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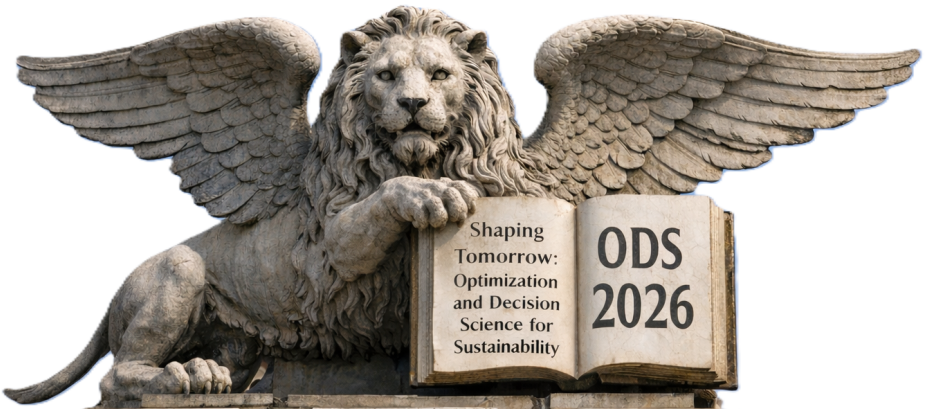

Optimization and Decision Science Conference 2026

Book of Abstracts

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Optimization and Decision Science Conference 2026: Book of Abstracts
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This book contains all of the abstracts accepted for presentation at the International Conference on Optimization and Decision Science, ODS2026, held in Galzignano Terme (Colli Euganei - PD) from the 7th to the 10th of September 2026. ODS2025, organized by AIRO, the Italian Operations Research Society is entitled "Shaping Tomorrow: Optimization and Decision Science for Sustainability". The conference scope in- cludes operations research, optimization, problem solving, decision making and their applications. The book of abstracts contains 148 contributions, 27 of which associated to papers accepted for publication in the AIRO Springer Series volume devoted to the conference. The contributions are organized into four parallel streams.

Three plenary sessions enrich the scientific part of the conference; they are given by world-renowned professors, and they are related to extremely topical and important issues.

Abstracts are listed session by session.

The conference hosts also satellite events; among them the AI4Rails workshop, whose presentations are featured in this Book of Abstracts.

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Plenary – Plenary Sessions

Abstract ID: PLEN-001 Session: Plenary

Why Explainable AI Matters: Novel Optimization Techniques for AI Explanations

Renato De Leone, Marica Magagnini

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Explainable Artificial Intelligence (XAI) has attracted growing attention from both the research community and practitioners. As Machine Learning models are increasingly deployed in high-stakes domains, such as healthcare, finance, and public administration, predictive accuracy alone is no longer sufficient. AI systems must also provide clear, reliable, and technically meaningful explanations of how their decisions are reached. This requirement has become even more pressing following the introduction of the European Union's regulatory framework for Artificial Intelligence, which emphasizes transparency, accountability, and human oversight. Consequently, the development of effective explanation methods is now a central challenge in trustworthy AI. In this talk, we will present the main research directions emerging from recent advances in explainable artificial intelligence (XAI). We will also discuss novel optimization techniques that incorporate a secondary objective, enabling users to choose from a set of equally appealing solutions based on their specific needs. These approaches apply to a range of settings, including robust counterfactual explanations, simple and sparse local surrogate models, and predictive models equipped with feature attribution methods.

Keywords: Explainable Artificial Intelligence; Optimization Techniques; Counterfactual Explanations

Abstract ID: PLEN-002 Session: Plenary

Automated Heuristic Discovery: from Deep Reinforcement Learning to Large Language Models

Kevin Tierney

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Designing high-performance heuristics is a complex task that requires both intuition and deep domain knowledge. Recent advances in deep reinforcement learning (DRL) and large language models (LLMs) have led to new ways of creating heuristics that rival the performance of state-of-the-art human-designed approaches. In this talk, I introduce these new mechanisms for heuristic design and describe their advantages and limitations, with a focus on routing and scheduling problems. The talk will include two methods: Neural Deconstruction Search, an approach harnessing DRL to learn policies for constructing routing and scheduling solutions, and VRPAgent, an evolutionary approach to generate novel routing heuristics.

Keywords: Routing heuristics, Artificial Intelligence, VRPAgent

Abstract ID: PLEN-003 Session: Plenary

Navigating Nonconvexity and Uncertainty: Tales from the Quadratic Optimization World

Immanuel Bomze

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Drawing upon recent work with numerous coauthors, this talk revisits some of the most challenging problems in optimization, which are tackled by combining rigorous mathematical analysis with scalable algorithmic developments. Topics include strengthened convex and copositive relaxations, (distributionally) robust and stochastic optimization models, as well as chance-constrained and bilevel quadratic problems. The presentation highlights how these developments can cope with difficult nonconvex problems under uncertainty, while maintaining computational tractability. It also illustrates their impact on applications ranging from machine learning and data science to network analysis and decision support.

Keywords: Robust and Stochastic Optimization; Nonconvex Optimization under Uncertainty

S01 – AI4RAILS 2026

Abstract ID: ODS-064 Session: S01

A Sustainable Framework for Joint Maintenance and Renewal Planning of Urban Railway Turnouts

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Maintaining urban railway networks is becoming increasingly challenging due to rising traffic demand, which accelerates infrastructure degradation [1]. As a result, maintenance interventions need to be carried out more frequently, increasing operational costs and placing additional strain on already limited maintenance windows and available resources.

At the same time, the increasing frequency of maintenance interventions raises significant environmental concerns [2]. Although each individual operation produces relatively low emissions, their cumulative effect over time results in substantial CO_2 emissions, thereby increasing the overall environmental impact of railway maintenance activities.

These challenges call for a shift from traditional time-based strategies toward data-driven maintenance planning approaches. In this work, we address the problem of maintenance planning for urban railway turnouts by leveraging historical data collected from a complete network with several tramway lines to model turnout wear. Each turnout is divided into several components with individual wear law, and maintenance rules are modelled and applied to reproduce the real life cycle. The modelled network comprises different types of turnout: simple and double communications, including diamond crossings. We propose a multi-objective optimization framework that jointly optimizes maintenance costs and CO2 emissions while considering both maintenance and replacement activities. Simulations are also used to anticipate the maintenance increase due to a foreseen increased traffic on the network.

The proposed approach supports more sustainable and efficient decision-making, improving system reliability and enhancing long-term lifecycle performance under evolving operational and environmental constraints.

Keywords: Predictive maintenance, Joint maintenance & renewal, Rail wear, Sustainibility, Cost optimization

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Abstract ID: ODS-092 Session: S01

A Two-Stage Problem Reduction Approach for Real-Time Train Rescheduling Optimization using Timetable-Decomposed Machine Learning

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Optimization-based train rescheduling models can efficiently solve small to moderately sized instances, but the combinatorial complexity of the problem limits their real-time applicability. Computational performance deteriorates significantly for large-scale instances, particularly under severe disruptions in densely utilized networks. To improve computational efficiency, problem reduction is a commonly applied strategy. While prior research has developed a data-driven problem reduction framework for local train rescheduling in station areas, its extension to network-level applications remains unexplored. This work therefore proposes a learning-based two-stage problem reduction approach for real-time train rescheduling on railway networks. In the first stage, a machine learning (ML) model predicts for a given disruption scenario which trains remain on their nominal routes, allowing their routing decisions to be fixed. In the second stage, a separate ML model predicts route utilization to prune irrelevant rerouting decisions from the search space. Additionally, a timetable decomposition technique partitions the timetable into equally sized intervals, enabling interval-specific predictions that are used to reduce the corresponding subproblems before solving the reassembled optimization problem. This timetable decomposition enables the isolation of distinct route assignments across intervals, further improving the problem reduction effectiveness in both stages. We train Random Forest classifiers on pre-solved disruption scenarios and evaluate the framework on a real-world railway network in Germany. Computational experiments show that the approach significantly accelerates convergence of the solver and achieves up to 94.1% fewer delays than the full-scope baseline. These findings highlight the potential of integrating ML into optimization-based train rescheduling to lower its barrier for real-time applications.

Keywords: Train Rescheduling, Problem Reduction, Machine Learning

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Sehmisch, S., Szymula, C., Haque, M. T., & Bešinović, N. (2025, October). A Data-Driven Problem Reduction Framework for Local Train Rescheduling in Station Areas. In 2025 IEEE International Conference on Intelligent Rail Transportation (ICIRT) (pp. 194–199). IEEE.

Abstract ID: ODS-043 Session: S01

Adaptive Railway Timetable Rescheduling using Meta-Reinforcement Learning

Zipei Zhang, Yongqiu Zhu, ,

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Disturbances in railway systems cause deviations from planned timetables, requiring real-time and conflict-free rescheduling. To tackle this, Reinforcement Learning (RL) has emerged as a promising tool due to its real-time response. However, existing RL methods often employ a uniform policy that struggles to effectively handle diverse disturbance scenarios and generalize across different disturbance scenarios. This study proposes a Meta-Reinforcement Learning architecture inspired by Latent Embedding Optimization (LEO). The rescheduling problem is formulated as a Markov decision process (MDP), where the agent learns a policy for real-time rescheduling under disturbances. To enable the application of meta-learning, disturbance scenarios are organized into tasks based on observable disturbance characteristics, such as the number, location, interdependency, and duration of initial delays. This grouping provides a structured approximation for training, while the actual task similarity is captured through representation learning. A two-loop meta-learning architecture is adopted to decouple task representation from decision-making. In the outer loop, a representation learning module encodes each task into a low-dimensional latent representation, which is used to generate model parameters. In the inner loop (i.e., task-specific policy adaptation), dispatching decisions for departure and arrival events are iteratively refined based on partial observations and specific model parameters. This design is expected to enable the model to adapt to previously unseen disturbance scenarios within the same task distribution by generating suitable initial parameters, thereby avoiding training from scratch. The entire two-loop framework is trained using trajectories collected from agent–environment interactions during exploration. The training process enables the model to learn both effective policies and task representations, facilitating knowledge transfer across similar tasks. As a result, the framework improves learning efficiency, enhances effectiveness across diverse scenarios, and strengthens generalization to previously unseen disturbance scenarios within the same task distribution, making it suitable for real-time railway rescheduling. Experimental evaluations on Dutch railway corridors demonstrate the solution quality and generalization of the proposed framework in comparison with existing learning-based timetable rescheduling approaches and optimization methods.

Abstract ID: ODS-119 Session: S01

An Empirical Evaluation of Algorithm Selectors for the Real-Time Railway Traffic Management Problem

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The computational efficiency of algorithms for the real-time Railway Traffic Management Problem (rtRTMP) is often sensitive to the configuration of the parameters of the algorithm. This paper investigates per-instance algorithm selection to enhance the performance of algorithms characterized by complex configuration spaces, using a state-of-art algorithm as a case study. We evaluate six machine learning selector architectures across task definitions (Regression vs. Classification), structural designs (Multi vs. Single selector models), and learning algorithms (Random Forest vs. Ridge). Evaluated on 1,800 instances from three French control areas, the results demonstrate that per-instance algorithm selection outperforms baselines in minimizing performance regret, which is the performance loss incurred by not selecting the best algorithm.

Abstract ID: ODS-138 Session: S01

Clustering models for regional rail freight transport in Europe: a big data analysis application

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Europe strives for a modal share of 50% by 2050 for rail freight as one of its solutions to reach its ambitious targets in Green Deal by 2050. Understanding the current status of rail freight transport in Europe is essential to identify the bottlenecks and potential for the modal shift. This research applies k-medoids clustering algorithms to identify regional rail freight transport levels in the Nomenclature of Territorial Units for Statistics (NUTS) level 2 and statistical regions from the European Free Trade Association (EFTA) from 2005 to 2020. This study is unique in aiming to achieve an overview of European rail freight transportation to pinpoint regional bottlenecks and potentials. The results show that more than half of the European regions have the lowest rail freight volume, indicating the high potential for the modal shift. These regions are scattered across Europe, with the highest number in southern Europe. Additionally, this paper highlights the regions with the highest rail freight volumes, which are located in central and the most northern regions of Europe. These results provide the potential for benchmarking for the modal shift between regions with the lowest and highest rail freight volumes. Finally, this paper contributes to assisting policymakers and rail freight stakeholders in the development and adaptation of policies that facilitate a modal shift on the comprehensive European level.

Abstract ID: ODS-049 Session: S01

Comparing LLMs on Investigating European Tramway Regulations

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Tramways have been a vital element of urban transportation for over a century. As part of the "tramway renaissance", new tramway systems have emerged, in particular in France. In other countries such as Germany, legacy tramway systems have been modernized. Although the underlying physical principles are the same, legal regulations differ throughout Europe, leading to different performance of tramways. Railway regulations have been partly harmonized by the EU, but a similar step for tramways is missing. Comparative analyses of railway standards exist [1], [2], but they have been compiled manually which may be time-consuming. LLMs have demonstrated utility in extracting information from telecommunications [3] and traffic law [4].

Hence, we suggest a novel approach using multiple LLMs to perform a cross-national comparative analysis of tramway regulations. Our methodology is as follows:

- First, we develop a structured prompt set containing technical and operational questions (e.g. "What is the maximum permitted speed on turnouts?"). We incorporate response constraints (cf. [5]) to ensure comparability.
- Second, we ask LLMs to find the regulatory documents in force in different countries. We evaluate the correctness of the responses using a pass-fail system.
- Third, we submit our prompts with technical and operational questions to LLMs via API, documenting responses, response times, and error messages. Accuracy is assessed using a similar pass-fail system, enabling blind evaluation of model performance.

Our proposed research shows the first application of LLMs to comparative tramway regulation analysis. It will be the foundation for improved tramway systems and services in the long-run, as planning professionals and decision-makers can learn from best-practice examples. Further research could investigate the operational outcomes of regulations of different countries, and try to find ways to harmonize tramway regulations.

Keywords: Tramway, Regulation, Comparison, LLM

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Abstract ID: ODS-142 Session: S01

Continuous Action Mapping under Box and Equality Constraints for Reinforcement Learning for Optimal Traction Force Allocation in Train Operations

Falk Pospischil[1], Ariane Fazeny[1], Yves Burkhardt[1],
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The allocation of traction force among parallel drives offers significant potential for reducing energy losses in modern railway vehicles. An optimal allocation can substantially improve drivetrain efficiency compared to the standard equal force distribution, however the optimization task is challenging due to complex loss characteristics, high-dimensional operating conditions and strict feasibility constraints. In this work,we address the optimal traction force allocation problem using reinforcement learning with continuous actions under feasibility constraints. We formulate the allocation task as a constrained nonlinear optimization problem and employ Proximal Policy Optimization (PPO) combined with explicit action mapping to ensure constraint satisfaction. A novel projection method, based on a ray-masking approach, is introduced to map unconstrained policy actions to the feasible action space. This method is compared to a distance-minimal projection, where an original action is mapped to the closest (with respect to the Euclidean distance) feasible action. Both action mappings are evaluated in a simulation-based railway traction model with multiple parallel drives. The results show that while the distance-minimal projection achieves slightly higher average performance due to its tendency to induce sparsity, the proposed ray-masking-based projection outperforms it in a majority of operating points. This behavior can be attributed to smoother induced action variance and improved exploration in constrained regions of the action space. The findings highlight the importance of action mapping design in reinforcement learning for constrained optimization problems and demonstrate the applicability of the proposed method to railway traction systems and other constrained control tasks.

Abstract ID: ODS-047 Session: S01

Deep reinforcement learning for locomotive assignment planning

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Locomotive planning under uncertainty is a key challenge in railway operations, where limited availability, maintenance constraints, and stochastic disruptions require continuous re-planning. Many existing optimization-based approaches struggle to represent such uncertainty, particularly random delays and unplanned maintenance, reducing their effectiveness in operational decision-making [1].

Deep Reinforcement Learning (DRL) methods have seen significant advances in recent years [2], and are able to deal with both stochastic and combinatorial problems at scale. We develop an event-driven simulation environment for locomotive planning, considering a small railway network, limited locomotive availability and both planned and unplanned maintenance processes. We train a reactive DRL agent on this environment using Proximal Policy Optimization (PPO) [3], and compare it to strong baseline heuristics based on Monte Carlo Tree Search (MCTS) [4] as well as rollout-based heuristics tuned to identify and correct geographical locomotive imbalances.

Experimental results indicate that the DRL-based approach can outperform heuristic baselines in terms of reducing delays and increasing the number of completed train services under stochastic disturbances. These findings suggest that DRL can effectively support operational decision-making in settings where uncertainty plays a central role. We further investigate initial steps toward extending the reactive agent to incorporate planning capabilities over a longer decision horizon and including stochastic trip durations. Future work will focus on increasing simulation realism and scaling to larger railway networks, further bridging the gap between simulation and real-world operations.

Keywords: Locomotive Planning, Reinforcement Learning, Monte Carlo Tree Search, Proximal Policy Optimization

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Abstract ID: ODS-150 Session: S01

Enhancement of the cost estimation model for the train routing selection problem

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In railway systems, unexpected events may perturb the planned train schedule, requiring real-time adjustments, such as train retiming, reordering, and rerouting to recover feasibility and minimize delays. This problem is commonly referred to as the real-time Railway Traffic Management Problem (rtRTMP). To tackle it within the required strict computing time, a preprocessing phase can be used to reduce the set of alternative routing options by selecting a subset of promising routes for each train. This preprocessing yields the Train Routing Selection Problem (TRSP), typically solved by identifying a set of minimum cost cliques in an undirected graph, where each clique represents a set of train routes and the clique cost estimates the corresponding delay. The benefit brought by this preprocessing step strongly depends on the accuracy of the cost estimation model used to evaluate routing options. This paper proposes targeted refinements to improve the predictive accuracy of an effective cost estimation model from the literature. Computational experiments on real-world instances show consistent improvements in route selection and delay reductions.

Abstract ID: ODS-131 Session: S01

Explainable Prediction of Rail Crack Initiation and Growth

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Railway infrastructure is subject to continuous mechanical stress, leading to rolling contact fatigue and the formation of rail cracks that can compromise safety and increase maintenance costs. This paper investigates the potential of data-driven methods to support predictive and preventive maintenance using eddy-current testing (ECT) data. We formulate two prediction tasks: (i) classification of crack-prone track segments and (ii) regression-based prediction of crack depth progression. Using a real-world dataset from a 300 km railway corridor in Germany, we apply linear regression and tree-based machine learning models, including random forests and gradient boosting decision trees. The results show that crack-prone segments can be identified with high recall despite strong class imbalance, while crack growth prediction achieves moderate explanatory power but tends to underestimate rapidly growing defects. In addition, we analyze model interpretability using statistical inference, feature importance, and SHAP explanations, highlighting the influence of traffic load, track geometry, and previously observed crack depth. Our findings demonstrate that ECT data provide valuable predictive signals for maintenance planning, while also showing that predictive performance alone is insufficient for assessing whether models capture plausible crack growth dynamics.

