentum algorithm by quadratic plane search

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*Abstract* Among many effective strategies to speed up iterative solvers for smooth nonlinear optimization problems, Polyak's momentum (or Heavy-Ball) [1,2] certainly stands out. The idea of Polyak consists of exploiting information about past iterates, carrying out a step along a direction which is a linear combination of a suitable gradient-related descent direction and the previous step. The idea of this update rule is that, partly following the direction of the last iteration, oscillations can be controlled and acceleration can be obtained in low curvature regions. The main computational advantage of introducing the momentum term lies in the fact that it only exploits already computed information: no additional evaluations of the objective function or, even worse, the gradient, are required. However, except for the quadratic case, the selection of the two parameters defining the update is not trivial; whereas one might be chosen by a line search, the other is usually set to a constant chosen somewhat heuristically; some adaptive strategies have also been proposed in recent years. In this talk, we introduce a novel approach for the selection of these two parameters: similarly as what is commonly done for the selection of the stepsize in line-search algorithms, we try to (approximately) solve an optimization problem in two variables; in particular, we show that we can cheaply construct a two-variables quadratic model of the objective function over the plane defined by the two directions, and then solve the subproblem in closed form. The results of thorough computational experiments show that a simple implementation of the proposed approach is at least as efficient as state-of-the-art solvers such as L-BFGS [3] and the nonlinear conjugate gradient method [4].

*Keywords:* Nonlinear optimization algorithms, Heavy-ball method, Polyak's momentum, quadratic subproblem, stepsizes computation

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# MWU 2.0 with approximation guarantee for the Distance Geometry Problem

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*Abstract* In this short paper, we define an approximation guaranteed algorithm for Distance Geometry Problem (DGP), by straightforwardly extending the framework proposed by Plotkin, Shmoys, and Tardos for fractional packing and covering problems. In particular, following the approach in [1], we adapt the Multiplicative Weights Update (MWU) framework to define an approximated algorithm which calls an ORACLE solving the surrogate relaxation of the feasibility problem a polynomial number of times. We implemented the algorithm and we present promising computational results in terms of mean and largest error of the produced solutions. We compare the new algorithm with the previous version of MWU for DGP introduced in [2].

*Keywords:* distance geometry problem, mixed-integer nonlinear programming, multiplicative weights update

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## Mixed interior-exterior point method for non-linear black-box optimization

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*Abstract* We consider constrained optimization problems where both the objective and constraint functions are of the black-box type. For such problems, we propose a new derivative-free optimization method that is based on the use of a merit function that handles inequality constraints by means of a log-barrier approach and equality constraints by means of an exterior penalty approach. We prove the convergence of the proposed method to KKT stationary points of the problem under standard assumptions. Furthermore, we also carry out a preliminary numerical experience on standard test problems and comparison with state-of-the-art solvers which shows the efficiency of the proposed method.

*Keywords:* Derivative-free optimization, Nonlinear programming, Interior point methods, Sequential Penalty

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## The Descent-Ascent (DA) algorithm for Difference-of-Convex optimization

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*Abstract* We introduce a new algorithm for the class of nonconvex and nonsmooth optimization problems where the objective function is the difference of two convex ones (DC). It is based on calculation of a novel type of descent direction, which is expected to be both a descent direction for the first one and an ascent direction for the second. Then the classic machinery of proximal-bundle methods enters into play. We pursue a parsimonious use of the data, with the aim of reducing the computational effort. Consequently, we reset the bundle every time sufficient decrease is achieved. No line search is embedded into the algorithm. We prove termination of the algorithm at a point satisfying a weak criticality condition and report the results of several numerical experiments on a set of benchmark DC problems.