Abstract ID: ODS-056 Session: S01

Forecasting future train supply using spatiotemporal graph modelling

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This study develops and tests a data-driven method for estimating future passenger rail supply, aiming to make forecast timetables more transparent and consistent in railway project appraisal. Current Swedish practice relies largely on past service development, expert judgement, operator plans, and regional ambitions. Since timetable assumptions can strongly influence demand forecasts and estimated investment benefits, the study responds to the need for a more explicit and reproducible basis for future rail-supply assumptions [1].

The pilot case is Sweden's East Coast Line between Stockholm and Sundsvall, a corridor with long-distance, regional, airport, and freight services, varied infrastructure capacity, and differing demographic conditions. A historical dataset for 1990–2023 was assembled from timetable records, train categories, travel times, stopping patterns, infrastructure variables, car travel conditions, fares, population, GDP per capita, car ownership, and inflation.

The core model is a Multi-Task Heterogeneous Graph Attention Neural Network. It represents combinations of station pair, hour, and year as graph nodes, connected through spatial, hourly, and yearly relationships. The model jointly predicts hourly train counts for six service categories: fast, commercial regional, tendered regional, night, Arlanda Express, and freight trains. In this sense, the study extends demand-sensitive timetable research by using graph-based learning to produce future supply estimates rather than a fully detailed timetable [2].

Validation on 2023 data shows strong overall performance, with an average MAE of about 0.17 trains. The 2045 scenario demonstrates the model's ability to translate socioeconomic and infrastructure assumptions into differentiated future supply estimates. The study concludes that graph-based AI is promising as a "starter motor" for forecast timetable construction, while further testing on other corridors and integration with full timetable generation are still needed.

Keywords: Forecast timetables, Spatiotemporal graph modelling, Rail investment appraisal

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Abstract ID: ODS-005 Session: S01

Implementation of Real-Time, Explainable Train Punctuality Predictions for Network-Level Coordination

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Central dispatch oversees the national-level performance of the railway services, and aims to improve timely communication and coordination with railway operators and neighboring networks by proactively monitoring the system-wide punctuality landscape. To this end, first a framework is built to systematically understand and predict punctuality outcomes in relation to the various factors that influence them, i.e. contextualize dependencies that shape punctuality. The framework is distinguished by a rich, multi-level feature set spanning weather, spatial and temporal context, network-level and train-path-level system features, and process-aware journey features derived from the prefix and suffix, including timetable information. Second, using Belgian railway punctuality as a case study, an XGBoost-based model is adopted to balance predictive performance, training efficiency, and interpretability, enabling explainability techniques (e.g., SHAP) supporting user trust and providing actionable insights. The model learns empirical relationships between observed operational contexts and punctuality outcomes per individual train, based on the information available at a given point in time and incorporating long-term prediction horizons. This XGBoost model demonstrates superior performance compared to the operational rule-based model. Consequently, we present a decision-support tool that is deployed for network-level coordination by central dispatch, enhancing real-time situational awareness and proactive monitoring through visualizations of predicted unpunctuality and corresponding feature influence interpretation, helping identify trains that require attention from a system-wide perspective.

Keywords: Delay prediction, Punctuality, Interpretability, Central dispatch

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Abstract ID: ODS-148 Session: S01

Iterated Passenger Reflowing and Timetable Retiming for Robust Cyclic Timetabling: Application to Denmark

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We present an iterative pipeline for constructing cyclic railway timetables that minimizes total expected passenger travel time, including knock-on delay propagation. The timetable is modeled as a Periodic Event Scheduling Problem (PESP) on an event-activity network with ride, dwell, transfer and headway activities, where primary delays follow negative exponential distributions. Since the resulting non-linear expected time functions cannot be handled by MIP solvers directly, we approximate them with adaptive K-segment piecewise-linear functions, where the number of segments is determined automatically to guarantee a maximum approximation error (e.g. 1%). The full pipeline alternates between passenger *reflowing* (K-shortest-path routing on the current timetable) and timetable *retiming* (PESP-MIP optimization with current passenger flows occurring as weights in the objective). Applied to all 88 hourly trains in Denmark, per retime iteration, solving the PESP model is addressed by another two-stage approach: ORTools' CP-SAT solver finds an initial solution more quickly than MIP solvers, which is then passed to a MIP solver (COPT, Gurobi or Xpress) to validate and further improve the solution and/or lower the optimality gap. On the Danish network, the MIP contains 120507 variables and 267953 constraints. After 160 iterations, an 11% reduction in the objective is obtained.

Abstract ID: ODS-153 Session: S01

Microscopic train path rearrangement under residual conflict tolerance

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Railway timetable rearrangement consists of modifying an existing timetable when train paths are incompatible with the available infrastructure capacity. This may occur due to new capacity restrictions, such as maintenance possessions. Additionally, conflicts that are invisible at a coarser planning level can be revealed when the timetable is evaluated using a microscopic representation of railway operations. This paper addresses the rearrangement of a single train path at the microscopic level when it conflicts with other capacity allocations, including overlapping train paths, rolling stock reutilizations and maintenance possessions, while preserving its service characteristics as far as possible. The work is carried out in collaboration with Infrabel, the Belgian rail infrastructure manager. The optimization rearranges one train path at a time with all others kept fixed, preserving planner control over the rearrangement process. Complete conflict resolution is not required: residual conflicts may be temporarily tolerated and retained for evaluation within the broader planning context. A mixed-integer linear programming model is proposed, capturing penalized conflicts together with microscopic operational constraints. Computational experiments on the Belgian network illustrate the applicability of the approach.

Abstract ID: ODS-088 Session: S01

Offline Reinforcement Learning for Train Timetable Rescheduling

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Train operations often deviate from the planned timetable due to perturbations, requiring rapid Train Timetable Rescheduling (TTR). Traditional mixed-integer linear programming (MILP), designed to address the TTR problem, provides high-quality solutions but is often too slow for real-time use. In contrast, (meta-)heuristic methods provide significantly faster solutions but are typically problem-specific and do not guarantee optimality. Recently, online deep reinforcement learning (DRL) has emerged as a promising data-driven approach for TTR, enabling fast decision-making under dynamic conditions [1]. Nevertheless, online DRL faces several limitations: it requires extensive training from scratch, depends on carefully designed simulation environments, and cannot directly exploit the high-quality solutions generated by state-of-the-art exact or heuristic approaches. To address these challenges, recent studies have highlighted the potential of offline reinforcement learning (offline RL), in which agents are trained exclusively on pre-collected historical data without interacting with a simulation environment [2]. In this study, we investigate the application of offline RL to the real-time train timetable rescheduling problem (rtTTR). The proposed agent is trained solely on historical solution data generated by different traditional optimization and heuristic methods. The approach is evaluated using realistic operational data from a corridor of the German railway network and benchmarked against both online RL and conventional rescheduling approaches. In addition, the study analyzes how the quality of the training samples influences the performance and generalization capability of the trained agent.

Keywords: Real-time railway traffic management, Train timetable rescheduling, Deep reinforcement learning, offline reinforcement learning

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Abstract ID: ODS-146 Session: S01

On the Limitations of Explainable AI for Safety Verification in OpenSource Railway Systems

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Explainable Artificial Intelligence (XAI) offers a promising framework for ensuring the safe operation of deep learning models within railway systems. While XAI has been widely adopted to interpret general-purpose machine learning decisions, its ability to produce understandable explainations, in the specialized, safety-critical context of rail operations remains under-explored. Using the example task of classifying people on tracks, this paper discusses the current limitations of known XAI approaches, such as saliency-based and concept-based XAI, when the backbone model is trained exclusively on publicly available, railway-specific datasets. Therefore, we train three backbones based on Convolutional Neuronal Networks and evaluate their decisions using respective saliency methods such as LRP and Grad-CAM as well as concept methods like CRAFT, and CRP. Our results demonstrate that even for models with high task performance, the resulting XAI explanations suffer from visual artifacts, such as *flickering* or *imprecise highlighting* as well as concept *entanglement* or *confusion*. As these are likely to reduce the informative value of XAI during human auditions, we advocate for the cautious development and validation of these behaviors in future rail-related XAI frameworks.

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Predicting Passenger Assistance Demand for Operational Workforce Planning

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Passenger assistance services are essential for accessible rail travel, yet demand varies substantially across stations and planning horizons, creating challenges for workforce planning and service delivery. A key difficulty is that assistance bookings accumulate progressively over time, with many requests made close to the date of travel. This paper presents a horizon-aware workforce planning framework that combines station-level demand forecasting with operational decision support. The forecasting component uses horizon-specific Prophet models that exploit the information available at different planning lead times, including booking accumulation signals, calendar effects, and weather data. Forecasts are translated into workforce planning decisions through an interpretable staffing-capacity model and a Red–Amber–Green (RAG) risk assessment framework that highlights periods of potential staffing pressure. The framework has been deployed across LNER-managed stations to support accessibility planning and operational decision-making. Results show substantial improvements relative to year-on-year planning approaches and early evidence of reduced passenger assistance delivery failures attributable to staff availability. The work demonstrates how interpretable forecasting can be integrated into railway operations to support accessibility, workforce planning, and service reliability

Abstract ID: ODS-124 Session: S01

Predicting the Vulnerability of Railway Line Concepts

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Railway operations are frequently affected by disruptions. To mitigate their consequences strategically, vulnerability assessment needs to be included in early planning stages. We introduce the *Vulnerability of Line Concept Predictor–VuLP*, a methodology that facilitates the rapid approximation of the multi-disruption vulnerability of railway line concepts. The OR-ML framework is employed to learn a regression model for each considered number of disruptions using a set of computed instances consisting of varied line concepts and a respective fixed-parameter timetable. The distinct line concepts aim to represent different planning preferences regarding cost-travel time trade-offs and consider both optimal and near-optimal solutions. Once trained for a specific macroscopic infrastructure and demand, *VuLP* enables railway planners to swiftly approximate the vulnerability of a new line concept, saving time compared to existing optimization models. Results show that a Random Forest model with the proposed features describing the line concepts can explain 84-90% of the variance in vulnerability. This model can reduce the prediction error by 75-87% compared to an uninformed baseline with a resulting average error of 0.24%, 0.33%, and 3.55% for 1, 2, and 3 disruptions.

Abstract ID: ODS-137 Session: S01

RAG-based Framework for Safety Reports Review: A Study on Railway Safety Standards Analysis

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This paper presents a conceptual framework that leverages Large Language Models to support railway safety assessors, specifically by automating the analysis of normative texts. The framework tends to extract and classify textual segments based on their regulatory impact and level of obligation (e.g, requirements, recommendations, etc.). It supports system providers in building safety cases and assessors in evaluating compliance. Concretely, we consider two complementary approaches: (i) a Retrieval-Augmented Generation pipeline for interactive, document-grounded question answering, and (ii) a transformer-based text classification approach benchmarked across multiple pretrained models. The effectiveness of the proposed framework is assessed through experiments on safety railway standards.

Abstract ID: ODS-006 Session: S01

Real-Time Estimation of Freight Train Braking Forces and Driver Input-Force Mapping under Operational Uncertainty

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Freight trains in mixed traffic with passenger trains often limit line capacity [1]. Accurately simulating their real-world movements is crucial for capacity planning, yet a lack of knowledge and models describing how drivers apply braking and the resulting actual braking distances is a major barrier.

As a step toward explicitly simulating freight train movements, this study proposes a hybrid physics- and data-driven framework for modelling freight train braking behaviour and stopping performance using on-board monitoring data, track information, and driver control inputs. The framework involves, first, application of an Unscented Kalman Filter (UKF) to On-Train Monitoring Recorder (OTMR) data to estimate net applied forces, revealing true braking capabilities [2]. Next, a Bayesian regression model maps driver inputs such as brake pressure to estimated forces, capturing nonlinear responses and uncertainty. Preliminary experiments using British freight OTMR data successfully estimated brake stop distance within 20 m error for various track sections and train consists.

The developed framework is applicable not only to capacity planning but also to driver training and braking curve optimisation, contributing to safer and more energy efficient railway operations.

Keywords: Freight train braking, Driver input mapping, Unscented Kalman Filter, Bayesian inference, Railway control

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Abstract ID: ODS-048 Session: S01

Short-term arrival time prediction for optimizing single-track train meetings using Temporal Fusion Transformers

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Connected Driver Advisory Systems (C-DAS) improve communication between the train and the Traffic Management System (TMS), enabling improved traffic capacity and energy optimization. Past trials of using C-DAS have highlighted the issue of coordinating C-DAS and non-C-DAS trains as an obstacle to realizing the benefits of C-DAS [1]. To achieve good traffic control, high-quality short-term runtime estimates for the non-C-DAS trains are needed [2]. Thus, the scope of this paper is to create such estimates, which can form an important part of a system for optimizing the traffic flow for both C-DAS and non-C-DAS trains.

We investigate whether a Temporal Fusion Transformer (TFT) model [3] can compute such estimates with sufficient precision [4]. The TFT is trained using train position data from the signaling system and onboard GPS units, and timetable data. The concept for optimizing the traffic flow, including the runtime estimates has been tested and evaluated on a single-track section in southern Sweden. The trained model has a Mean Absolute Percentage Error (MAPE) of around 10% when evaluated on historical data for typical prediction horizons. Predicting dwell times with passenger exchange is more difficult than predicting runtimes, resulting in a slightly worse MAPE when predicting over such stops. Ablation analysis indicates that the attention layer of the TFT is largely superfluous for this task.

One conclusion is that the calculation performance is sufficient to serve as a basis for improving traffic plans in real-time. In future research, we will scale this system to larger railway sections and new use cases.

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Keywords: Connected Driver Advisory Systems, Single-track meetings, Sequence models, Railway systems

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Abstract ID: ODS-129 Session: S01

Towards Explainable Autonomous Rail Perception: A Systematic Evaluation of CAM Explanations for Rail Track Segmentation

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Reliable track detection is a prerequisite for safe autonomous train operation where perception cannot depend on human intervention. Deep neural networks achieve high segmentation accuracy but their black-box nature hinders proper verification for safety-critical applications, since the relation between neural network elements and observed behavior is difficult to trace. Class Activation Mapping (CAM) methods provide visual explanations for this purpose, yet no systematic evaluation of these methods exists in the railway domain. This paper presents the first benchmark comparing six segmentation-adapted CAM variants on a railway test set under an eight-metric evaluation framework covering faithfulness and plausibility, structured around necessity, sufficiency, and spatial precision. We further introduce the Contour Alignment Score, a boundary-aware metric addressing the interior bias of standard overlap measures. Results reveal systematic divergences between visual plausibility and quantitative faithfulness, and expose method-specific deficiencies with direct implications for GoA3/4 certification workflows.

S02 – Combinatorial Optimization

Abstract ID: ODS-013 Session: S02

A cluster and solve approach for Capacitated Assignment Problems

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Large-scale capacitated assignment problems, where entities compete for shared resources, are often intractable when tackled via *Mixed-Integer Linear Programming* (MILP). Many practical instances, however, can exhibit an inherent cluster-based structure: entities interact strongly within local groups but weakly across them, suggesting that an appropriate decomposition could reduce the global problem into smaller, more tractable subproblems. To the best of our knowledge, in this work, we provide a first attempt to automatically detect such structures, if existing, and exploit them to reduce the computational burden without compromising solution quality. In more detail, we develop a four stage pipeline that

i partitions entities into size-bounded clusters using a procedure that first builds a dissimilarity tree via hierarchical clustering using shared resources as dissimilarity metric, and then prune branches to obtain the final partition

ii computes a set of indicators to measure clusters separation and predict the solution quality before any optimisation is performed;

iii solves each cluster as an independent MILP subproblem; and

iv restores global feasibility through targeted re-optimisation restricted to resources and entities involved in cross-cluster capacity violations.

We tested our approach on two problems: the Space-Time Capacitated Path Assignment and Capacitated Facility Location, considering both the single and multiple source versions of the latter. The results show that our approach delivers increasingly better performance, both in terms of computation time and optimality gap, as the separation between clusters increases. Furthermore, the proposed indicators for a-priori assessment of the method's applicability, while improvable, prove promising. These findings demonstrate our approach to be a valuable strategy for solving large-scale capacitated assignment problems.

Keywords: capacitated assignment problems, hierarchical clustering, large-scale combinatorial optimisation

Abstract ID: ODS-061 Session: S02

A Column-Generation Approach for the Irregular Shape Bin Packing Problem

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We study the packing of two-dimensional irregular polygons (items) into larger rectangular containers (bins) of various sizes, in order to minimize the number of containers used. In the recent survey by Leao et al. [3], it is pointed out that nesting problems, that is, identifying a feasible placement of a set of items into one bin, are widely studied. Despite this, integrating multiple bins, with the high-level choice association of an item to a bin, and the subsequent nesting problem, has not been studied intensively.

We solve this packing problem using a tailored column-generation algorithm. The master problem is formalized as a covering formulation, as in Gilmore and Gomory [2], where each variable (column) represents a feasible nesting. The pricing problem seeks a feasible nesting, selecting items with maximum profit, in terms of dual price. A direct solution of such a problem is computationally challenging for large-scale instances. Therefore, we relax it into a Bounded Knapsack Problem (BKP). BKP selects items with the largest profit, ensuring that their area is at most equal to the bin's. Patterns are validated using either exact or heuristic nesting algorithms. If the packing is infeasible, it is removed with a no-good cut. This procedure is iterated until a feasible pattern is found. A feasible pattern is a new column for the master problem. The whole procedure guarantees an optimal solution if the nesting algorithm is exact. Moreover, we also study several pricing heuristics, in order to find high-quality columns quickly. We present computational studies about our pricing heuristic and a heuristic nesting algorithm, based on Sparrow, a Strip Packing solver from Gardeyn et al. [1].

Keywords: Packing; Column-Generation; Pricing Heuristics.

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Abstract ID: ODS-105 Session: S02

A Customer-Classification-Based Matheuristic for Truck-and-Drone Routing Problems

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Truck-and-drone delivery systems have attracted increasing attention as a promising solution to improve the efficiency and sustainability of last-mile logistics. This has led to the definition of several challenging routing problems, including the Flying Sidekick Traveling Salesman Problem and the Parallel Drone Scheduling Traveling Salesman Problem. Although exact approaches can provide high-quality solutions, they are generally limited to small-size instances due to the combinatorial complexity of these problems. Conversely, heuristic methods can handle larger instances but often rely on problem-specific design choices and provide no direct information on the structure of high-quality solutions.

In this work, we propose a machine-learning-based heuristic framework for truck-and-drone routing problems. The main idea is to exploit data-driven classification techniques to identify, a priori, whether each customer should be served by the truck or by a drone. This initial classification enables the rapid construction of an initial solution, which is then improved by local search moves that allow customers to be reassigned between the truck and the drones.

An extensive computational campaign on benchmark instances is conducted to assess the effectiveness of the proposed approach. The results show that machine learning can successfully capture relevant structural properties of truck-and-drone solutions and support the construction of high-quality routing plans. Moreover, the proposed framework provides useful insights into the relationship between customer features, vehicle assignment decisions, and the performance of combinatorial optimization methods.

Keywords: Routing, Drones, FSTSP, PDSTSP

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Abstract ID: ODS-097 Session: S02

A mathematical programming approach for intrusion detection in heterogeneous in-vehicle networks

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In-vehicle communication networks are increasingly exposed to cyber threats, making effective intrusion detection systems a key research challenge. Many existing approaches focus on temporal communication patterns, since normal vehicle operation is usually characterized by stable and quasi-periodic message exchanges. As a result, deviations from these regular patterns can be used as indicators of anomalous or malicious behavior.

We propose a new approach that combines temporal analysis with a structural representation of network interactions. We model the communication between Electronic Control Units (ECUs), as a temporal graph. In this graph, nodes represent ECUs, while time-dependent edges describe communication patterns inferred from observed traffic. This representation makes it possible to analyze both the timing and the structure of the network at the same time.

We observe that Denial of Service and flooding attacks can generate structured communication patterns that can be seen as bipartite subgraphs. In these scenarios, a set of compromised nodes repeatedly communicates with a distinct set of target nodes. This persistent and asymmetric behavior differs from normal network operation and can therefore serve to report an attack. Based on this idea, we introduce the maximum τ-persistent bipartition problem. The goal of this optimization problem is to identify a maximum-cardinality bipartite subgraph that persists for at least τ timestamps in the temporal graph. We formulate the problem using integer programming and solve it with the state-of-the-art optimization solver Gurobi.

Experimental results on real in-vehicle network instances show that the proposed method can effectively detect attacks that directly affect communication timing, demonstrating the potential of temporal graph-based analysis for automotive cybersecurity.

Keywords: temporal graphs, intrusion detection, maximum bipartition problem

Abstract ID: ODS-127 Session: S02

A Mixed-Integer Optimization Approach for Finite 2D Tiling Problems

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Finite two-dimensional (2D) tiling problems represent challenging optimization tasks due to the combinatorial explosion of valid tile arrangements. We introduce a mixed-integer second-order cone programming (MI-SOCP) framework to model and solve these geometric containment problems. By mapping the continuous search space to a discrete lattice grid, permissible tile configurations are represented as bounded discrete states. To ensure computational tractability over large variable spaces, the framework employs an efficient geometric preprocessing pipeline to prune symmetric, redundant, and overlapping topological states prior to optimization. Evaluated on benchmark Tangram puzzles, computational experiments demonstrate that this integrated approach efficiently traverses the discretized space, yielding correct solutions with a high success rate.

Abstract ID: ODS-107 Session: S02

A price-and-branch algorithm for the k-balanced partitioning problem

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We study graph partitioning problems where the vertices must be divided into sufficiently balanced components while minimizing the number of intra-component edges. When the number of components k is specified a priori and all components are required to be the same size, the problem is known in the literature as k-balanced partitioning (k-BP) problem. In this talk, we additionally consider two generalizations: the k-near balanced partitioning (k-NBP) problem, where the size of a component is allowed to vary within a given threshold, and the near balanced partitioning (NBP) problem, where neither the number of components nor their size is fixed and they can both vary with respect to a specified parameter. We provide compact and extended ILP formulations for all three problems, and we present a price-and-branch algorithm that first solves the linear relaxation of the extended ILP via column generation, and then solves a restricted ILP over the set of generated columns. The performances of the proposed approaches are compared through extensive computational experiments.

Keywords: Integer Linear Programming, Price-and-Branch, Graph Partitioning

Abstract ID: ODS-007 Session: S02

Bi-Level Hierarchical Multi-Follower Knapsack With Leader-Activated Items

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This work addresses a bilevel optimization problem in which a leader has to select exactly N items to activate from a larger set, and multiple followers independently choose which activated items to include in their knapsack, each maximizing her own utility subject to an individual budget constraint. Follower decisions are further constrained by a hierarchical preference structure: dominated items are excluded unless preferred alternatives are unavailable. The leader aims to maximize the total profit generated by all followers' purchases. The problem is formulated as a single-leader multi-follower bilevel hierarchical knapsack with leader-activated items, and solved via an ad-hoc Combinatorial Benders Cuts (CBC) procedure, enhanced with problem-specific valid inequalities to improve convergence. The algorithm iterates by fixing the leader's solution, evaluating follower responses, and generating penalty-based cuts to tighten the optimality gap. An ML-based heuristic is also developed and benchmarked against the exact method. Computational experiments assess the scalability of the approach in several real-world inspired scenarios, including retail settings with complementary and/or substitutable items, providing actionable managerial insights.

Keywords: Bilevel Optimization, Combinatorial Benders Cuts, Machine Learning

Abstract ID: ODS-035 Session: S02

Collision-Free Close-Enough Arc Routing Problem: Formulation and Heuristic Solution Methods

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The *Collision-Free Close-Enough Arc Routing Problem* (CF-CEARP) considers a fleet of m unmanned ground vehicles (UGVs), based at a common depot, that must cover a set of target points by traversing arcs belonging to their associated coverage sets while delivering a prescribed amount of pesticide. The problem is subject to battery and tank capacity constraints and requires a minimum time separation between any two vehicles visiting the same node, in order to prevent collisions. The objective is to minimize the length of the longest route among all vehicles, thereby reducing the overall mission completion time.

The CF-CEARP is motivated by precision agriculture applications, where fleets of autonomous ground vehicles are deployed to perform site-specific crop treatments. The spatial flexibility in arc selection, which allows vehicles to pass *close enough* to a target rather than reaching it exactly, combined with the collision-avoidance constraints and the vehicle capacity limitations, makes CF-CEARP a challenging and practically relevant problem.

The CEARP, introduced by Hà et al. [6,7], considers a customer served if the vehicle traverses any arc within a prescribed distance threshold. Multi-vehicle extensions include the DC-CEARP [4,5], minimizing total cost subject to route-length constraints, and the MM-CEARP [1], minimizing the longest route. CF-CEARP shares the min-max objective of [1] but adds collision-avoidance and capacity constraints, with a formulation inspired by [2,3].

To address CF-CEARP, we propose a Mixed-Integer Linear Programming formulation together with a three-phase matheuristic that combines a constructive greedy arc-selection phase, a MIP hint-injection phase, and an exact MILP-based temporal scheduling phase enhanced with dynamic arc fixing, enabling the efficient computation of high-quality solutions.

Keywords: Arc Routing, Close-Enough Coverage, Collision Avoidance, Unmanned Ground Vehicles, Mixed-Integer Programming, Precision Agriculture

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Abstract ID: ODS-083 Session: S02

Column Generation-Based Heuristics for a Variant of the Single Batch-Processing Machine Scheduling Problem

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The Single Batch-Processing Machine Scheduling Problem with Non-identical Jobs, Compatible Families, and Sequence-dependent Setups (SBPM-NCS), recently introduced by [1], extends the classical parallel-batching scheduling problem by incorporating family compatibilities and sequence-dependent setup times. Jobs are processed simultaneously in batches, whose processing time is determined by the longest job in the batch, while setup times depend on the dominant family of consecutive batches. The objective is to minimize the makespan. The original problem is decomposed into a master–pricing structure, following the framework presented in [2]. The master problem is formulated as an arc-flow set partitioning model and is solved via a restricted master problem, initially defined on a subset of variables and solved in its linear relaxation. It is progressively enriched through a column generation scheme driven by a pricing problem, which introduces new variables by identifying promising batch configurations (columns). In detail, the pricing problem is reformulated as a knapsack-type selection problem with capacity, cardinality, and family compatibility constraints, and solved to optimality via pseudo-polynomial dynamic programming. We further develop primal heuristics for constructing feasible integer solutions from fractional column generation lower bounds, including Price-and-Branch, Variable Rounding, Early Variable Rounding, and Global Variable Rounding, which exploit both the structure of the generated columns and the dual information of the master problem. Computational results on synthetic instances show that the proposed approach provides significantly improved lower bounds compared to existing formulations, while also yielding high-quality feasible solutions and competitive computational performance.

Keywords: Combinatorial optimization; scheduling; parallel-batching; column generation

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Abstract ID: ODS-062 Session: S02

Learning from Relaxations to Accelerate Dynamic Programming for Resource Constrained Shortest Path Problems

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Resource-Constrained Shortest Path Problems are fundamental optimization problems that arise in several solution methods, notably as pricing subproblems in column generation algorithms. In this context, bidirectional dynamic programming labeling algorithms, combined with iterative relaxation schemes [1], are among the most effective approaches to guarantee exact elementary solutions, with no repeated nodes.

In this work, we propose learning from previously solved relaxations to guide and accelerate the solution of subsequent ones and, more generally, the overall dynamic programming algorithm. To this end, we present two main techniques. In the first approach, we exploit information from an already solved relaxation to identify the most promising regions of the search space. For each node, we analyze the predecessor nodes that generated the labels stored in its pool and use this information to prioritize label extensions toward these regions in subsequent relaxations. This allows high-quality solutions to be identified earlier in the solution process, also enabling the pruning of unpromising states. In the second technique, we exploit sets of labels from a solved relaxation to construct feasible solutions for the subsequent one. These solutions are then used to define tighter relaxations earlier, often allowing several intermediate iterations to be skipped.

Computational results on state of the art instances from SPPRCLIB [2] show that these techniques reduce both the number of generated dynamic programming states and the number of relaxation iterations required for convergence, leading to significant runtime improvements while preserving exactness.

Keywords: Dynamic programming, Learning, Shortest Path Problems

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Abstract ID: ODS-126 Session: S02

Lower Bounds and an Exact Model for the Circle Bin Packing Problem with Rectangular Items

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We study the Circle Bin Packing Problem with Rectangular Items, where rectangles must be packed in the minimum number of circular bins. We propose a refined procedure to estimate the reduced bin area for packing rectangles in a circle and introduce new lower bounds: an area-based bound that incorporates geometric incompatibilities between items, and a graph-based bound using cliques and incompatibility propagation. We also present a mixed integer quadratically constrained model that leverages a reduced bin area and geometric incompatibilities. Computational results on benchmark instances show a significant tightening of lower bounds, which allows to prove the optimality of several small instances. The proposed lower bounds also show competitive performance with respect to the bounds of the model, while the latter outperforms existing formulations in the literature.

Abstract ID: ODS-084 Session: S02

Optimization models for a constrained generalized maximum flow with concave gains

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The present work studies a generalized maximum flow problem on a multigraph with concave transfer functions and an upper bound on the number of selected arcs, a nonlinear network design problem. Due to the presence of the cardinality constraint on the number of selected arcs, the optimality conditions of algorithms presented in the literature, such as the one based on fat paths [1] or its extension built on a piecewise linear approximation method for generalized networks with concave gains [2], are no longer applicable. We propose an approximation of the transfer functions, through their linearization and bounding, and two optimization models for the problem, where binary decision variables are used to select arcs. The proposed optimization models differ in the characterization of the flow variables: the first one is an arc-based formulation, while the second is a path-based one. We solve the first formulation with GUROBI while for the second formulation, we propose a Branch-and-Price algorithm. Computational experiments demonstrate that the path-based formulation dominates the arc-based one.

Keywords: Constrained Generalized Flow, Concave gains, Column Generation, Branch and Price

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Abstract ID: ODS-166 Session: S02

Relax-and-Explore Kernel Search for the Multidimensional Multiple-Choice Knapsack Problem

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We propose Relax-and-Explore Kernel Search (REKS), a novel matheuristic for the Multidimensional Multiple-Choice Knapsack Problem (MMKP). While the MMKP is a well-known combinatorial problem, existing methods often suffer from a heavy reliance on Linear Programming (LP) relaxations and high sensitivity to parameter tuning. Building upon the original Kernel Search (KS) framework [1] and its two-phase variants [2], REKS introduces a more robust approach to variable selection and subproblem exploration.

The core of the methodology is a controlled-relaxation mechanism that identifies promising variables by solving a sequence of MILPs with incrementally relaxed resource constraints. By slightly increasing resource availability, the algorithm uncovers high-quality integer solutions (generally infeasible for the original problem) that provide a more informative set of variables for the initial kernel set than standard LP reduced costs. This is paired with an incremental bucket-exploration strategy, which dynamically enlarges subproblems during the search to mitigate the traditional KS dependence on fixed bucket sizes. Additionally, a multi-policy parallel search scheme is employed to balance intensification and diversification through varying kernel-update rules.

Extensive computational results on standard benchmark instances [3] demonstrate that REKS outperforms state-of-the-art heuristics. The algorithm matched or improved the best-known solutions in most instances and established itself as the unique best performer in a significant number of cases. These results confirm that REKS is a robust and highly effective framework capable of delivering near-optimal solutions for complex MILP problems while substantially reducing overall solution times.

Keywords: Knapsack Problem, Matheuristic, Kernel Search

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Abstract ID: ODS-009 Session: S02

The Diversity Optimization Problem: Modeling and Column Generation Approaches

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Optimization models typically aim at identifying a single optimal solution. However, in many practical settings, decision makers benefit from having access to multiple high-quality alternatives exhibiting significant structural differences. In this work, we study the *Diversity Optimization Problem* (DOP), which consists of generating K feasible and near-optimal solutions that maximize their total pairwise Hamming distance over a set of core binary variables.

We first present compact formulations for DOP and derive combinatorial upper bounds on its optimal value. We then develop a frequency-based reformulation that leads to a set partitioning model, enabling the application of a column generation scheme. In this framework, columns correspond to feasible solutions of the underlying problem, and diversity is optimized without explicitly enumerating the solution space, which is typically exponential.

A key contribution of the work is the design of a structure-exploiting pricing strategy. When the underlying problem admits efficient combinatorial algorithms, the pricing subproblem can be approached by leveraging its specific structure rather than relying exclusively on general-purpose MIP solvers. We illustrate this idea on the assignment problem, where a tailored pricing procedure based on Lagrangian relaxation provides a viable alternative to standard MIP-based pricing.

Computational experiments on MIPLIB instances show that the proposed approach produces diversity values that are competitive with, and often superior to, existing methods in the literature ([1], [2]). Additional results on synthetic assignment instances confirm the effectiveness of the column generation framework.

Keywords: Diversity optimization problem, Column generation, Assignment problem

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S03 – Energy

Abstract ID: ODS-110 Session: S03

An Optimization-Based Framework for Reducing Territorial Vulnerability

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Territorial systems face interacting pressures—notably climate change and overtourism—that impact communities, services and ecosystems. Vulnerability assessment is a key diagnostic tool but rarely links to operational decision-making. This work proposes an optimization-based decision-support framework to help local authorities select adaptation and mitigation actions under limited resources [1]. Inspired by VARNA Model [2] for computing vulnerability, i.e. a socio-ecological approach based on three interacting dimensions (exposure, sensitivity, and adaptive capacity), the main impacting drivers considered are climate-related hazards and overtourism flows, while the exposed elements include residents, visitors, economic activities, services, and environmental and cultural assets. The proposed approach focuses specifically on increasing adaptive capacity through targeted interventions capable of reducing the overall vulnerability of the territorial system. Each action is characterized by implementation costs, expected effectiveness (in short, medium and long terms), time horizon, feasibility conditions, and contribution to one or more adaptive-capacity indicators. A mixed integer linear optimization formulation is introduced to allocate available resources among competing actions in order to maximize adaptive-capacity improvement and vulnerability reduction along a specified planning horizon. The model incorporate budgetary, technical and policy constraints, including minimum protection requirements for specific exposed elements, precedence relations among actions, including also a multi-period perspective, distinguishing between short-term operational measures and medium- to long-term structural interventions.

Preliminary results on a case study are presented, together with a scenarios analysis for understanding the capability of the proposed approach.

Keywords: Vulnerability assessment, Decision-support systems, Multi-period planning, Mixed-Integer Linear Programming,

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Abstract ID: ODS-021 Session: S03

PowSyBl Open RAO: a Toolbox for Remedial Action Optimization

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Europe's energy transition is leading to an increase in cross-border power flows. Investing in new transmission lines is a long and expensive process, and existing grids must be operated intelligently to safely increase the available transfer capacity between countries. Remedial Action Optimization (RAO) plays a major role in the operation of the European electricity system and is being more and more integrated by Transmission System Operators (TSOs) in Europe and around the world.

Open RAO stands for "Open Remedial Actions Optimizer". It is part of the open-source PowSyBl library [1], and it aims at providing a modular engine for RAO and an efficient solution for power systems coordinated capacity calculation and security analysis projects. It is released by RTE (the French TSO) and Artelys actively contributes to its developments.

Given an input including contingencies, assessed elements and remedial actions, the goal of RAO is to provide a list of optimal remedial actions to apply to secure a network, minimizing the costs for their activation. PowSyBl Open RAO provides a modular and multi-step optimization algorithm, which includes load flow calculations to detect violations, and which selects the best available preventive and curative remedial actions. The optimization algorithm combines a search tree, for all actions that have an impact on the network topology, and an iterative resolution of a mixed integer linear problem (MILP), to optimize range-based actions that can be treated as linear.

This talk presents PowSyBl Open RAO, its underlying algorithms, and its ongoing development directions, aimed at performance improvements, including the integration of countertrading remedial actions into the MILP formulation. This feature, currently under development, will replace the need for an outer-loop process to perform countertrading.

Keywords: Power Systems, Remedial Action Optimization, Security Analysis, Mixed-Integer Linear Optimization

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Abstract ID: ODS-125 Session: S03

Risk Aversion in a Bilevel Energy Market

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This work explores the impact of risk aversion in the context of bilevel programmes. Bilevel programmes such as mathematical programmes with equilibrium constraints (MPECs) are common in the energy literature. However, they frequently fail to adequately account for risk-averse decision-making. This work addresses this gap in the literature by analysing how risk aversion influences an MPEC. In particular, it applies conditional value-at-risk (CVaR) to an MPEC featuring one price-making leader and two price-taking followers facing capacity expansion and dispatch decisions. It derives analytic and numerical results from this stylised model, and a discussion of the impact and insights thereof. These results indicate that risk aversion can cause prices and profits to increase. The work further explores the impact of heterogeneous risk preferences amongst the players, highlighting that risk aversion for the leader has a distributive effect, whilst risk aversion for the follower benefits the leader. It explores the interlinking between risk aversion, market power, and Stackelberg oligopoly. In the context of the energy transition, which induces further uncertainty and risk, understanding the impact of risk aversion is imperative in order to accurately model energy markets.