*Keywords:* Nonsmooth Optimization, Difference of Convex, Bundle Methods

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# Packing problems
## Chair: Maria Elena Bruni

### A Branch-and-Price approach for the two-dimensional circular packing problem

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*Abstract* The two-dimensional circular packing problem (2D-CPP) is under-investigated in the field of packing problems despite its importance in some real-world applications [1]. The objective is to pack a set of rectangular-shaped objects as densely as possible in a circular container by maximizing either the total area or the number of items packed. 2D-CPP has several applications, including cutting wooden boards from logs, handling satellite stability control and performance, and dicing silicon wafers during the manufacturing process. The problem, when originally defined, was formulated as a non-linear model. More recently, it has been formalized as a MILP and solved using a Branch-and-Cut approach [2]. In this paper, we propose a Branch-and-Price approach to address the problem. As far as we are aware, no previous Branch-and-Price approach has been developed to solve this problem optimally. The 2D-CPP even simple to state, belongs to the class of strongly NP-Hard problems generalizing the two-dimensional Knapsack problem. We define a new linear model based on the approximation of the circular container with rectangular shapes. The column generation approach, that reckons on a dynamic programming solution method, looks for the best subset of items fitting inside a given rectangular shape. Feasibility of the resulting solution must be proved. Since the problem to decide if a feasible packing exists given a set of items, known as Two-Dimensional Orthogonal Packing Problem (2D-OPP), is NP-complete, we develop ad hoc solution methods to check if the selected set of items can fit into the circular container. Preliminary results on benchmark instances seem to be very promising.

*Keywords*: Packing, Circular container, Branch-and-Price, Dynamic Programming, Optimality

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**Two-dimensional strip packing models and algorithms for HPC clustering applications**

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*Abstract* We consider the problem of scheduling a given set of independent tasks on a set of identical processors, so as to minimize the total completion time. Each task must be repeated a given number of times and each task is supposed to be parallelizable, i.e., it can be assigned to multiple processors provided all of them start the execution of the job at the same time. We model the problem as a two-dimensional strip packing problem with deformable items, where each task is associated with a set of candidate rectangles (items). The width of an item represents the number of processors assigned to the task, whereas its height represents the corresponding completion time. We propose two ILP models based on existing approaches in the two-dimensional bin packing literature. The first ILP formulation models level-oriented solutions, whereas the second formulation is based on a discretization of the coordinates at which items can be placed. Finally, these formulations are combined in a heuristic fashion, so as to derive a matheuristic approach. Exhaustive computational experiments on a set of realistic instances show that our approaches produce high-quality solutions in reasonable computational time.

*Keywords*: Combinatorial Optimization, Bin Packing, ILP models

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## The Balanced Bin Packing Problem

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*Abstract* This work introduces a new variant of the classic Bin Packing Problem called the Balanced Bin Packing Problem (BBPP). The Bin Packing Problem (BPP) is a well-known NP-Hard optimization problem. Over the years, several variants have been proposed and studied, such as the two-dimensional bin packing problem [1], three-dimensional bin packing problem [2], bin packing problem with conflicts [3], and online bin packing problem [4], among others. The BBPP aims to optimally fill all available bins while minimizing the excesses and shortfalls in the occupation of each bin. The problem's key features include that the bins' capacity can be exceeded by the items contained in them and that the number and size of the bins are given to the problem, unlike in the classic Bin Packing Problem. This study defines the BBPP and proves that it is NP-Hard. An exact mathematical model of Integer Linear Programming (ILP) is presented. Several generators capable of generating test instances of the problem have been created. In particular, we have implemented a generator capable of producing random instances with a known optimal solution. Computational tests have been conducted to highlight conditions under which the problem becomes computationally challenging for the proposed mathematical model. Overall, this work presents a new and challenging problem with significant practical applications in the field of electronic document conservations and data transmission protocols.

*Keywords*: Bin Packing Problem, Balanced Problem, Combinatorial Optimization

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## Beam Search for the Pallet Loading Problem

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*Abstract* We consider the Pallet Loading Problem (PLP), a variant of the three-dimensional bin packing problem which includes practical constraints related to the loading of boxes on pallets. In particular, we consider constraints on item rotations, static stability, load bearing and weight limit. We develop a new constructive heuristic for the PLP called Support Planes (SP), where a set of highly heterogeneous boxes is loaded on one or more pallets by solving a series of two-dimensional bin packing problems on planes created by placed boxes. We use SP as a component for developing an efficient beam search algorithm for the PLP called the Support Planes Beam Search (SPBS). The proposed algorithm is evaluated on test instances from the literature, where it outperforms the current state-of-the-art algorithms both in terms of the quality of solutions and in terms of time efficiency. After demonstrating the effectiveness of the developed algorithm, we test it on a series of large instances obtained from our industrial partner.