Abstract ID: ODS-113 Session: S03

Scenario Generators with Time Series Foundation Models for Multi-Horizon Scenario Trees in Renewable Energy

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In multistage stochastic optimization for renewable energy management, scenario trees must capture both long-term investment and short-term operational uncertainty without introducing spurious predictability. We develop a data-driven Doob generator that reinterprets scenario generation as compensator extraction, decomposing each time series of renewable production, demand, and prices into a predictable component and a martingale innovation component. The predictable part is learned using time series foundation models, which exploit large-scale pretraining to capture complex temporal structure even in scarce or non-stationary energy data, while the innovation component is calibrated so that residuals behave as martingale differences. Our pipeline trains a one-step-ahead foundation model, extracts residuals, and enforces the martingale-difference property via statistical tests, autoregressive refinements, and conditional variance modeling when needed. The resulting standardized innovations define a flexible innovation distribution from which we sample shocks that preserve zero conditional mean and avoid re-injecting hidden predictability into the scenario tree. We embed this generator into a multi-horizon scenario tree construction; the resulting trees align conditional expectations with foundation-model forecasts and maintain martingale consistency along all branches, yielding statistically coherent scenarios for risk-averse scheduling and investment.

Keywords: Scenario generation, Time series foundation models, Doob decomposition, Multistage stochastic programming, Renewable energy

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Abstract ID: ODS-118 Session: S03

The petrol station game: the regional average price. A mean field analysis

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In January 2023, the obligation for petrol stations to display the average fuel price calculated on a regional basis was introduced by the Italian Government. A mean field game model is here proposed to describe the evolution of the fuel price. In particular, each petrol station decides its own price, for the next day, taking account of an estimate of the average price, to be communicated by the Local Authority. The existence and the evolution of a mean field equilibrium are analytically investigated. Some simulations are compared with real data from the Autonomous Province of Trento, Italy.

S04 – Health Management

Abstract ID: ODS-117 Session: S04

A mathematical programming model to assess personnel deployment in Community Houses

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This talk presents a model to assess the allocation of personnel resources within Community Houses (CHs), which have been introduced in the Italian Healthcare System in 2022 and are undergoing a phase of full implementation. One of the main purposes of CHs is to reduce the pressure on hospitals and other healthcare facilities by ensuring timely and accessible care closer to patients' homes. This decentralization of healthcare services aims to enhance the overall patient experience and promote better health outcomes across the territory [1].

We propose an ILP model which computes an ideal allocation of services to personnel and of patients to CHs, given the capacity of each CH and the demand for specific classes of services (visits, diagnostic exams...) originating in a certain territory. Our model explicitly accounts for the opportunities offered by IT connectivity to fulfill the demand for services also through telemedicine. The objective is to minimize a disutility function, namely the total distance traveled by patients to receive the services. The model can be viewed as a decision support tool for personnel deployment to enhance operational efficiency and access to care.

Using demographic and epidemiological data from Tuscany South-East Local Healthcare Authority, we performed a set of experiments which investigated a number of design issues. Some of the main findings include: (i) using telemedicine, and without changing the current capacity of CHs, centralized patient assignment may result in a 36% reduction of traveled distance; (ii) the reallocation of a limited amount of person-hours across the territory can yield significant benefits in terms of traveled distance; (iii) applying the model to a scenario that includes some prospective CHs, and restricting the analysis to the population suffering from the major chronical diseases, the total distance traveled by this class of patients can be reduced by 57% through centralized planning.

This research was supported by the Italian Ministry of University and Research, grant PNRR - THE - Spoke 10 - CUP: B63C22000680007.

Keywords: Community Houses, Healthcare Territorial Planning, Resource deployment

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Abstract ID: ODS-074 Session: S04

A multi-granular approach for the management of no-shows in healthcare appointment scheduling

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Patient no-shows represent a significant challenge in healthcare appointment scheduling, as missed appointments can lead to resource underutilization and operational inefficiencies. This research addresses this issue by investigating various scheduling techniques to deal with no-shows in function of information granularity, spanning from a baseline model with aggregated daily capacity to a more detailed slot-based scheduling, testing several policies within a Mixed-Integer Linear Programming architecture. Policies include uniform reaction, day-specific adjustments, and temporal-based strategies for both proactive overbooking and visit time reduction (applying discounting factors to the expected appointment durations) as means to protect the system against no-shows.

At the most fine granularity, we test policies on patient-specific risk scores. Specifically, we implement a machine learning (ML) pipeline for individual no-show risk prediction using a real dataset from the Brazilian public health system. Individual probabilities are integrated into the scheduling framework, enabling patient-specific risk management where capacity constraints are expressed in terms of expected attendance.

The various approaches are evaluated ex-post evaluations using Monte Carlo simulation. While aggregated baseline models prevent overtime, they result in significant resource wastage. The visit time-reduction model has a balanced behaviour, and the ML-driven one drastically improves efficiency.

In summary, this work proves that moving from homogeneous assumptions to individualized risk profiles allows for more efficient management of resources but, crucially, also provides planning tools for low-data scenarios, so that that efficient capacity management is achievable regardless of the available information.

Keywords: healthcare, robustness, scheduling

Abstract ID: ODS-095 Session: S04

A Realistic Discrete Event Simulation model for Ambulance Location and Deployment within a regional Emergency Medical Service

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This work presents a realistic, general-purpose Discrete Event Simulation (DES) model developed to reproduce the workflow and stochastic behavior of Emergency Medical Services (EMSs), with a particular focus on ambulance location and deployment. The DES model captures the entire sequence of activities in an ambulance mission: emergency call arrival, telephone triage, ambulance dispatch, travel to the scene, on-site treatment, transport to an emergency department if necessary, ambulance offload delay, sanitization, and return to base or direct reassignment. In accordance with recent literature emphasizing the need for realistic EMS simulation, the proposed framework explicitly accounts for stochastic demand, spatial and temporal heterogeneity, calibrated road-network travel times, urgency-dependent service times, hospital selection based on clinical suitability, and ambulance unavailability during the different phases of a mission. Validation against historical data shows that the model reproduces the main operational patterns of the real EMS system, in terms of call volumes, response time coverage, and ambulance workload across bases.

Therefore, EMS managers can use this validated framework as a decision support tool, providing a realistic basis for future analyses of ambulance deployment policies and resource allocation strategies in different EMS settings.

Keywords: Emergency Medical Service, Ambulance Location, Discrete Event Simulation

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Abstract ID: ODS-051 Session: S04

A Robust Optimization Model for Home Care Service Planning with Uncertain Operator Availability

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The continuous ageing of the population, combined with the need to contain healthcare costs, is placing increasing pressure on traditional hospital-centered systems. In this context, Home Health Care (HHC) services represent a sustainable alternative, providing medical, paramedical, and social assistance directly at patients' homes while improving quality of life.

Although the HHC literature is extensive, uncertainty has only recently been addressed. However, properly managing uncertainty is crucial to limit service disruptions when adverse events occur, thereby preserving patients' well-being.

We consider an integrated HHC planning problem involving patient-operator assignment, visit scheduling, and routing decisions over a given planning horizon, subject to skill compatibility, operator availability, and geographical constraints. We address this problem under uncertainty in operators' availability. To this end, we propose a robust optimization framework that accounts for deviations from nominal availability when defining the service plan.

Preliminary computational results, obtained using a commercial solver, are presented on instances based on real data provided by a cooperative organization operating in the Home Care sector.

Keywords: Robust Optimization, Robust Home Health Care, Uncertain Operators' Availability

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Abstract ID: ODS-096 Session: S04

A Simulation based Optimization approach for the Ambulance Location Problem in Emergency Medical Service

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Ambulance Location problem is a crucial and widely studied problem within Emergency Medical Services systems. It is a strategic and tactical problem which aims at determining the number of ambulances and the placement of the ambulance base stations across a service region, to ensure timely response to emergency calls. The purpose is typically to minimize the response time, while accounting for limited resources, stochastic demand, and operational constraints. Discrete Event Simulation (DES) is by far the most used approach for dealing with this problem.

In this work, we adopt a novel and realistic DES model recently proposed in Ref. 3 to evaluate system performance under different operating conditions. Moreover, following the Simulation Based Optimization approach, we combine the use of this DES model with an optimization algorithm, "ad/hoc" developed for efficiently handling such a Simulation-based (Black Box) Integer Nonlinear Optimization Problem. This allowed us to go beyond the standard scenario ("what-if") analysis and to obtain significative and interesting results on a real case study.

Keywords: Emergency Medical Service, Ambulance Location, Simulation based Optimization

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Abstract ID: ODS-086 Session: S04

Blood Component Production Scheduling Using Rule-Based Policies

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Whole blood collected from healthy donors is typically separated into its main components for transfusion purposes, as each component fulfills a distinct physiological function. The production of blood components is carried out in specialized facilities, such as blood centers and hospitals, and represents a complex process due to the need to manage perishable resources under high-throughput operational constraints. Despite the relevance of advanced scheduling methodologies in this context, no dedicated approaches have been proposed in the blood supply chain literature to explicitly address the scheduling of separation activities [1].
This study builds on our previous work, in which an ILP model was developed to generate optimal schedules for blood component production [2]. Although the model was capable of producing high-quality and realistic schedules, it required significant computational time and resulted in non-intuitive schedules for the human operators that are involved in the production process. To address these limitations, we now propose a set of rule-based scheduling policies that enable the rapid generation of practical and interpretable solutions. The proposed policies account for both machine processing times and manual activities performed by human operators at the beginning and end of each operation. The objective is to achieve high-quality schedules with substantially reduced computational effort, while also providing actionable insights to support decision-making in the production process.
We validated the proposed approach through a real-life case study at Niguarda Hospital in Milan, Italy. The results indicate that effective schedules can be obtained with substantially lower computational time compared to the ILP model. Moreover, the rule-based policies improve operational clarity and support operators in making more structured and informed decisions.

Keywords: blood component production, production scheduling, rule-based scheduling policies

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Abstract ID: ODS-028 Session: S04

Building a Fair and Efficient Surgical Unit: Insights from Academic Vascular Surgery

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University hospitals must deliver efficient surgical care while ensuring high-quality training for medical residents [1]. Surgical education relies on hands-on Operating Room (OR) experience and benefits from exposure to diverse clinical cases. At the same time, ORs are resource-intensive and require careful scheduling to guarantee timely and safe patient care.

Our case study conducted at Molinette Hospital in Turin [2] shows that high OR utilization and balanced resident training can coexist. Building on this evidence, we generalize the approach to broader university hospital settings. We propose a sequence of Mixed-Integer Linear Programming (MILP) refinements that progressively enhance the modelling of fairness, culminating in a fairness-over-time framework.

The proposed approach integrates operational efficiency and educational fairness in OR scheduling by jointly assigning elective surgeries and residents, while accounting for patient urgency and training needs. Fairness is modelled as an equitable distribution of surgical cases among residents, aligned with their experience and learning progression.

Since a training program spans multiple weeks, it is naturally represented as a sequence of interconnected OR schedules. Therefore, evaluating training quality requires solving a sequence of optimisation problems over the entire planning horizon.

To address the computational challenges posed by real-world instances, we develop a matheuristic based on Large Neighbourhood Search with destroy-and-repair strategies, enabling scalable solution of sequential problems.

Results confirm that efficient OR utilization and equitable training are compatible objectives. Future work will extend the framework to capture more complex operational constraints and richer educational dynamics.

Keywords: Operating room planning and scheduling, Resident training, Fairness

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Abstract ID: ODS-057 Session: S04

How to model a regional healthcare system leveraging healthcare big data

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Healthcare Big Data (HBD) is generated from a plurality of sources and offers possibilities for new insights, for understanding human systems at the systemic level to develop personalised medicine, prevent diseases and support healthy life. From a management perspective, HBD is a key enabling technology for analysing the healthcare system at the individual patient level.

We propose a general framework in which the HBD can power a detailed health system analysis using Discrete Event Simulation (DES) methodology: indeed, one can replicate the behaviour of the health system modelling how each single patient flows within their care pathway exploiting the HBD. Unlike other more traditional analytical approaches for the health system analysis, our framework allows to (i) better represent the variety of the patients accessing the health system, (ii) better capture the actual capacities of each wards over time, and (iii) replicate the day-to-day admissions process.

Based on our previous work [1], we illustrate this approach by modelling the regional healthcare system in Piedmont using three years' worth of hospital discharge records (more than 1.5 million records) in order to analyse the flows of patients asking for a specialist treatment as a result. We detail the various steps that lead to the development of the complete quantitative model. We also outline the various analyses that can be carried out using the resulting model.

Keywords: Healthcare logistics, Patient flow, Optimisation and simulation

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Abstract ID: ODS-159 Session: S04

Master Surgical Scheduling under Uncertain Surgery Duration via Chance Constraints

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The design of a Master Surgical Schedule (MSS) remains a significant challenge for hospital administrators balancing operating theater utilization against the risks of overtime and ward congestion. This paper proposes a stochastic chance-constrained mixed-integer programming model for cyclical weekly schedules. To derive a computationally tractable reformulation, we employ a scenario-based approach that addresses the mathematical complexities of aggregate surgical duration distributions. By integrating downstream ward capacity, the framework regulates operating room overload while preventing bed shortages. Numerical experiments on a realistic case study show that as reliability requirements increase, the model reconfigures the surgical portfolio by prioritizing categories with more predictable durations to maintain throughput. These findings demonstrate that the proposed approach provides a robust decision support tool for balancing resource efficiency and operational stability in complex clinical environments.

Abstract ID: ODS-012 Session: S04

Parallel Batch Scheduling for Sterilization Operations

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In [1] Schlembach et al. propose a Column Generation procedure for managing the seterilization operations of surgical instruments. The sterilization process is modeled as a parallel batch scheduling problem on parallel identical machines with job release dates (see [2]).

In the practical setting described, each surgical instrument j to be sterilized (job) is released at the end of some surgical operation performed during the day. A number m of identical sterilizing machines is available, where the surgical instruments are processed in batches that must be formed and scheduled. Capacity constraints have to be taken into account in order to form the batches since each instrument j has some size s_j and the sterilizing machine "trail" has a limited capacity q. The instruments belong to different families, and each family has its own requirements about the temperature and the time required for sterilization; specifically, each batch must be composed of jobs/instruments from the same family f that induces a given processing time p_f. Schlembach et al. choose the total flow time as performance measure, leading to a scheduling model that can be written, adapting the classical three-field notation, as $Pm|\text{p-batch}, \text{fam}, p_j = p_f, r_j, s_j \leq q| \sum_j F_j$.

Adapting ideas from [3], we develop an arc-flow reformulation that is able to optimally solve all instances studied by Schlembach et al., including the real-world ones, in less than one second. We also elaborate on the techniques developed in [1] by equipping their Column Generation procedure with a fast pricing routine based on Dynamic Programming. Furthermore, by introducing a Lagrangian-based procedure to solve the Reduced Master Problem, we get comparable results with far less generated columns – an order of magnitude less, on average. Eventually, we extend the computational study by generating "difficult" instances, that proved to be practically hard to solve. Computational results will be discussed at the conference.

Keywords: OR in Health Services, Batch Scheduling, Mixed-Integer Programming

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Abstract ID: ODS-162 Session: S04

Pharmacy congestion avoidance in an intensive care unit

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We consider a combinatorial optimization problem stemming from a real context, in which an assignment must be decided between a set of nurses and a set of patients. Each patient must receive a prescribed set of treatments at prescribed points in time within a given tolerance. Each treatment requires the assigned nurse to access the pharmacy. the goal is to avoid congestion to simultaneous access of several nurses to the pharmacy. We have developed a mathematical programming model that can be solved to optimality by MILP solvers when the instance size is relatively small. Preliminary tests have validated its useful ness in calibrating the trade-off between several conflicting objectives in a real environment.

Abstract ID: ODS-017 Session: S04

Project Scheduling with Probabilistic Activity Outcomes: an Application to Heart Donor Management

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This work studies the optimization of project scheduling decisions in settings where activities are characterized by durations, execution costs, and uncertain outcomes, and where scheduling choices significantly affect operational efficiency and deadline compliance. We propose a cost-aware optimization framework that explicitly incorporates probabilistic activity outcomes, with the objective of minimizing expected total cost while ensuring completion within a specified time horizon, considering that if any activity has a negative outcome, the project stops. The problem is formulated as a Mixed Integer Linear Programming model. To account for uncertainty in activity durations and assess the risk of adverse timing outcomes, the framework is complemented by quantile-based risk measures, including Value at Risk and Conditional Value at Risk, which support the evaluation of trade-offs between expected cost and schedule robustness. The motivating application concerns the pre-transplant assessment phase in heart donation, where multiple diagnostic procedures must be performed under severe time constraints and uncertainties regarding donor suitability or consent acquisition may affect the value of performing subsequent tasks. In this setting, explicitly accounting for uncertainty allows the model to identify more effective scheduling decisions, reducing inefficiencies and limiting costly delays. The proposed framework provides a decision-support tool for this specific application while also offering a general approach for project scheduling problems involving uncertainty, and cost considerations.

Keywords: Decision-making under Uncertainty, Project Scheduling, Mathematical Programming, Healthcare management.

Abstract ID: ODS-038 Session: S04

Robust elective surgery advance scheduling via a probabilistic regression-driven implementor-adversary framework

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In healthcare, the effective use of resources is crucial to ensuring high-quality service while controlling costs. Operating theater (OT) management is one of the most extensively studied subjects in the field, as its management influences multiple steps of the clinical pathway. Within this context, elective surgery advance scheduling stands out as an especially crucial problem: this decision determines the assignment of routine procedures to specific dates and OTs, thus playing an important role in defining daily OT operations [1]. However, managing it is a complex task, mainly because of the non-deterministic nature of surgery times, which frequently causes schedules to result in overtime.

This work addresses a robust version of the elective surgery advance scheduling problem using a data-driven approach, with the goal of controlling overtime while minimizing the waiting time of all patients on the elective waiting list [2]. We use a probabilistic regression model trained on historical data to generate realistic surgery time distributions, thereby enabling the definition of a flexible uncertainty set that can be adapted to several robustness profiles [3]. We use an implementor-adversary framework [4] to create robust solutions: a first model produces a solution for known parameters, followed by a second model that introduces solution-violating realizations that exist within the uncertainty set. These are then passed back to the first model in the form of new constraints, and this process is iterated until no more solution-violating realizations can be found. Computational tests on realistic data show satisfactory solution quality and computational efficiency, also in comparison to two other commonly used methods for non-deterministic data – budget set and chance-constrained formulations.