*Keywords*: 3d bin packing, pallet loading, beam search

# An Integer Programming Approach for a 2D Bin Packing Problem with Precedence Constraints in the Sheet Metal Industry

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*Abstract* We consider an optimization problem of practical relevance arising in Salvagnini Italia, a multinational corporation in the sheet metal industry. The problem falls into the well-know area of Two-Dimensional Bin Packing Problems, and aims at determining efficient item-to-sheet assignments by minimizing the material waste and by keeping into account several technological constraints involving, in particular, hard and soft precedence relations among groups of items. We devise two Mixed Integer Linear Programming (MILP) formulations able to address the different practical aspects of the problem. Based on the MILP models, we propose an exact approach and a matheuristic. The two methods have been applied to instances of practical relevance, and we report computational results and a comparison with the current company's procedure.

*Keywords*: 2D Bin Packing, Sheet Metal Industry, Mixed Integer Linear Programming, Matheuristic, Precedence Constraints

## Service Network Design with Bin Packing Constraints

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*Abstract* Modern transportation and Supply Chain systems require a holistic view of the sustainability of their operations, considering different aspects (operations, economies of scale, social and environmental impacts) while finding a trade-off between maximization of the revenues and high quality of service for customers. One of the principal modeling frameworks in this context turned out to be the Service Network Design. Some aspects of it, however, may limit its applicability. One of those is the absence of explicit packing aspects related to the services to be operated on the network. In this talk, we discuss new variants of service network design, namely the Service Network Design with Bin Packing Considerations that incorporate the families of packing problems already in use in capacity planning. We also show how several realistic settings can be modeled through this new family of Service Network Design problems.

*Keywords*: Service Network Design, Bin Packing, Combinatorial Optimization

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# Invited Session
# OPTSM – Air Transport
### Chair: Luigi De Giovanni

## An Integer Programming approach to dynamic airspace configuration

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*Abstract* Aviation is one of the most global industries and has become essential for global business, thus generating increasing air traffic demand. The simultaneous transit of several aircraft over a region can cause safety issues and difficulties in monitoring tasks, so it is necessary to organise the airspace structure to avoid imbalances, i.e., under and over-utilised portions of the airspace. To this end, we model the airspace by means of elementary sectors, 3D portions of the airspace, and collapsed sectors, union of elementary sectors that are connected in 3D. A capacity is associated to each collapsed sector, limiting the maximum number of flights that controllers can monitor in a time unit without exceeding their maximum workload. Capacities depend, among other factors, on the sector's size and geometry, and they change over time to allow safe operations. An airspace configuration is a partition of elementary sectors into collapsed sectors. Based on the same elementary sectors, different configurations can be achieved. Given a pre-determined set of configurations with related capacities and the dynamic air traffic demand in a time horizon, we aim to determine a sequence of configurations that meets the demand as much as possible, which allows reducing air traffic delays. The sequence must also satisfy operational restrictions that limit feasible transitions among configurations, as to avoid, e.g., too frequent switching between configurations (quiescence or permanence constraints). The problem is known as Dynamic Airspace Configuration and is mostly faced by means of heuristic approaches [1,2,3,4,5]. Based on time discretization, we propose an Integer Linear Programming model and a shortest path formulation on a graph whose nodes represent the available configurations for each time interval and arcs represent feasible transitions. We discuss the properties of the graph and preliminary computational results of the two formulations on randomized instances.

*Keywords*: air traffic flow management, optimization, airspace configuration

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**Impact assessment of capacity reduction policies at major hubs: Network and societal implications**

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*Abstract* Capacity reduction initiatives are practical means to alleviate congestion at major hubs and improve their environmental footprint at short notice, possibly at little expense of passenger surplus. This paper proposes an optimization framework to assess and inform the design of such policies. We develop an airport-centric welfare-orientated flight scheduling and fleet assignment optimization model, inspired by state-of-the-art airline scheduling models with supply and demand interactions. From a methodological standpoint, the proposed model augments existing work by proposing a new linearization scheme based on local approximation for the non-linear demand function and a tailored warm start approach to accelerate convergence. The model is formulated as a mixed-integer nonlinear program with three different objective functions: (i) the maximization of airline operating profits; (ii) the maximization of passenger surplus; and (iii) the minimization of $CO_2$ emissions. This, in turn, allows us to comprehensively evaluate the implications of capacity reductions on these three key dimensions characterizing the quality of the network and investigate trade-offs among them. We deploy our model to address three main research questions: (i) investigate the impact of capacity reductions on the hub carrier's network connectivity and profitability; (ii) investigate the trade-off between airline profits, local passenger surplus, and $CO_2$ emissions; (iii) investigate the impact and policy implications of different policies, i.e., the setting of air transport movements vs. $CO_2$ limits.

*Keywords*: Airline scheduling, Sustainability, Airport capacity reduction

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## The airport network slot allocation problem: an exact approach

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*Abstract* The seasonal airport slot allocation procedure is currently still conducted via a negotiation process among airlines' representatives and the network authorities. The task is of particular complexity as the allocation must take into account airports' slot availability and airlines' business and connectivity requests, and it must be compliant with the International Air Transport Association Worldwide Slot Guidelines (WSG) and its empirical management results highly inefficient [1]. In this work we propose an automated solution for this procedure by the use of an integer programming model that represents the update to the current WSG as well as the extension on the whole summer season of the work presented in [2]. The model aims to optimise the airlines' requests fulfilment, in accordance with the international rules and the available resources, and additionally considering aircraft rotations and turn-around time constraints. Its design has been also developed in order to be flexible and easily adaptable to different allocation policies. The model has been tested on several real-like instances obtained via a refined data driven procedure, proving its capability to solve the slot allocation problem of more than 400.000 flights covering 67 European airports in less than an hour. To ensure robustness as well as the model's applicability in the real scenario, several levels of demand-capacity unbalances have been tested without deteriorating the model performance.

*Keywords*: airport slot allocation, air traffic management, real data-driven instances

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# A primal-dual copy generation approach for aircraft recovery problem with flight duration control

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*Abstract* Airline schedules are frequently disrupted by unexpected events such as bad weather conditions, aircraft mechanical failures, airport congestions and crew absences, resulting in tremendous costs to airlines and passengers in addition to those originally planned. The Aircraft Recovery Problem is usually solved to help airlines repair the disrupted schedules by properly rescheduling the flights and rerouting the aircrafts, such that the total recovery cost is minimized while a set of operational and maintenance constraints are satisfied. In this work, we consider changing flight duration as a recovery option in addition to flight delay, flight cancelation and aircraft swap. Specifically, we assume that the duration or the block time of a flight can be reduced by increasing its airborne speed, so that the aircraft can arrive earlier and catch the next flight which could be missed due to delay propagation. We model each possible change in flight duration as a discrete copy in a time-space network, and propose a primal-dual approach for quantitatively evaluating each copy and generating attractive copies accordingly.

*Keywords*: airline recovery, copy generation, flight duration control

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## Fighting Terrorism: How to Position Rapid Response Teams?

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*Abstract* Over the past years terrorism has claimed hundreds of lives. Improving the protectability against terrorism is therefore an important societal concern. To address this concern, several countries decided to deploy so-called rapid-response teams. These are heavily-armed and highly-trained teams located at high-potential attack regions being capable to respond to terrorist attacks within minutes. The aim of the government is to carefully position these rapid response teams. In light of this, we introduce and study a Stackelberg game between a government and a terrorist. In this game, the government positions a number of heavily-armed rapid response teams on a line segment (e.g., a long boulevard or shopping avenue) and then the terrorist attacks a location with the highest damage. This damage is the product of the time it takes the closest rapid response team to react and the damage caused per time unit, which is modelled via a damage rate function. We prove that the best response of the leader balances the possible damage on all intervals that result from positioning the rapid response teams. We discuss the implications for various types of damage rate functions.