Keywords: operating theater, robustness, scheduling

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Abstract ID: ODS-078 Session: S04

Towards Service-Quality-Aware Staff Rostering in Emergency Departments

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Emergency Departments (EDs) must provide timely care under highly variable demand while ensuring fair and sustainable working conditions for clinicians and nursing staff. ED crowding and staffing levels may affect access to care, delays, and service quality [Pearce et al. 2023]. Traditional rostering models mainly focus on coverage and fairness [Ernst et al. 2004], while the quality delivered during a shift may also depend on the capability profile of the on-duty team, including competencies, seniority, and experience [Burke et al. 2004]. We propose an integrated staff rostering model that assigns physicians and nurses to shifts over a finite planning horizon. The model includes legal and organisational constraints, such as working-time rules, minimum rest periods, and shift succession, together with coverage, competency, and preference requirements. Service quality is represented through indicators derived from staff capability profiles, with the aim of reducing variability in shift-level capability while balancing workload distribution and undesirable shifts. The framework is designed for evaluation using data from a Canadian hospital Emergency Department.Current work focuses on implementing the optimization model and defining capability indicators that reflect team composition in each shift. Computational experiments will assess how service-quality levelling affects roster feasibility, workload equity, and shift composition under realistic operational constraints, and will examine trade-offs between conventional rostering objectives and capability balancing.By explicitly incorporating service quality into ED staff rostering, the proposed approach aims to support more balanced and robust staffing plans. It also provides a basis for future empirical analyses of downstream operational performance, including waiting times, length of stay, and left-without-being-seen rates.

Keywords: Health care, Staff rostering, Combinatorial optimization.

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S05 – Knitro

Abstract ID: ODS-015 Session: S05

Introduction to Artelys Knitro

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Artelys Knitro is a leading optimization solver designed for challenging non-linear (NLP) and mixed-integer non-linear (MINLP) problems. Problems can be composed of linear and quadratic structures, as well as black-box functions. The optimization solver relies on derivative-based algorithms to compute locally optimal solutions. For non-convex continuous problems, it converges to a first-order stationary point (*i.e.* a local optimum), while for non-convex MINLPs it operates as a heuristic. In contrast, for convex NLP and MINLP problems, Knitro is guaranteed to find the global optimum.

The solver includes five state-of-the-art algorithms for continuous NLPs: two interior point methods [1], a sequential linear–quadratic programming (SLQP) method, a sequential quadratic programming (SQP) method, and a recently introduced augmented Lagrangian algorithm added in Artelys Knitro 15 [2]. MINLP problems are addressed through a non-linear branch-and-bound framework and a mixed-integer SQP algorithm.

In this talk, we will present the main features of these algorithms together with the new developments introduced in Artelys Knitro 16.0, which is expected to be released before the conference. Performance results on both academic and industrial non-linear benchmarks will be shown and compared with previous versions of the solver to highlight the improvements.

Keywords: Solver, Non-linear optimization, Mixed-integer non-linear optimization, Derivative-based algorithms

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S06 – Logistics and transportation

Abstract ID: ODS-076 Session: S06

A Column Generation-based Heuristic for Integrated Train Rescheduling and Speed Management

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Large-scale disruptions can cause trains to deviate from planned timetables and speed profiles, leading to prolonged delays. Real-time generation of conflict-free timetables and executable speed profiles, along with rerouting of affected trains, is crucial for service recovery. This study addresses an integrated train rescheduling and speed management problem on high-speed railway networks under multiple disruption scenarios, involving global rerouting, local rerouting, flexible stops, and dynamic driving strategy adjustments. We propose a path-based model that prevents train conflicts by employing a dynamic set of maximal conflict cliques on block sections. In addition, train paths are assembled from predefined driving strategy segments on a space-speed network. To solve this problem efficiently, we develop a column generation-based heuristic to handle new path generation and conflict constraints update. Preliminary results on Chinese high-speed railway networks demonstrate the efficiency of the proposed approach.

Keywords: Train rescheduling, speed management, column generation

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Abstract ID: ODS-180 Session: S06

A mesoscopic model for optimal siding placement for an innovative rail-road vehicle transport system

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Capillary railway lines offer crucial territorial connectivity but have been massively abandoned over recent decades due to high operating costs and low demand. The FERROMOBILE [1] project explores the use of rail-road electric vehicles to revitalize such lines, operating on single-track infrastructure where bi-directional service is inherently constrained by limited crossing opportunities. Increased service frequency is made possible by the construction of new road-type sidings between existing stations. This work proposes a mesoscopic optimization model to support infrastructure decision-making, specifically on the joint selection of the number and optimal placement of sidings for a given fleet size. It extends a previous study based on a microscopic model and a Mixed Integer Linear Programming formulation [2]: the new mesoscopic model reduces the computational burden, thereby allowing the scaling up to larger fleets and a higher number of candidate siding locations.

The line is represented as a sequence of typed areas (terminals, open lines, intermediate stops, and sidings), each governed by specific constraints to model vehicle headways, running times, and rolling stock reutilizations, in addition to infrastructure capacity. A constraint satisfaction problem over integer time variables is solved with the OR-Tools CP-SAT solver. The optimizer produces conflict-free timetables by scheduling all train movements, routing crossing trains at sidings, and minimizing total delay with a penalty on siding use. A cadenced variant enforces uniform spacing between successive trains in each direction, enabling the search for the most compact cyclic timetable.

The model is evaluated on the real-world Limoux-Quillan line (29 km, 6 stations, France), with fleet sizes ranging from six to ten vehicles and up to twenty-five candidate siding locations.

Keywords: rail-road vehicle, capillary railway, single-track, siding placement, mesoscopic model, timetable optimization, constraint programming

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Abstract ID: ODS-042 Session: S06

A Multi-Train Unloading Planning Problem in Maritime Container Terminals

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Rail transport is a key component of modern logistics systems and is expected to play an increasingly important role, leading container terminals to enhance rail-side operations; however, despite their growing relevance, the coordination of such operations in non-automated terminals remains largely unexplored. This work introduces a Multi-Train Unloading Planning Problem, a generalization of the problem in [1] that, building on related landside train-handling settings [2], jointly captures multiple trains on parallel tracks, several gantry cranes (GCs) sharing a common longitudinal track to unload the trains, and a fleet of reach stackers (RSs) serving the export yard. Each GC is equipped with an adjustable spreader and a trolley that moves laterally to a landside zone, where containers are released for collection. Tow tugs then carry the containers to the yard, where RSs store them in compatible bay-locations. Compatibility depends on container size, weight class, and port of destination, subject to bay-location capacity limits.

A Mixed-Integer Linear Programming (MILP) formulation is proposed to minimize the makespan, i.e., the time at which the last container has been stored in the yard. Crane completion times capture longitudinal travel along the train, lateral trolley movement, spreader adjustments between consecutive containers of different sizes, and hoisting. The model jointly enforces container-bay compatibility, operation contiguity, safety-distance and non-overtaking conditions between adjacent cranes, RS positional continuity and cumulative timing, and a crane-RS precedence linking the transfer time of every unloaded container to its storage operation.

Due to the strong coupling among crane sequencing, lateral coordination, and yard-side operations, exact methods quickly become impractical. A decomposition based approach exploiting the structure of the problem is being developed to address realistic instance sizes. Preliminary computational experiments based on industrially-inspired random instances will be executed and presented.

Keywords: Maritime container terminal, Train unloading, Makespan minimization, Mixed-Integer Linear Programming

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Abstract ID: ODS-069 Session: S06

A Petri Net based Formulation for the Scheduled Service Network Design Problem

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Modern freight forwarding relies heavily on efficient vehicle scheduling and consolidation of goods to effectively connect senders and receivers. This problem is typically referred to as the scheduled service network design problem (SSNDP). While current state-of-the-art methods often utilize time-expanded network models, these approaches face significant scalability challenges when applied to large-scale problem instances. To address this limitation, Hewitt et al. (2023)[1] proposed a consolidation-based model that offers a more tractable solution for large instances. However, their approach requires the enumeration of all potential consolidation opportunities, making the problem still computationally intensive. In this work, we propose a novel Petri net-inspired approach to solve the SSNDP, which integrates both consolidation and vehicle dispatching decisions in a single model without time expansion. Our methodology leverages timed Petri net modelling, mixed integer programming (MIP), and cycle constraints to minimize the number of deployed vehicles and optimize commodity consolidation and vehicle deployment w. r. t. given time requirements (e. g. earliest availability, latest delivery). To tackle computational challenges, we employ a row generation method to identify critical cycles and implement a lower-bound technique to estimate the optimality gap. We conduct extensive experiments to evaluate the strengths and weaknesses of our approach in comparison to the existing state-of-the-art methods. The results highlight the potential of our Petri net-based framework for addressing scalability challenges in freight forwarding and improving network performance. This work contributes a significant step forward in scalable and efficient freight network design, with implications for modern logistics and supply chain optimization on road and rail.

Keywords: SSNDP, Petri Nets, MIP, Freight Transport

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Abstract ID: ODS-082 Session: S06

A Sequential Local Optimization Approach for Train Platforming with Flexible Time Adjustments

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Large-scale railway stations are critical bottlenecks in passenger railway systems, where platforming decisions coordinate platform tracks, routes, and train arrival/departure times under limited infrastructure capacity. To coordinate train platforming with timetable planning, train times are treated as adjustable planned values rather than fixed inputs. This motivates a flexible-time formulation in which these times may shift within tolerance windows to mitigate conflict propagation. Each train is associated with feasible platforming patterns specifying an inbound route, platform track, outbound route, nominal times, and time-deviation windows. Building upon this, a mixed-integer linear programming (MILP) model is developed to jointly determine train-pattern assignments and time deviations subject to headway, track-occupation, route-compatibility, and dwell-time constraints. To improve tractability, the problem is decomposed into train-wise local optimization problems, each adding one train to the partial plan. For each candidate pattern, heuristic time-deviation suggestions from feasible time-deviation windows and conflict-boundary points are used to derive tentative precedence relations for conflicting train pairs. Given these relations and the candidate pattern, a fixed-order local integer linear programming (ILP) model jointly re-optimizes the time deviations of the current and previously scheduled trains while keeping selected patterns fixed. If this model is infeasible, conflict information is extracted and a flexible-order local MILP model is solved by relaxing only selected precedence relations. Bounded backtracking revises conflict-related pattern decisions, and a no-good memory avoids repeated exploration of failed train-pattern combinations. The objective is to construct a feasible platforming plan with minimum total deviation from the nominal timetable. Computational experiments demonstrate the effectiveness and efficiency of the proposed approach.

Keywords: Train platforming; Flexible time adjustments; Sequential local optimization; Bounded backtracking

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Abstract ID: ODS-102 Session: S06

A Tactical–Operational Framework for Revenue Management in Car Rental Systems

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Revenue management is a key challenge for car rental companies, where pricing and capacity allocation decisions must account for uncertain demand, limited fleet availability, rental duration, booking lead time, and the spatial distribution of vehicles across stations. This work proposes an integrated tactical-operational framework to support these decisions over a finite planning horizon. At the tactical level, the problem is formulated as a Mixed Integer Nonlinear Programming model that jointly determines the price levels to be offered for each rental request type and the capacity allocated to each vehicle class. The model considers multiple vehicle categories, different rental start and end times, historical demand and price data, station capacities, one-way bookings, and possible vehicle relocations between stations. At the operational level, the results of the tactical model are used to derive a booking control policy for real-time request acceptance and pricing decisions. The proposed approach allows rental companies to better balance revenue opportunities with fleet utilization and service feasibility. Computational results show that the framework improves profitability, increases resource utilization, and provides effective decision support in dynamic and uncertain car rental environments.

Keywords: Car Rental, Pricing, Capacity Optimization.

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Abstract ID: ODS-128 Session: S06

A Three-Phase Matheuristic for the Two-Echelon Location-Inventory-Routing Problem in a Reverse Logistics Network

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This study addresses the Multi-Period Heterogeneous Fleet Split Delivery Two-Echelon Location-Inventory-Routing Problem applied to the reverse logistics of empty agrochemical packaging in Brazil. The system faces agricultural seasonality and climate-driven demand volatility, requiring complex synchronization between decentralized collection from retailers and homogeneous dispatch to recycling facilities. We propose a novel three-phase matheuristic framework integrating strategic, tactical, and operational decisions. Phase 1 employs a surrogate-assisted Simulated Annealing metaheuristic to optimize consolidation facility location. Phase 2 solves a set-partitioning Mixed-Integer Linear Program (MILP) using heuristic column generation to size the heterogeneous fleet and synchronize multi-echelon inventory buffering. Phase 3 resolves operational vehicle scheduling via an assignment MILP minimizing empty trips and overtime. A Monte Carlo simulation generates probabilistic collection demand trajectories over a 15-year horizon. Applied to the Brazilian *Campo Limpo System* using real data from 139 municipalities, the proposed method outperforms human-planned baselines by achieving 18–20% total life-cycle cost savings, eliminating lost demand, and demonstrating that effective infrastructure decisions can prevent system failures under extreme volatility.

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Combining Discrete-Event Simulation and Metaheuristics in DSSs: from Logistics to Telecommunication Networks

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Operations management in port logistics, warehousing platforms, and telecommunication networks requires the optimal organization and evaluation of complex service systems. Under dynamic and stochastic conditions, these systems are expected to provide fast, resilient, and high-quality services while minimizing congestion, user interference, and energy consumption, as well as satisfying predefined performance requirements. Consequently, resource allocation and activity scheduling within decision support systems (DSSs) require effective algorithms to generate, explore, and evaluate feasible solutions over large combinatorial search spaces to identify the best system configuration. Discrete-event simulation (DES), driven by stochastic events and supported by statistical output analysis, represents an effective engine for realistic system modeling, temporal and state-dependent performance evaluation, and what-if optimization. Metaheuristics provide efficient search mechanisms when exact optimization approaches become computationally infeasible, making them particularly valuable in contexts where simulation is used to evaluate the objective function associated with the problem under investigation. This work presents major insights gained across different real-world application domains using informed heuristics (e.g., beam search and A*), adaptive heuristics (e.g., tabu search and adaptive large neighborhood search), and randomized heuristics (e.g., simulated annealing and iterated local search). The effectiveness of decision-making processes depends on the alignment between metaheuristic strategies and the requirements of DSSs and DES-based frameworks, with particular attention to the trade-off between solution quality and computational effort, adaptability to dynamic environments, and scalability. Developing this understanding may support the transition from isolated application-specific solutions toward the definition of a reusable methodological paradigm.

Keywords: logistics, operations, discrete-event simulation, metaheuristics, optimization

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A Variable Neighborhood Search Approach for a Multi-Objective Non-Emergency Healthcare Transportation Problem

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Non-emergency healthcare transportation is an essential service for many patients, involving transfers to and from hospital facilities for medical treatments, examinations, and discharges. This service is typically coordinated by a Local Health Care Agency (AUSL in Italy) and carried out by non-profit organizations operating heterogeneous fleets of vehicles, including ambulances, cars, and specially equipped vehicles, located at geographically distributed depots. The service is subject to several operational constraints, including arrival and departure times, patient-vehicle compatibility, patient preferences, and service-quality requirements. The problem can be modeled as a Multi-Depot Dial-a-Ride Problem (DARP) [1,2,3] with time windows and additional real-world constraints.

In the problem under study, the actors involved pursue different objectives: the Local Health Care Agency aims to minimize transportation costs reimbursed to non-profit organizations; patients seek high service quality; and non-profit organizations aim to use as few vehicles as possible, preserving them for other services. A multi-objective framework has been developed to capture these competing objectives, by minimizing transportation cost, the number of vehicles used, and the maximum patient waiting time as a measure of fairness across patients (following a different approach from [4]). Given the computational complexity of the problem, the Variable Neighborhood Search metaheuristic introduced in [5] has been adapted to tackle the above objectives and efficiently solve real-world instances. Computational experiments are performed on real-world data from Italy, provided by AUSL Toscana Sud-Est and the non-profit organizations Misericordia and Pubblica Assistenza. Computational and managerial insights are derived by analyzing the correlations among the three objectives and the resulting Pareto front.

Keywords: Healthcare Transportation, Multi-objective Optimization, Variable Neighborhood Search

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An Adaptive Large Neighborhood Search for a real-world case of Auto-Carrier Transportation

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This paper addresses an Auto-Carrier Transportation Problem faced by a leading Italian automotive logistics service provider. Given a set of orders, each one corresponding to delivery one vehicle from an origin to a destination with an associated urgency level, the problem requires to determine which orders to deliver in a certain day and to define the corresponding routes by using a fleet of auto-carriers. The goal is to maximize the sum of route efficiency, which accounts for route distance and loading quality, and orders' priority. Constraints are imposed on auto-carrier capacity, full load requirements, allowed combinations of vehicles in the same route, maximum route length and compatibility between orders that can be served within the same route. To tackle the large-scale instances typically encountered in practice, we propose a parallel Adaptive Large Neighborhood Search algorithm. We conduct computational experiments to compare the solutions generated by our heuristic with those produced by decision-makers.

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An airport network slot allocation model for airspace congestion reduction

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Integrating airspace congestion management into seasonal slot allocation represents an open challenge, and although some attempts have addressed congestion at a few airports considering only neighboring airspace [1,2], a network-wide solution has remained unexplored. As demonstrated in the literature [3], strategically balancing demand can significantly reduce the risk of peak traffic loads on critical resources. For this reason, this study presents the first network-level series allocation model that explicitly incorporates congestion management. The model proves that strategic minimal changes in the slot allocation (such as small shifts in departure and arrival times) can reduce traffic overload and mitigate congestion while preserving airlines' operational efficiency.

The methodology employs a two-stage MILP framework. Stage 1 performs allocation implementing the decision-maker's policy (e.g., maximising allocations based on airport capacity). Stage 2 reshapes the timings of series allocated in Stage 1 within flexibility windows to reduce peak occupancy in forecasted loaded sectors. Both stages account for airport coordination, ensuring departure-arrival time compatibility with flight durations and turnaround constraints.

Experiments conducted on Fridays of the 2019 European summer season, covering 152 Level 3 airports and 30 days, show that for sector traffic peaks where forecasted demand exceeds three standard deviations above the mean demand, the model reduces overload by approximately 20%. These findings prove that small strategic time shifts of series departures (within ±30 minutes) can significantly reduce congestion while fully respecting airlines' operational constraints.

Keywords: slot allocation, airspace congestion, network optimization, air capacity, seasonal scheduling

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Bundle Compensation Menus for Occasional Transporters

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Crowdshipping is a popular delivery strategy especially in last-mile. We investigate the case of a company (grocery, shop) which owns premises located close to a public transport stop (bus, metro...). The company receives orders online which should be delivered at customers' place. In addition, *regular* customers visit the company premises to do their own shopping. The company would like to promote a *green* delivery strategy based on crowdsourcing deliveries of online orders to regular customers coming by public transport, also called *Occasional Transporters (OTs)*. More specifcally, the system works this way. Online customers place their order up to a given cutoff time (say noon). Then, the company observe the entire set of orders received. When an OT appears to do her shopping, she first reveals her availability to deliver some orders and what is her destination (represented by the bus stop where she will leave). On the basis of this information, the company offers a menu of order bundles, where each bundle includes a set of orders and is associated with a compensation. We assume that all orders in a bundle are associated with a single bus stop (i.e., they can be delivered on foot with a single stop on the bus network). The process continues until a given deadline. Orders which remain unserved after the deadline are assigned to a 3PL at a higher cost.
We model the problem as a Markov Decision Process (MDP). We develop a theoretical analysis which enables to determine analytically the optimal policy to construct bundles and the corresponding compensation. Due to the course of dimensionality, we develop approximations of the cost-to-go associated with each state of the MDP. We present simulations on synthetic data generated from benchmark instances proposed in Delle Donne et al. (2023) where we compare different policies and approximation rules.

Keywords: Crowdshipping, Compensation Menus, Occasional Transporters

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Drone-Based Meter Reading with Relocatable Targets

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This work introduces the Relocatable-Target Close-Enough Traveling Salesman Problem (RT-CETSP), a new optimization problem motivated by drone-based reading of radio-frequency utility meters. In the classical Close-Enough Traveling Salesman Problem, each target has a fixed position and can be served when the vehicle enters its communication range [1, 2]. In many practical applications, however, the exact installation position of a meter can be selected within a predefined admissible area. This additional flexibility can be exploited to reduce the length of the route. The RT-CETSP jointly optimizes the placement of sensors within their admissible regions, the reading points visited by the drone, and the visiting order of these points. We formulate the problem as a mixed-integer second-order cone program that combines assignment, routing, relocation, and geometric feasibility constraints. We also consider relevant variants, including the case in which only a limited number of targets can be relocated and the fixed-target case. To solve the problem, we propose an iterative exact-heuristic framework based on reduced MISOCP models, following the idea of combining lower and upper bounds within an adaptive scheme [3]. Computational experiments on residential-grid instances show that relocation can substantially reduce route length. Relocating only 15% of the targets yields average reductions of about 9–13%, while full relocation leads to reductions up to 16%. Additional tests on classical CETSP instances show that the proposed method remains competitive also in the non-relocatable setting.

Keywords: Close-Enough Traveling Salesman Problem, drone routing, sensor placement, mixed-integer second-order cone programming

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Abstract ID: ODS-158 Session: S06

Efficient quasi-Monte Carlo optimization for model-predictive guidance of autonomous surface vehicles

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In this paper we propose an efficient adaptive quasi-Monte Carlo (QMC) optimization scheme for Model Predictive Control (MPC) to perform advanced guidance tasks for overactuated Autonomous Surface Vehicles. In this kind of application, real-time responsiveness is a key requirement, yet the complexity of the optimization problem underlying the MPC control makes traditional solvers unfeasible. The QMC scheme for MPC we propose here relies on a model embedding guidance kinematics, control dynamics andthrust control allocation, taking as reference the SWAMP-class ASVs. The cost function is designed to perform path following on arbitrary curves without virtual targets, while the constraints allow straightforward adaptation to faults, aiming at a fault-tolerant optimization scheme. Simulation tests in various conditions validate the efficacy and efficiency of the optimization methodology, as a proof of concept in view of at-field tests.

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Emission-Aware Adaptive Large Neighborhood Search for Two-Echelon Last-Mile Delivery with Hybrid Service Options

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This paper investigates how company-driven service policies can be designed to improve the environmental sustainability of urban last-mile delivery systems [1]. We consider a two-echelon distribution network in which parcels are transported from a central depot to urban satellites and then either delivered to customers' homes or made available for self-collection. The problem is formulated as an emission-aware Two-Echelon Location-Routing Problem that jointly optimizes satellite activation, vehicle routing, and the assignment of customers to delivery modes [2]. The focus of the study is on the evaluation of alternative operational policies available to logistics providers, in particular the extent to which self-collection is enabled and promoted within the delivery system. Different policy configurations are modeled and compared, ranging from full home delivery to hybrid strategies that incorporate satellite-based self-collection. These policies are assessed under both emission minimization and distance minimization objectives, highlighting their impact on system performance and environmental outcomes. To support this analysis, an Adaptive Large Neighborhood Search is developed to efficiently solve large-scale instances. The algorithm integrates tailored destroy and repair operators that coordinate routing and assignment decisions across both echelons, combined with an adaptive operator selection scheme and a temperature-based acceptance criterion. Computational experiments on realistic urban instances show that the proposed method consistently identifies high-quality solutions within short computational times. Results indicate that hybrid delivery strategies leveraging satellite self-collection can significantly reduce total CO_2 emissions, with only limited increases in traveled distance. These findings highlight the potential of flexible service integration as an effective lever for improving the environmental sustainability of urban logistics systems.

Keywords: Location-Routing Problem, Last-Mile Delivery, Self-Collection, Adaptive Large Neighborhood Search, Environmental Sustainability

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Abstract ID: ODS-103 Session: S06

General model and simulation of a complex production or service system

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Let us consider a generic complex production or service system. Such a system accepts from the environment incoming entities (customers requiring services, raw materials or semi-finished products to be processed, data to be analyzed) and generates required final entities. Incoming entities are subject to operations transforming them into successive intermediate entities according to predefined plans; some final entities may be obtained through different alternative operation sequences.

Some operations may be executed only if given human or technical resources are seized at the starting time or later and released at the end time or before it; other operations require consumed resources.

At a further abstraction level, an operation may be defined as an autonomous activity, executed according to a common predefined scheme and completed once started. Every operation absorbs entities and resources and generates produced entities and released resources. Absorbed entities are generated by preceding operations and produced ones are ready for subsequent operations; resources are exchanged with resource stores whose availability changes in time.

Every operation is characterized by starting conditions, required resources, duration functions and sequent operations. Such a way, any system is structurally described by all its operations, constituting its fundamental operational units, and functionally described by the evolution of resource stores.

The resulting abstraction naturally supports discrete-event simulation implementations and is independent from the considered system and adopted simulation software, where every operation becomes a parametrized version of the same subroutine. Applications in health, industrial and transport systems were successfully tested.

Keywords: discrete-event simulation, complex systems, process modeling, resource allocation

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Heuristic Frameworks for Integrated Timetabling and Vehicle Scheduling in Mixed-Fleet Public Transport

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Timetabling and vehicle scheduling are two closely interconnected problems in public transport planning, whose joint treatment becomes particularly challenging when the fleet includes both electric and conventional buses. In this context, vehicle scheduling decisions must account not only for standard trip compatibility constraints, but also for additional operational features arising from the use of electric vehicles, such as limited battery autonomy, charging times, and charging infrastructure capacity (see e.g., [2]). In this work, we address the Integrated Timetabling and Vehicle Scheduling problem by jointly selecting a subset of potential trips and constructing a feasible vehicle schedule, with the aim of balancing users' satisfaction and service provider cost. The objective function combines penalties associated with deviations from ideal headways and operating costs related to fleet usage, pull-in/pull-out activities, excess waiting times, and CO_2 emissions.

Two heuristic frameworks are proposed. The first consists of a sequential procedure, in which the timetabling problem is addressed first and the vehicle scheduling problem is then solved for the trips selected in the timetabling phase. The second consists of an integrated procedure, in which both decision levels are addressed jointly. In both approaches, the timetabling component is modeled through a compact graph-based formulation (see [1]), while the vehicle scheduling component is represented as a set partitioning problem and solved within a column generation framework. Additionally, we assessed the performance of each approach when transit lines were solved independently with shared resources, and when all transit lines were solved jointly. The proposed methods are computationally evaluated on real-world instances from the MINOA Challenge Professional. The results highlight the trade-offs between the sequential and integrated approaches with respect to solution quality, computational effort, fleet usage, and timetable regularity.

Keywords: Public Transport, Electric Vehicle Scheduling, Heuristic Algorithm

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Integrated Optimization of Railway Predictive Maintenance with Structural and Economic Dependencies

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Maintenance of railway infrastructure is critical for safe and reliable operations, yet most existing approaches assume independent components and focus on replacement-only strategies, limiting their applicability in complex railway systems. This paper proposes a mixed-integer linear programming (MILP) model for multi-component railway predictive maintenance that explicitly incorporates structural and economic dependencies. The model captures realistic operations by allowing multiple intervention levels and modeling disassembly precedence relationships between components. A condition-based deterioration process is represented using renewal age and effective maintenance age, with nonlinear degradation approximated via convex piecewise-linear functions to ensure tractability. The model integrates labor and equipment constraints, enabling coordinated planning across multiple segments and time periods. Computational results demonstrate improved realism and cost efficiency, highlighting the importance of structural dependencies and multi-level interventions.

Keywords: Railway Infrastructure, Predictive Maintenance, Structural and Economic Dependencies

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Modeling delays induced by congestion in human-picker-to-part systems

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Order picking is one of the most labor-intensive activities in warehouse operations, especially in picker-to-part systems where human operators move through shared picking areas. Classical optimization models for order batching and picker routing usually assume independent picker movements, although congestion may generate delays and alter the execution of planned tours. This work addresses this limitation by proposing a modelling framework for delays induced by congestion in multi-picker warehouse operations.

We define congestion through a speed proportion function that links picker density in a given space to travel speed of the pickers in this space. Based on this representation, we develop a discrete-event algorithm to exactly evaluate the delays experienced by a set of pickers following predefined tours. Since this exact evaluation is difficult to embed directly into optimization models, we introduce three linear approximations based on a time discretization of picker density.

The proposed approach is applied to the Joint Order Batching and Picker Routing Problem, a well-known problem in warehousing. The methodology makes it possible to account for interactions between simultaneous picking tours within a compact mixed-integer linear programming framework. It therefore provides an optimization model that aim at minimizing total time including delays induced by congestion.

Keywords: Warehouse operations, order picking, picker routing, order batching, congestion, mixed-integer linear programming

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New valid inequalities and sensitivity analysis for the Flex Route Transit problem

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The Flex Route Transit (FRT) problem has been formalised two decades ago as a hybrid public transport problem with the following characteristics:

- One or more shuttles perform trips on a predefined route with fixed stops and an associated timetable for departure times.
- The customers can either use the predefined fixed stops or request to be picked up (from a specific moment onward), dropped off or both at specific, on-demand stops, within a max distance from the base route.
- An additional *slack time*, defined as the difference between the earliest possible arrival time and the predefined departure time at fixed stops, is used for route deviation in order to handle the customers with on-demand requests.
- Given the limited available slack time between fixed stops, the shuttle cannot always pick up customers as soon as they are available, so we need to assign customers to a specific shuttle trip.
- The objective function consist in balancing the total shuttle travel distance, the customers total riding time and their total waiting time.

The problem has been tackled through MILP models or, for more recent extensions, through meta-heuristic approaches. MILPs tend to suffer from the presence of big-M constraints used to link, e.g., the routing variables to the waiting time variables, yielding very low lower bounds for the linear relaxation. We propose specific valid inequalities designed to circumvent this problem, coupled with a simple warm start procedure. We quantify the improvements of such inequalities and demonstrate their efficiency on a set of benchmark instances.

Using our improved MILP formulation, we perform an extensive sensitivity analysis over some of the problem parameters. While all other existing sensitivity analysis use the one factor at a time method, we use a more sophisticated ANOVA (analysis of variance) method which underlines the weakness of varying only one parameter at a time to quantify the system reaction to a change in parameters.

Keywords: on-demand transportation, hybrid public transport, valid inequalities

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Abstract ID: ODS-073 Session: S06

Optimal routing and scheduling in a multi-rollin classification yard of railway marshaling stations

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Railway marshaling stations are key components of freight transportation systems. These stations include yards with different functions. In particular, classification yards reclassify inbound trains into outbound trains and may operate as single- or multi-rollin yards. In multi-rollin yards, routing and scheduling of operations, including roll-in, pull-back, and pull-out operations, must be coordinated to avoid resource conflicts, support train formation, and facilitate future operations. Here, pull-back refers to repositioning railcars from classification tracks back to the hump, which may conflict with roll-in operations because of shared track resources. Such operation coordination has received limited attention. This paper addresses this gap through a rolling horizon approach that solves a sequence of consecutive stage problems, where each stage (typically covering 3-4 hours) is formulated as an individual optimization model. Temporal dependencies between stages are explicitly considered, while at most one pull-back is allowed for each railcar in a stage. At the start of each stage, the need for pull-back operations is evaluated based on railcar positions and connection requirements, and feasible pull-back schemes specifying which railcars are to be pulled back within the current stage are generated. A scheme is then selected using a heuristic rule. Given the selected scheme, a mixed-integer linear programming model is solved to determine routing and scheduling decisions. The model incorporates microscopic railcar movements, assembly constraints, and operational requirements. Its objective is to minimize the weighted sum of outbound train delays, track utilization, and assembly conflicts associated with undispatched railcars. After solving the model, feasibility determines whether the solution is accepted or a backtracking is invoked to revise the selected scheme. Computational experiments demonstrate the effectiveness and efficiency of the proposed approach.

Keywords: Railway marshaling station; Multi-rollin classification yards; Routing and scheduling; Pull-back

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Abstract ID: ODS-010 Session: S06

Optimised emergency flight landing plan under disruptive airspace events

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This study develops an optimisation framework for emergency rerouting and safe landing allocation of en-route aircraft during disruptive crisis, such as volcanic eruptions, terrorist attacks or other major unexpected events that cause sudden closures of large portions of the airspace. The objective is to support air traffic management with an automated decision tool that accounts for safety, fuel feasibility, and operational constraints across a wide affected region.

The problem is formulated as a MILP model that, differently from previous approaches ([1], [2]), introduces multiple decision criteria and prioritises them in a hierarchical way. Geographical feasibility and fuel availability are enforced first, ensuring flights within the closed airspace are explicitly prioritised. Then safe-routing reallocation is performed to avoid intersection with closed sectors whenever possible. Finally, aircraft-airport compatibility and operator-based preferences are then incorporated to improve recovery quality.

The model is tested on a simulated disruptive event on the 19th of July 2019, centred in Catania and affecting the surrounding 550 km area, which covers 59 airports. Our test show that in negligible computation time (0.19 sec) the model is capable of successfully solve the problem. In the solution provided, among 2,831 impacted flights, 2,501 were cancelled or grounded and 260 were managed while airborne. In particular, 18 aircraft required emergency landings within the affected area due to fuel restrictions, while the remaining 242 were landed outside the critical zone. Of these latter, 159 were successfully re-directed according to operators preferences. Future developments should consider extending the management of airspace capacity, including dynamic capacity adjustments, sector reconfiguration, and coordination with neighbouring air navigation service providers.

Keywords: air traffic management, emergency rerouting, resilience, mixed-integer linear programming, safe landing, no-fly zones, disruption recovery

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Abstract ID: ODS-054 Session: S06

Optimizing Freight Distribution through Integrated Transportation and Sponsored Search Models

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By merging transportation optimization with sponsored search advertising, this study addresses freight distribution inefficiencies within retail networks. Our multi-objective framework simultaneously minimizes operational costs and underutilization while driving sales through targeted advertising. Using an adaptive NSGA-III approach, we provide robust solutions even under demand uncertainty. The findings confirm that synchronizing logistics and marketing materially improves vehicle utilization and decision-making efficiency.

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

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Optimizing the energy consumption of a metro line system by exploiting regenerative braking

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Sustainability in public transport is one of the trending topics in the optimization community. With the recent threats on resources availability and increases in the prices of energy, it is crucial to make the most out of the available supplies. Recent advances in the railways sector, such as the development of automatically driven (ATO) trains, open the field to new possibilities for reducing the energy consumption of electrical trains. At the single train level, dedicated software is able to compute efficient speed profiles that minimize the energy consumption and ATO trains have the capability of implementing such speed profiles. At the global line level, energy consumption can be reduced by exploiting the regenerative braking power. In fact, the trains are fed from the electricity provider via a third electrified rail. While the current can flow across this rail and be transferred to the trains, it cannot be sent back to the main grid. In addition, providing the infrastructure with batteries to store power has not yet been proven to be a fruitful investment. Hence, either the energy released by braking trains is dissipated in the resistors, or it is converted into power and fed, via the third rail, to accelerating trains that are electrically connected to the braking train ([1],[2]).

In this work we want to present a novel model that combines these two optimizations: by exploiting a set of pre-computed optimal speed profiles, we aim at optimizing the energy consumption at the dispatching level by modifying the departure times and the speed profiles of the trains, thus affecting also the running times. The result is a multi-objective linear programming model, where the goal of not incurring in high delays competes with the goal of minimizing the energy consumption.

The model has been developed under the DSH2.0 project and tested on realistic instances based on the Berliner Tor - Aumuhle S-Bahn line in Hamburg city.

Keywords: Energy optimization, Multi-objective, Train Dispatching

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Partitioning a Large Freight Railway Network into Connected Regions for Train Dispatching: A Hybrid Optimization Approach

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Computational performance is a critical aspect of optimal train dispatching software, as it determines whether an optimal, or near-optimal, schedule can be produced within the required time limits. This issue becomes particularly challenging on large-scale networks, where the number of trains and the size of the infrastructure may make the dispatching problem excessively complex to be solved by the dispatching algorithm. One way to reduce this complexity is to decompose the problem by partitioning the network into smaller components, or regions, and running the dispatching algorithm on each of them individually. In real-world scenarios, each region would fall under the supervision of a dispatching center; therefore, they must be defined to satisfy specific requirements established by the infrastructure manager or other stakeholders. Although the k-partitioning of graphs has been widely studied in the literature, fewer contributions address the case in which the graph represents a railway infrastructure and must comply with external requirements. This paper presents a hybrid pipeline integrating heuristic and exact methods to partition a large railway network into k connected regions. The core of the pipeline is an integer linear optimization program for the k-partitioning problem where the connectivity of each region is ensured through a branch-and-cut solving technique. The objective function is twofold: *(i)* to balance the complexity of the regions as evenly as possible, and *(ii)* to minimize the complexity at region boundaries. The proposed metrics of complexity capture those factors affecting the computational effort required during the subsequent optimal scheduling phase. It includes both static infrastructure characteristics and dynamic traffic-related features. Results from applying the proposed pipeline to a real-world railway network show that a solution satisfying all the requirements can be generated within a few hours.

Keywords: integer linear programming, graph partitioning, railway networks

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Robust line planning under disruptions and recovering bus service

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Temporary Capacity Restrictions (TCR) can often occur in railway networks, leading to inefficient services and excessive recovery costs. The existing literature treats the problem with static disruptions by arranging a bus-bridging recovery mode, which locally replicates the disrupted train routes, without considering uncertainty in the disruption. However, uncertainty in the disrupted portion of the railway has been taken into account, without any bridging emergency mode, in the design of robust lines with respect to passenger coverage. In this work, we consider both uncertainty in the disrupted portion of the network and a recovering service designed to cooperate with the operational part of the railway, thus exploiting the network structure of both the primary and alternative modes. We develop an adjustable robust optimization model, where the here-and-now decisions concern the railway line planning and the wait-and-see decisions comprise the recovering bus line planning and the partial replanning of the railway lines after disruption. Thanks to new modelling choices, we can reformulate the problem as a (single-level) MIP because of the finite number of scenarios. We have run preliminary tests within the activities of the REPLACE project (Infrastructure Investments for Optimal Rail REPLACEment Bus Services), concerning the use case of the Oslo-Ski-Sarpsborg corridor of the Norwegian public railway system. Results are promising, as the problem appears tractable for networks of practical interest.