*Keywords*: Counter-terrorism, Stackelberg Game, Resource Allocation

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**An analysis of trajectory-centred Air Traffic Flow Management with airspace users' preference scores**

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*Abstract* We compare two trajectory-centred Air Traffic Flow Management (ATFM) architectures that assigns a 4D (space-time) trajectory and a departure time slot to each flight. Both architectures use trajectories that are feasible from the operational point of view, and as much as possible aligned to airspace users' preferences [1,2,3,5]. The first architecture is inspired by the first-come-first-served principle that currently underpins most of ATFM initiatives [4]: for each flight, following the scheduled time of departure, it considers the trajectory that is proposed by the airspace user, and a delay is allotted to resolve air traffic congestion. The second architecture considers, for each flight, a set of alternative trajectory options and explicitly takes the preference score of each option into account [1]. It aims to provide better trade-off between user-preferred trajectories (airspace users' perspective) and system efficiency (network manager's perspective). To this end, the core of the architecture is an optimization module: it solves an integer linear programming model that simultaneously assigns a trajectory in the option set and a departure time slot to each flight, as to maximize the total preference score while taking efficiency into account. Individual trajectory option preferences are learned, by means of clustering and classification techniques, from repositories that collect historical information on flights and daily requested trajectories. The two architectures are applied to real instances, each related to a whole day of operations in the European Airspace. The comparative analysis highlights the benefits of the preference-aware ATFM architecture in terms of both system efficiency, measured by total delay and traffic-capacity balance, and satisfaction of airspace users' preference, thus paving the way to its potential use as a tool for accelerating the ATFM collaborative decision-making process involving the network manager and the airspace users.

*Keywords*: Air Traffic Flow Management, Airspace Users' Preference, Trade-off Analysis, Data-driven optimization

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# Vehicle Routing IV
**Chair: Daniele Ferone**

## Evaluating the effect of prediction methods in real-time Dial-a-Ride problem using regression trees

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*Abstract* The dial-a-ride problem (DARP) is a vehicle dispatching problem aiming to serve customers with certain pick-up and drop-off locations. DARP solutions determine which vehicles serve which customers while allowing for ride-pooling and aiming at minimizing total passenger waiting times.

Determining optimal solutions to DARP, known to be NP-hard even if all ride requests are known in advance [1], and therefore is especially challenging when solved online. However, finding such a solution is paramount as deviations from the optimum affects both passenger convenience and service providers operating costs due to failing to account for future ride requests.

Even though the performance of the methods proposed for real-time DARP depends critically on the quality of the predictions, the state-of-the-art has focused on finding efficient methods to dispatch the vehicles. For example, [2] uses various demand rates rather than making predictions, [3] uses a certain prediction method but does not assess its effect, [4] solves the problem periodically with known requests.

In this study, we train regression trees to predict future ride requests to support the dispatching of vehicles to best serve the anticipated demand. Regression trees offer a powerful method especially when there are decision paths in the data and considering the spatio-temporal patterns of trip requests. In addition, the explainable property of regression trees is instrumental in increasing the service provider's trust in the

solution quality and thus its potential applicability.

The proposed methodology discretizes the time horizon and for each period it forecasts the demand for the next period. The vehicle dispatch decision is updated after solving the optimization problem where both known and forecasted requests are taken as input. The long-term total waiting time of passengers is compared with benchmarks. The performance of the proposed prediction method is assessed based on the final optimization results.

*Keywords*: Real time Dial-a-Ride, Regression trees, Discrete optimization

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# Comparing QUBO formulations of the Travelling Salesman Problem for Quantum and Digital Annealing

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*Abstract* In the recent years, the use of quantum computing techniques, and in particular Quantum Annealing (QA) [1], have been applied to solve combinatorial optimization problems. QA is an alternative type of computation in which problems are encoded in quantum Hamiltonians (energy functions) and quantum dynamics is used to find solutions (ground states of minimal energy) [2]. Quantum computers such as the D-Wave systems are indeed implementing those ideas in hardware, as well as “quantum-inspired” devices based on classical electronics such as Fujitsu’s Digital Annealing Unit. Interestingly, all those systems use the same modeling language: Quadratic Unconstrained Binary Optimization (QUBO), which has been proposed about 15 years ago and follows from decades of researches in pseudo-Boolean optimization [3]. The travelling Salesman Problem (TSP) is a classical constraint optimization problem that can be modeled in QUBO and solved by quantum annealing or quantum-inspired annealing. Several ways of modeling the TSP are possible in QUBO, in particular by using the permutation formulation. Indeed, one first have to choose an encoding for integer variables and then encode the permutation constraint in the objective function as an additional penalty. Two main schemes exist for encoding integers in QUBO: one-hot encoding and unary/domain-wall encoding proposed recently in [4]. In the one-hot encoding, the permutation constraint is implemented as a series of two-way one-hot constraints. In unary/domain-wall encoding, an implementation of the permutation constraint has been proposed by [5], which gives a very different penalty term for the objective function, and produces QUBO matrices sparser than with one-hot encoding. We have implemented both QUBO models on the Fixstar Amplify Annealer Engine, which is a quantum-inspired annealing solver based on clusters of GPUs and we experimented with several TSP instances from TSPLIB. We will present and compare the results for both models: one-hot encoding and unary/domain-wall encoding.

*Keywords*: QUBO, constrained optimization problems, quantum annealing, TSP

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## Analysing the access to education services through public transport

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*Abstract* One of the main targets of the policies of the European Union (EU) that are part of the European Green Deal is to achieve climate neutrality by 2050. Transport plays a crucial role in this task, as a major consumer of energy and significant contributor to emissions. Public transport is overall a greener and relatively more affordable way for users to connect to services and opportunities, compared to private cars. To this extent, different metrics to evaluate access to services can be built and used to monitor the impact of public transport infrastructure policies, such as those that are part of the EU's cohesion and territorial policy packages [1]. These metrics (or accessibility indicators) are in general straightforward to interpret, and account not only for the distribution of services and opportunities, but also for the adequacy of the transport infrastructure that is needed to reach them. To build accessibility indicators at EU level it is required to solve (large-scale) routing problems. In this work, we present examples of such analyses based on an ad-hoc optimization framework that uses VelociRAPTOR [2], a newly built parallel solver for public transport, based on the commonly known RAPTOR algorithm [3]. Multimodality is explicitly considered in the search for optimal routes, as modes not based on schedules (e.g. walking) are incorporated into the public transport graph. The proposed framework finds optimal solutions to large scale (schedules-based) routing problems in a reasonable time, in a way that allows setting user-related constraints. The framework is applied in this work to evaluate access to secondary education services by public transport in two test cases (two different EU Member States). The public transport performance results presented can be used to assess how access to secondary edu-

cation plays a key role in access to (good) job opportunities, and with that, how it benefits social inclusion, well-being and economic integration across the EU.

*Keywords*: heuristics, public transport, routing, policy

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**A mobile satellite two-echelon vehicle routing problem with multiple depots and multi commodities.**

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*Abstract* This study studies the 3M-2E-VRP (Mobile satellite, Multiple depots, and multi-commodity two-echelon vehicle routing problem) to tackle last-mile delivery challenges in e-commerce and online shopping. Our approach extends the existing literature on two-echelon vehicle routing problems ([1], [2], [3]) by incorporating mobile satellites, multiple depots, and multi-commodity aspects. The 3M-2E-VRP model allows for multiple depots in the first echelon and multiple parking locations for second-echelon vehicles, capturing the complexity of real-world last-mile delivery scenarios.