Keywords: Adjustable Robustness, finite recourse problem, flow-based line planning

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Rule-based and Bayesian-learning Hybrid Heuristics for Passenger Railway Scheduling

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Railway scheduling problems are becoming increasingly complex as operators seek to improve resource efficiency while maintaining service reliability and passenger experience. In practice, real-world train unit scheduling and crew scheduling involve large-scale networks, tight temporal constraints, and operational feasibility rules that make exact optimisation difficult to apply at scale. This research introduces a rule-based and a Bayesian-learning hybrid heuristics within an Activate-and-Generate (A&G) framework for large-scale passenger railway scheduling.

The approach builds on a hybrid heuristic framework, in which the full problem is decomposed into a sequence of smaller, dynamically constructed sub-instances by selectively activating subsets of decision variables. The rule-based scanning variant categorizes the components based on predefined rules, while a Bayesian-based variant incorporates adaptive learning that learns component usefulness from previous search outcomes to iteratively improve solutions. A Beta-Bernoulli model is used to estimate the likelihood that a candidate component is selected in promising subproblem solutions once activated. At each iteration, observed optimisation outcomes are used to update posterior beliefs, and activation decisions are then guided by Thompson Sampling, where components are selected according to samples drawn from their posterior distributions.

The framework is tested on sequential train unit and driver scheduling, and on integrated train unit and driver scheduling. Computational experiments on synthetic and real-world UK railway instances show that integrated scheduling generally reduces total cost compared with sequential scheduling. The results also indicate that the relative performance of two variants is instance dependent. Rule-based scanning is highly competitive on instances which have regular structural patterns, whereas Bayesian-learning based shows stronger potential on real-world timetables with less regular structures.

Keywords: Train unit scheduling, Driver scheduling, Integrated railway scheduling, Hybrid heuristics, Bayesian Learning

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Short-term rolling stock scheduling with platform assignment

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In railway systems, passenger demand fluctuations often require short-term adjustments. In planning, mandatory trips, which must be operated, and flexible trips, which may be implemented or canceled, are created, and a rolling stock plan is derived ([1]). In the short-term period (i.e., a few days before operations), extra trips may need to be added to accommodate additional passenger demand and decisions have to be made whether to schedule or cancel the flexible trips. These changes lead to dynamic adjustments to the Rolling Stock Schedule (RSS), which defines the sequence of trips assigned to each train units (TU) and the maintenance appointments. Moreover, to avoid shunting operations, two trips executed consecutively by the same TU must be assigned to the same platform. Therefore, changes to the RSS lead to changes to the Train Platforming Plan (TPP), which determines the assignment of platforms to TUs.

In this work, we address the integrated adjustment of the RSS and TPP. We propose an Integer Linear Programming model and an exact Branch-and-Check (B&C) algorithm to solve it ([2]). The proposed methods are tested on real-world instances of the Chinese high-speed railway system. The results show that the B&C algorithm clearly outperforms solving the integrated model with a general-purpose solver. In addition, comparisons with sequential approaches, where the RSS is first adjusted and the TPP is then defined, highlight the advantages of the fully integrated framework.

Keywords: Rolling Stock Scheduling, Short-term adjustment, Logic-based Benders decomposition

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Synchronized Multimodal Urban Air Mobility

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Urban Air Mobility is an emerging paradigm for developing innovative transport services using manned and unmanned sustainable vehicles, such as drones and air taxis. In the literature, several works address the optimal location of the necessary infrastructure for such a paradigm. However, there is still limited work on efficient routing and scheduling of these innovative vehicles, often with simplifying assumptions that neglect temporal synchronization among them and other critical operational challenges (see, e.g., [1,2]).

In this work, we discuss the progress made on the *Multimodal Urban Air Mobility Problem with Synchronization Constraints*, originally introduced in [3], to address these gaps. More precisely, we propose a non-trivial event-based representation of the problem and develop a new Mixed-Integer Linear Programming formulation. Then, we explore alternative formulations to enable the application of decomposition techniques and to design tailored branch-and-price-and-cut algorithms. Finally, we compare our approaches through an experimental evaluation in which we (i) show that the problem by Golden et al. [2] can be treated as a special case of ours, (ii) assess the efficiency of our methods on their instances, (iii) derive a new set of instances from New York City taxi data [4], and (iv) derive managerial insights.

Keywords: Urban Air Mobility, Mixed-Integer Linear Programming, Exact Methods

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Train Unit Scheduling with Within-Formation Ordering under Platform-Feasible Operations

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In Train unit scheduling problem, platform coupling and decoupling can make a rolling-stock plan circulation-feasible yet station-infeasible: without explicit within-formation orders, a unit needed for a coupling/decoupling operation at platform may be blocked by another unit. We study the Train Unit Scheduling Problem under platform-feasible operations, where train units cannot overtake or be resequenced at platforms unless shunting is explicitly permitted. We propose, to our knowledge, the first fully integrated model for this setting. The model tracks units on a unit-indexed connection network and jointly determines unit movements, coupling/decoupling decisions, and formation positions; each feasible integer solution is therefore interpretable as a blockage-free unit-level schedule under the modelled platform restrictions. For a fixed assignment, active coupling and decoupling decisions induce trip-wise precedence digraphs, while continuation arcs impose pairwise carry-over consistency. We prove that a unit schedule is orderable if and only if these digraphs admit a continuation-consistent family of topological orders, yielding an exact ordering certification test. This ordering certification test for whether a selected schedule solution admits at least one blockage-free ordering witness. We implement this model in TUSOU, an exact branch-and-cut framework with lazy recovery of missing ordering constraints, activated cycle inequalities, and customised orbital branching for breaking unit-label symmetry. Experiments on four real-world-derived TransPennine Express corridor instances show that TUSOU produces certified blockage-free schedules. The Shallow TUSOU strategy solves all instances to zero reported gap and is faster than direct full-model Gurobi baselines on all datasets. Certification rejects 106 of 151 integer solution candidate encounters, confirming that platform orderability must be embedded in optimisation rather than treated as post-processing.

Keywords: Train unit scheduling; Platform-feasible operations; Branch-and-cut; Ordering certification; Orbital branching

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S07 – MachineLearning

Abstract ID: ODS-019 Session: S07

A Multi-Agent LLM-Assisted Genetic Programming Hyper-Heuristic with Knowledge Management for Uncertain Agile Earth Observation Satellite Scheduling

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To better meet the current development demands of space technology, the Uncertain Agile Earth Observation Satellite Scheduling Problem (UAEOSSP) is proposed. UAEOSSP takes into account uncertainties in request profit, resource consumption and task visibility. These uncertainties often make pre-planned schedules suboptimal or infeasible.
To better address UAEOSSP, we develop the Large Language Model-Assisted Genetic Programming Hyper-Heuristic (LLM-GPHH). This framework integrates evolutionary computation with LLM-driven multi-agent systems and includes four dedicated LLM agents. The Evolution Control Agent (ECA) leverages stagnation detection to adjust genetic operators and their corresponding probabilities, balancing exploration and exploitation effectively. The Evolution Guidance Agent (EGA) applies short-term thinking to create new policies. It also uses long-term thinking to extract inherent patterns from accumulated experience for knowledge distillation. The Knowledge Transfer Agent (KTA) enables knowledge migration across diverse scenarios. The Evolution Scheduling Agent (ESA) serves as a meta-scheduler following a four-step Chain-of-Thought reasoning process. The knowledge management structure of LLM-GPHH combines internal and external knowledge bases. This structure supports efficient knowledge management via semantic deduplication and temporal decay mechanisms.

Experimental results from 16 scenarios show that LLM-GPHH outperforms standard GPHH by a notable margin. It achieves performance improvements of 1.1380% in optimal results and 1.4215% in average results. The Wilcoxon rank-sum test verifies this performance advantage at the 95% confidence level. LLM-GPHH boosts model interpretability by integrating learned knowledge into a structured knowledge base, which supports stable generalization to unseen scenarios.

Keywords: Uncertain Agile Earth Observation Satellite Scheduling, Genetic Programming Hyper-Heuristic, Large Language Models, Multi-Agent System, Knowledge Management

Abstract ID: ODS-037 Session: S07

Adversarial Threats in Semi-Supervised Learning: Poisoning TSVM Models

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As Machine Learning becomes increasingly integrated into security-sensitive applications, ensuring resilience against adversarial threats has become a major challenge. Adversarial Machine Learning frameworks model such threats as intentional perturbations crafted to compromise a classifier by manipulating its decision boundary and violating classical statistical assumptions. Transductive Support Vector Machines (TSVM) extend standard SVMs by incorporating unlabeled data and exploiting the geometry of the dataset under the cluster assumption. While offering improved generalization, this approach also exposes new vulnerabilities, as decisions depend on the global distribution of data.

We propose novel poisoning attack schemes specifically tailored to TSVM, where an attacker manipulates unlabeled samples to steer the separating hyperplane. These attacks can be expressed as bilevel optimization problems involving nonconvex and nonsmooth objectives at both levels, solvable through Difference-of-Convex (DC) optimization techniques.

Preliminary experiments show the effectiveness of these adversarial strategies. We also discuss possible countermeasures, highlighting robust TSVM training as a defense mechanism capable of accounting for worst-case perturbations and reinforcing decision boundary stability.

Keywords: Semisupervised Classification, Trasductive Support Vector Machine, Nonconvex-nonsmooth optimization

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Abstract ID: ODS-045 Session: S07

Enhancing Optimization Algorithms with Kernel Density Estimation: a Statistical Learning Strategy for Smarter Metaheuristics

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Metaheuristics are a cornerstone of modern combinatorial optimization, providing high-quality solutions to NP-hard problems within practical time limits. Yet their effectiveness depends crucially on a fundamental question: when should the search stop? Running too long wastes computational effort, while stopping too early may sacrifice solution quality. Effective stopping rules are therefore essential.

Classical stopping criteria are usually resource-based, such as a maximum number of iterations or a time limit, or stagnation-based, stopping after w consecutive non-improving iterations [1]. While intuitive, these rules ignore the actual search dynamics and cannot distinguish true exhaustion of promising regions from temporary plateaus. Probabilistic stopping rules [2] are more informative, but existing approaches often rely on parametric assumptions, such as normal or gamma distributions, and are frequently tailored to specific metaheuristics.

We propose **KDE-STOP**, a nonparametric stopping rule applicable to any metaheuristic. Instead of assuming a parametric model, KDE-STOP uses Kernel Density Estimation to approximate the distribution of objective values observed during the search. Every N_b iterations, the estimate is updated using recent observations. At each subsequent iteration, the method computes the probability p of improving the incumbent $\bar{z}$ by at least a fraction π. The search stops when p falls below a user-defined threshold τ. Because it only requires objective values, KDE-STOP is algorithm-agnostic and easy to integrate.

We tested KDE-STOP on four combinatorial optimization problems from different OR domains, each solved by a different metaheuristic, and compared it with competing stopping rules. Using a bi-objective score combining solution quality and computational savings, KDE-STOP obtained the best average performance on three of the four problems and ranked first on most benchmark instances.

Keywords: Smart Metaheuristics, Statistical Learning, Combinatorial Optimization, Kernel Density Estimation

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Abstract ID: ODS-136 Session: S07

Evaluating Monotonicity Constraints in Machine Learning for Markdown Pricing

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Markdown Optimisation (MO) is the sequential process of reducing the prices of seasonal retail products with the aim of maximising revenue from their sales. The effectiveness of this type of optimisation depends critically on the quality of the underlying demand model according to which the expected outcomes of alternative pricing scenarios are quantified. While predictive accuracy is necessary, it is insufficient without causal validity in respect of the estimated price-demand relationship. Estimating this relationship from historical data is challenging due to price endogeneity and correlated covariates, which may bias the price effect on demand. *Machine Learning* (ML) models are commonly employed in pricing optimisation contexts due to their strong predictive performance. These models may, however, learn spurious price-demand relationships, which may, in turn, lead to suboptimal pricing decisions. One way to improve the estimated price-demand relationship may involve imposing monotonicity constraints whereby economically consistent price-demand relationships are enforced during the ML training process. In this paper, we apply simulation to model demand, so that the true structural effect of price on demand is known. We then perform a direct comparison between monotonicity-constrained and unconstrained ML models in terms of their demand estimation performance at observed prices and under counterfactual price scenarios. Our results indicate that, while monotonicity-constrained models underperform at observed prices, their performance improves significantly for moderate price reductions, whereas the relative gains become negligible at larger price changes.

Abstract ID: ODS-081 Session: S07

Exotic Bayesian Optimization via a weighted Wasserstein Barycenter of Gaussian Processes

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Bayesian Optimization (BO) is a well-known and successfully applied method for the global optimization of black-box, expensive-to-evaluate, and non-convex objective functions. A Gaussian Process (GP) model is typically used to approximate the objective functions depending on the current set of function evaluations, while an acquisition function drives the choice of the next evaluation balancing between exploration and exploitation. On the other hand, real-world applications have called for the extension of this *vanilla* schema, leading to different *exotic* BO algorithms devoted to specific tasks, such as collaborative/federated BO, batch BO, and multi-fidelity BO, which are specifically considered in this study. By exploiting the analogy between Gaussian Distributions and the posterior of a GP, we propose a weighted Wasserstein Barycenter of GPs as a unifying mechanism to implement a unique BO framework addressing the exotic tasks previously mentioned. Indeed, we empirically prove that a task-specific weighting schema in the Wasserstein Barycenter of GPs is sufficient to efficiently solve the associated exotic task through the vanilla algorithm – and the weighted Wasserstein Barycenter of a set of GPs. Finally, we will show that most of the well-known BO acquisition functions can be re-interpreted in statistical terms under the proposed framework. We conclude with some research perspectives arising from our work.

Keywords: Bayesian Optimization, Gaussian Process, Wasserstein distance

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Abstract ID: ODS-052 Session: S07

Learning to Initialise Genetic Algorithms in Bilevel Optimisation: A Reinforcement Learning Approach

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The hybridisation of metaheuristics with reinforcement learning (RL) has emerged as a promising direction for tackling complex optimisation problems [1]. Within genetic algorithms, population initialisation is one of the most critical components [2], yet RL-based initialisation strategies remain largely unexplored for problems with continuous decision variables, particularly in bilevel settings [3]. We propose an RL framework that learns an instance-conditioned policy, parameterised by a graph attention network, that maps problem-specific features to probability distributions over the leader's continuous decision variables. This enables informed sampling of high-quality initial populations, biasing the genetic algorithm's search toward promising regions of the solution space and reducing reliance on purely random initialisation. The policy is optimised using the REINFORCE algorithm, with rewards derived from the objective values of solutions produced by the policy. We evaluate our approach on two bilevel problem classes: the network pricing problem and the Stackelberg Knapsack Weight Problem, for which we introduce a novel multi-follower extension that increases combinatorial complexity. In both settings, the RL policy is trained exclusively on small-scale instances and deployed, without re-training, on significantly larger and more complex instances. Computational experiments demonstrate that RL-based initialisation consistently outperforms canonical random initialisation, yielding improvements of up to 40% in objective value across both problem classes. These gains transfer to out-of-distribution instances, demonstrating strong generalisation capabilities of the learned policy. The additional computational overhead introduced by the RL policy is negligible relative to the genetic algorithm runtime, making the proposed hybrid metaheuristic a practical and effective approach for bilevel problems where exact solution methods become computationally prohibitive.

Keywords: bilevel optimization, genetic algorithm, reinforcement learning

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Abstract ID: ODS-079 Session: S07

Machine Learning Methods to Forecast Employee Absenteeism in the Service Sector

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Service companies are fundamentally dependent on manual labor and operate on a job-order basis. Employee absences generate additional costs, as compensation is paid for work not performed. Forecasting absences would therefore contribute to a more accurate economic evaluation of individual jobs, while supporting the daily planning of work shifts [1]. In this work, we investigate how to estimate workforce absenteeism in a real-world case study involving a company with over 10,000 employees in the integrated facility services sector. We consider a dataset spanning more than two years of active contracts with daily absence information, and use it to train and test several Machine Learning (ML) algorithms. For each employee, the dataset includes features such as gender, age, contract type, and business unit, differentiated by geographical area and type of service.

We evaluated seven models in two forecasting families: time-series prediction of aggregated absenteeism for all workers in the set (Random Forest, LSTM, LinearSVR, and Amazon Chronos 2 [2]) and per-worker forecasting, with summed individual predictions yielding the total absenteeism forecast (MLP, XGBoost, and GPU-accelerated linear reg.). Models were tested at three horizons: daily with a 1-day lookahead (i.e. forecasting Tuesday from Monday), daily with a 7-day lookahead (i.e. forecasting the following Monday), and weekly, using Mean Absolute Percentage Error (MAPE). XGBoost achieved the best daily and weekly MAPEs (6.5% and 3.1%), while Chronos 2 achieved the best 7-day lookahead performance (5.4%) whose zero-shot architecture removes the need for a dedicated training phase.

In conclusion, the weekly XGB model achieves the lowest MAPE among all combinations. In practice, this aligns well with company management needs, where weekly planning is generally more useful than a day-by-day approach.

Keywords: absenteeism forecasting, machine learning, zero-shot, XGBoost

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Abstract ID: ODS-145 Session: S07

Model-to-Heuristic via Graph Convolutional Neural Networks: A Case Study on Vertex Cover

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Greedy heuristics are a fundamental tool in combinatorial optimization, as they provide simple and scalable procedures for constructing feasible solutions. However, their performance strongly depends on the quality of the selection rule, which is usually handcrafted, problem-specific, and based on domain expertise. In this work, we propose *Model-to-Heuristic*, a methodological scheme in which the selection rule of a greedy algorithm is learned from optimal solutions generated by a mathematical model. Starting from an optimization model of the problem, we generate instances that can be solved to optimality within acceptable computational times. The resulting optimal solutions are then used to derive labels for training a neural network. Once trained, the network is embedded into a greedy procedure and used as a scoring function to guide the construction of feasible solutions. We test the proposed approach on the Minimum Vertex Cover problem. In particular, we train a Graph Convolutional Neural Network on graphs labelled through an integer programming formulation and use the learned model to guide the selection of vertices within a greedy heuristic. Computational experiments on BHOSLIB/FRB benchmark instances show that the learned greedy policy improves upon the classical maximum-degree greedy heuristic and reduces the aggregate gap to the optimum values. The evidence is limited to this benchmark family and baseline, but suggests that optimal solutions produced by exact models on tractable instances can provide useful information for designing learning-guided heuristics.