To increase flexibility, we allow the first echelon vehicles to do direct deliveries. Also, the second echelon vehicles can visit specific meeting points (pickup nodes) or customer locations (delivery nodes). Additionally, we consider the environmental costs besides logistic costs as our objectives in the problem formulation. We develop a mixed-integer linear programming (MILP) formulation to model the 3M-2E-VRP. Then to show the validity of our formulation, we solve the problem exactly using the Gurobi solver for several small instances.

To solve larger instances of the 3M-2E-VRP, we propose a matheuristic that combines the concepts of Large Neighborhood Search (LNS) and Guided Ejection Search (GES ([4])). We evaluate the effectiveness and applicability of the proposed heuristic through experimental results using test instances. Our findings highlight the potential of the 3M-2E-VRP approach with mobile satellites to optimize last-mile delivery operations, improve resource utilization, and reduce environmental impact. The approach shows promise in revolutionizing the last-mile delivery landscape by leveraging innovative technologies such as mobile satellites for more efficient and sustainable delivery operations.

*Keywords*: Two echelon vehicle routing problem, Mobile satellites, Multi commodities, 3M-2E-VRP, Matheuristic

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## A Two-echelon Time-dependent Green Location-Routing-Scheduling Problem

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*Abstract* This paper addresses a two-echelon time-dependent green location-routing problem (2E-TDGLRP) in last-mile delivery. The problem aims to locate intermediate hubs between regional depots outside the city and end customers in urban areas, determine vehicle routes, and schedule deliveries by minimizing economic and environmental costs. To provide a more realistic representation of urban transportation, we consider the impact of traffic congestion on city logistics by assuming time-dependent step functions for speed on urban arcs. The bidirectional relationship between logistics and traffic congestion, affecting strategic and operational planning levels, is the motivation for capturing the variability of traffic congestion over time [1]. The cost of emissions is estimated using a comprehensive modal emission model (CMEM) which calculates the cost of CO2 according to the fuel consumption depending on the vehicle's speed, load, and travel distance [2]. We have formulated a mixed-integer linear programming (MILP) model and solved small instances with the Gurobi optimizer to evaluate the model. Moreover, we have developed a matheuristic algorithm for the problem to be able to solve real-size instances. The algorithm contains an adaptive large neighbourhood search (ALNS) process, which uses a single-route scheduling MILP as a subroutine. Results show that the proposed model outperforms the time-independent solutions, which are infeasible for all large instances when considering the congested time-dependent network. Besides, considering emission costs in the objective improves emissions by 10% in large instances. This study provides valuable insights for practitioners to design a green transportation network that accounts for the impact of urban congestion on city logistics.

*Keywords*: Freight transportation, location-routing, congestion, time-dependency, emissions

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## An Adaptive Large Neighborhood Search for a Real-World Vehicle Routing Problem

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*Abstract* The European Environment Agency reported that about 25% of the total greenhouse gas emissions in Europe is due to the transportation sector. Therefore, to reach net-zero greenhouse gas emissions by 2050, it is crucial to cut emissions due to this sector. By pursuing this goal, sustainable city logistics emerged as a concept for reducing the negative impact of urban transportation activities on society and the environment. The Vehicle Routing Problem is one of the most studied problems in the Operations Research literature [1], and during the last years, many variants to address sustainability goals have been proposed: Green VRP [2], E-VRP [3], etc. Nevertheless, in the real-world, each courier has its specificities and it is not possible to apply one of the many variants of routing problem presented in the literature to solve its instance. This work emphasizes this concept focusing on the solution of a real-world scenario: the planning of the deliveries of a distribution center in the north of Italy. We will show that the requests of the courier impose a peculiar mixture of constraints, like forbidden vehicle-areas pairs, a maximum distance between deliveries, conflicting clients, and others. The problem has been solved with a tailored approach based on an Adaptive Large Neighborhood Search in order to minimize delivery costs and, at the same time, minimize CO2 emissions. The solutions have been validated through a comparison with historical data and hand-made solutions. Moreover, we performed a deep computational experimentation, with the aim of understanding how and how much the performance of the solution approach is influenced by the different constraints imposed by the courier.

*Keywords*: Vehicle Routing Problem, ALNS, Metaheuristics

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