Abstract ID: ODS-140 Session: S07

PubTables-Complex: A stress-test dataset for evaluating structure-aware tabular extraction

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Standard evaluation datasets for tabular extraction within intelligent document processing, frequently skew toward simple, structurally uniform grids. Consequently, aggregate benchmark scores dilute the impact of extreme topological edge cases, masking the architectural vulnerabilities of state-of-the-art models. To address this benchmarking deficit, this research introduces the *PubTables-Complex* dataset, a targeted 154-table gold-standard stress-test corpus. This dataset is systematically isolated from the one-million-table *PubTables-1M* repository utilising a novel, quantitative complexity scoring mechanism driven by cell mergers, grid dimensionality, and content density. A gradient analysis mathematically justifies a threshold that captures worst-case extraction scenarios without incurring the exponential cost of lower-tier data. To validate the structural challenge of this corpus, four leading tabular extraction models (*TATR, UniTable, Docling, and Azure Document Intelligence*) are benchmarked using standard metrics (TEDS and GriTS). The baseline evaluation exposes severe structural over-segmentation and sequence fragility, demonstrating that current architectures successfully approximate broad visual matrices but frequently fail to maintain the underlying relational sequencing required for semantic utility. The *PubTables-Complex* dataset provides a mathematically rigorous foundation for stress-testing tabular extraction, securing the reliable data pipelines necessary to drive resilient digital operations and advanced decision science.

Abstract ID: ODS-141 Session: S07

Structure-aware metrics for semantic evaluation of tabular extraction

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The quantitative assessment of tabular extraction remains constrained by the limitations of conventional scoring methodologies. While volume-centric approaches, such as *tree edit distance*, provide broad layout comparisons, their application of uniform edit costs renders them mathematically insensitive to the cascading semantic damage induced by complex topological misinterpretations. To rectify this benchmarking deficit, this study introduces a structure-aware metric suite comprising Topology F_1 and aligned grid accuracy. By decoupling relative logical adjacency from rigid spatial coordinates, these instruments facilitate the rigorous measurement of true relational fidelity. To validate these metrics empirically, leading tabular extraction architectures (*TATR*, *UniTable*, *Docling*, and *Azure Document Intelligence*) are evaluated against the *PubTables-Complex* stress-test corpus. The resulting analysis indicates an illusion of semantic recovery: contemporary models frequently optimise for visual matrix alignment while simultaneously dismantling internal data hierarchies. Notably, architectures that demonstrate high geometric similarity on baseline metrics exhibit substantial relational sequencing degradations of up to 0.31 when evaluated under the proposed suite, underscoring the necessity of these novel protocols for measuring actual downstream data utility.

S08 – Non-linear optimization

Abstract ID: ODS-139 Session: S08

A Generalized Network Game with Shared Eigenvector Centrality Constraints

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The inverse eigenvector centrality problem in a directed graph is to find arc weights that are consistent with a specified target centrality profile. It is well-known that this problem may have an infinite number of solutions for any given centrality profile. To select an arc weight configuration, we propose a generalized Nash equilibrium problem on the network, where each player is a node that chooses the weights of the arcs outgoing from it so that all arc weights are consistent with a specified target eigenvector centrality profile. We prove that the proposed model is a generalized potential game and investigate the existence and uniqueness of its variational equilibria.

Abstract ID: ODS-135 Session: S08

Convex Programming Approximations for Co-Skewness Portfolio Optimization

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We propose convex approximations for long-only portfolio optimization problems involving third-order co-moments. The two proposed formulations combine rank-P tensor decompositions of the co-skewness tensor with power-cone representations in order to construct convex approximations of such third-order comoments in portfolio selection. An in-sample empirical analysis on two real-world datasets shows that both formulations provide accurate approximations of the portfolio third-order co-moment, with high agreement measures between the realized and model-implied quantities. In particular, one of the formulations exhibits an almost linear relationship with the realized third moment and yields more stable and diversified portfolio allocations across datasets. These results suggest that the proposed convex programming formulations provide a promising framework for higher-moment portfolio optimization.

Abstract ID: ODS-109 Session: S08

DC Optimization Approaches for Sparse Data Poisoning of Spherical Classifiers

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Data poisoning in adversarial machine learning poses severe security risks by strategically modifying training data to manipulate subsequent model behavior. We consider the vulnerability of binary spherical classifiers to geometric shift. In particular, we investigate a clean-label center-displacement poisoning attack aimed at maximizing the displacement of the sphere center, while keeping the radius fixed to its optimal value, ensuring that the corrupted model retains high training accuracy on the perturbed dataset. Furthermore, to ensure the stealthiness of the attack, individual perturbations are structurally restricted via local L_2-norm bounds.

To optimize the attack, we embed the selection of instances to be poisoned directly into the continuous model. Rather than relying on combinatorial binary variables, we propose two distinct formulations based on sparse optimization. The first approach uses an L_1-norm regularization to promote sparsity in the choice of poisoned instances. The second approach models the exact L_0-norm cardinality constraint continuously by means of the difference between the L_1-norm and the vector k-norm (i.e., the sum of the k largest unsigned component of a vector). The resulting nonconvex program is turned into an exact penalty minimization problem that yields a Difference of Convex (DC) objective over a convex feasible set. This structure allows to adopt the classical Difference of Convex Algorithm, where at each iteration, by linearizing the smooth component of the DC decomposition, the nonsmoothness of the penalty terms is efficiently resolved via auxiliary variables. This reduces the problem to a sequence of smooth, convex Quadratically Constrained Quadratic Programs. Numerical experiments illustrate the behavior of the proposed approaches.

Keywords: Adversarial learning, Poisoning attack, DC programming

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Abstract ID: ODS-091 Session: S08

Inducing Augmented Tchebycheff Scalarizing Functions from Decision Maker Preferences

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Recent literature on Tchebycheff-based interactive multi-objective optimization focuses on incorporating the decision maker preferences. In particular, [1] proposes an iterative and interactive procedure for multi-objective integer programming in which the search progressively converges toward the most preferred nondominated solutions according to a distance-based preference function. In the same stream of reserch [2] further improves the method by addressing cases of equal preferences and by generalising the distance metric via an α-parameter, making the procedure adaptable to different notions of distance.

Working in this research stream, we propose a model to induce the parameters of an augmented Tchebycheff scalarising function from decision maker preferences expressed through pairwise comparisons. The model is embedded in an iterative search procedure that uses mixed-integer linear programming to estimate parameters and guide exploration of the solution space. Computational experiments on classical multiobjective optimisation problems illustrate the effectiveness of the proposed approach.

Keywords: Multiobjective Optimization, Decision Maker Preferences , Interactive Algorithms

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Abstract ID: ODS-001 Session: S08

On the approximability of the balanced minimum evolution problem

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Keywords: Network design, Approximation Algorithm, Combinatorial Optimization

Consider a set $\Gamma = \{1, 2, \ldots, n\}$ of $n \geq 3$ items and let $\{d_{ij}\}$ be a *dissimilarity* matrix on Γ, i.e., a symmetric matrix with all diagonal entries equal to 0 and nonnegative off-diagonal entries. An *Unrooted Binary Tree* (UBT) T on Γ is a tree having Γ as its leaf-set and internal vertices of degree 3. Let τ_{ij} denote the number of edges on the unique path P_{ij}^T in the UBT T between items i and j. Then, the *Balanced Minimum Evolution Problem* (BMEP) seeks a UBT minimizing $\sum_{i\in\Gamma}\sum_{j\in\Gamma,\, j\neq i} d_{ij}2^{-\tau_{ij}}$.

The BMEP arises from the literature on molecular phylogenetics [2]. In this setting, Γ represents a collection of distinct aligned molecular sequences (commonly referred to as *taxa*), such as DNA; $\{d_{ij}\}$ encodes estimated evolutionary distances between pairs of taxa; and a UBT on Γ represents a candidate *phylogeny*, i.e., a tree encoding the evolutionary relationships among the considered taxa. Fiorini and Joret [1] proved that the BMEP is $\mathcal{NP}$-hard, and inapproximable within any factor c^n, for some constant $c > 1$, unless $\mathcal{P} = \mathcal{NP}$.

First, we show that when the input matrix $\{d_{ij}\}$ satisfies $d_{ij} = w(P_{ij}^T)$, for every $i, j \in \Gamma$, where T is any tree with leaf-set Γ and edge-weights w, then every UBT obtained as a binary refinement of T is an optimal solution for the BMEP.

Second, we show that when all pairwise distances are strictly positive and confined within a prescribed interval, the problem admits a polynomial-time approximation algorithm, whose performance guarantee depends on the width of this interval.

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S09 – Optimization under Uncertainty

Abstract ID: ODS-032 Session: S09

A novel L-shaped refinement chain cuts method for two-stage stochastic programs

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L-shaped decomposition is a widely adopted strategy for solving large-scale two-stage stochastic programming problems, where a relaxed version of the original problem is repeatedly solved by incorporating Benders feasibility and optimality cuts. A key drawback of this approach is the need to generate a Benders cut for each individual scenario, which significantly increases the computational complexity.

To address this issue, in this work we propose a novel method, called the *L-shaped refinement chain cuts method*, which integrates the concept of refinement chain of scenarios introduced in [2] into L-shaped framework (see [1]). In this approach, at each level of the refinement chain, the full set of scenarios is partitioned into subgroups, and optimality cuts are generated based on the corresponding group subproblems. Under this formulation, we prove that, at each level of the refinement chain, the proposed method converges to the optimal solution of the original two-stage stochastic program. Moreover, we derive theoretical relationships between optimality cuts at consecutive levels of the refinement chain. This result enables the design of an iterative algorithm that solves the relaxed problem at a given level while incorporating optimality cuts obtained at the previous level of the refinement chain. To evaluate the effectiveness of the proposed approach, we apply the method to a two-stage stochastic multicommodity network design problem under a mean-risk formulation. Numerical results demonstrate promising performance and computational advantages compared to standard L-shaped approaches.

Overall, this work advances the stochastic programming literature by introducing a novel L-shaped refinement chain method that enhances the methodological flexibility of the L-shaped framework while preserving convergence guarantees and exploiting structural relationships across refinement chain levels to improve computational efficiency.

Keywords: Two-stage stochastic programming, L-shaped decomposition, Refinement chain, Network design

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Abstract ID: ODS-157 Session: S09

A Refinement Procedure for Locally Optimal Solutions to the Quantization Problem

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This paper investigates the local optimality of solutions to the classical quantization problem and its regularized counterpart, namely the soft-quantization problem. We introduce a refinement procedure to improve local optimal configurations obtained by the stochastic gradient descent algorithm. The method is based on a separating metric that promotes a more uniform spatial distribution by redistributing points to better approximate the underlying probability measure. Preliminary results on a two-dimensional quantization problem with a uniform distribution show that the proposed refinement procedure improves the quality of the solutions. These findings suggest that the separating metric provides an effective tool for enhancing quantization solutions and may offer promising directions for further theoretical investigations and practical applications.

Abstract ID: ODS-058 Session: S09

Bounds for multi-horizon stochastic optimization with application to power generation and transmission expansion planning

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This work investigates computationally efficient methods for deriving bounds on the optimal value of multi-horizon stochastic optimization problems, with a particular focus on applications in power generation and transmission expansion planning. Multi-horizon stochastic programs capture sequential decision-making under uncertainty across multiple time scales—e.g., strategic (long-term) and operational (short-term)—jointly. Due to their inherent complexity, especially when uncertainties span several time horizons, solving these problems directly becomes computationally prohibitive. To address this, the paper develops and analyzes various novel bounding techniques, based on the dissection of scenario trees. We investigate systematically dissecting (i) only the operational, (ii) only the strategic, or (iii) both scenario trees simultaneously, and we devise two ways to recombine them to obtain valid bounds. Each method leads to a monotonic chain of inequalities that approximate the optimal value of the original problem from below. One of these methods results in a significantly smaller number of subgroups to recombine in the operational and simultaneous dissections, leading to substantial computational savings. Numerical results on a multi-horizon mixed-integer generation and transmission expansion planning problem show the efficiency of the proposed approach through different dissection and recombination strategies.

Keywords: Multi-Horizon Stochastic Programs, Bounds, Power generation and transmission expansion planning

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Abstract ID: ODS-011 Session: S09

Learning the Follower: A Machine Learning Approach to Bilevel Stochastic Optimization under Partial Observability

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We study a dynamic donation problem in retail settings where a decision maker repeatedly allocates excess inventory to a receiving agent. A key challenge is that the agent's acceptance behavior depends on an exogenous donation demand which is not observable by the leader. As a result, the leader must make decisions under partial information, inferring the underlying state of the system only through observed accept/reject outcomes. This naturally leads to a stochastic bilevel optimization problem in which the leader's decisions influence the follower's response over time, while the true state driving such responses remains hidden. To address this issue, we propose a machine learning-based approximation of the bilevel problem. We learn the follower's acceptance behavior from data generated by an oracle model with perfect information and embed the resulting predictive model into a scenario-based stochastic optimization framework. We consider both parametric (linear regression) and non-parametric (lookup table) representations, including a time-dependent lookup structure that captures the joint effect of system state, decision level, and time. The proposed approach enables tractable decision making under partial observability while preserving the endogenous interaction between decisions and acceptance dynamics. The results emphasize the value of learning under partial observability for effective dynamic decision making.

Keywords: Bilevel Optimization, Multi-stage stochastic, Machine Learning

Abstract ID: ODS-026 Session: S09

Multi-horizon optimization for domestic renewable energy system design under uncertainty

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In this talk we address the challenge of designing optimal domestic renewable energy systems (RES) under multiple sources of uncertainty appearing at different time scales. Long-term uncertainties, such as investment and maintenance costs of different technologies, are combined with short-term uncertainties, including solar radiation, electricity prices, and uncontrolled and static load types. We formulate the problem as a multistage multi-horizon (MH) stochastic Mixed Integer Linear Programming (MILP) model. It integrates long-term investment decisions, such as the technology type and capacity of photovoltaic panels and battery energy storage systems, with short-term operational decisions at an hourly level, including energy dispatch, grid exchanges, and supply of a variety of load types. To ensure robust operation under extreme scenarios, first- and second-order stochastic dominance risk-averse measures are considered preserving the coherency and time consistency of the solution. Given the computational complexity of solving the stochastic MH MILP for large instances, a rolling horizon-based matheuristic algorithm is considered. Additionally, various lower-bound strategies are explored, including wait-and-see schemes, expected value approximations, multistage grouping and clustering schemes. An extensive computational experiment validates the effectiveness of the proposed approach on a case study based on a building complex in South Germany. We tackle models with over 43 million constraints and 12 million binary, 700 integer and 10 million continuous variables, solved with up to 0.32% optimality gap in reasonable computing time.

Keywords: Domestic renewable energy systems; Multi-horizon stochastic optimization; Stochastic dominance; Matheuristics

Abstract ID: ODS-053 Session: S09

Neural Network Surrogates for Multi-Horizon Stochastic Programming: an application to energy system planning

Enza Messina, Hongyu Zhang, Gabriele Sormani,
Alan King, Francesca Maggioni

In this talk we propose a machine learning based framework for solving Multi-Horizon Stochastic Programming (MHSP) problems, a class of multistage stochastic programs designed to handle uncertainty across multiple timescales simultaneously. The core methodological contribution is the embedding of a trained feed-forward neural network as a surrogate for computationally expensive operational recourse subproblems, effectively decoupling scenario complexity from the online optimization phase. To assess the practical viability of the proposed framework, we discuss an experimental case study on a power system investment planning problem, involving investment decisions over a portfolio of generation and storage technologies under both short-term uncertainty, related to wind and solar availability and hourly demand profiles, and long-term uncertainty, related to demand growth and CO_2 budgets. We investigated the trade-off between approximation accuracy, computational efficiency, and solution robustness across multiple network architectures and scenario set sizes, comparing surrogate-based solutions against the deterministic equivalent in terms of scalability, in-sample stability, and out-of-sample generalization. Results suggest that a moderately sized network architecture achieves the best balance between fitting the recourse function accurately and producing investment decisions that remain robust under unseen operational conditions.

Abstract ID: ODS-120 Session: S09

Random spatial price equilibrium control problem and its stochastic inverse variational formulation

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It has been established in [1] that the price formulation of the random spatial price equilibrium problem can be equivalently reformulated and investigated through stochastic variational inequalities. Nevertheless, in certain applications, regulatory policies may be introduced with the aim of controlling production and consumption quantities. In such cases, the problem naturally extends to a random spatial price equilibrium control framework, which can be represented in the form of a stochastic inverse variational inequality. The existence of optimal solutions is then analyzed.

S10 – Preferences, teaching, music and behavioral/financial optimization

Abstract ID: ODS-104 Session: S10

Multi-objective optimization and graph-based algorithms for *rich* fingering of monophonic melodies on fretted instruments

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The term fingering refers to the selection of fingers used to perform a musical passage on a specific instrument. Finding an effective fingering is crucial both for expressive purposes and for minimizing the performer's physical effort. As a result, automatic fingering generation has become a standard feature in modern music notation software, although existing approaches fail to account for the many conflicting criteria involved.

In this work, we study the multi-objective optimization problem of automatically generating fingerings for monophonic melodies to be played on fretted string instruments such as the guitar, aiming to minimize hand and finger movements along and across the fretboard, as well as maximize performer comfort by reducing excessive hand stretching and avoiding undesirable positions. We then extend the problem by incorporating expressive articulations and timbre-related preferences, thereby introducing the additional goal of maximizing the timbral quality of the performance. For both problem variants, we develop a Mixed-Integer Linear Programming (MILP) formulation and an equivalent, yet computationally more efficient, shortest-path approach defined on a tailored graph structure. The multi-objective nature of the problem is addressed through several a priori and a posteriori scalarization techniques, including weighted-sum, ϵ-constraint, and lexicographic methods. These approaches are evaluated on both randomly generated and existing melodies under different parameter configurations.

Preliminary results demonstrate the quality and scalability of the proposed methods and shed light on the intrinsic trade-offs between performer comfort, movement efficiency, and desired timbral quality. Moreover, the high configurability of the framework makes it a promising decision-support tool for applications in instrumental pedagogy, assisted composition and arranging, and computational models of expressive music performance.

Keywords: Automatic fingering, Multi-objective optimization, Shortest Path

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Abstract ID: ODS-132 Session: S10

Optimal Behavioral Strategy Analysis of Liar's Dice with an Asymmetric Die

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This paper extends the analysis, made by Ferguson & Ferguson (1991), of a single-die two-player version of Liar's Dice, by introducing a perturbation parameter λ to the uniform probability distribution of the die's outcome, also correcting a few gaps present in the original proof, which refers to the case $\lambda = 0$. We analyze the perturbed game in terms of behavioral strategies, assuming that λ is sufficiently small such that the core structure of the optimal strategies remains topologically equivalent to that obtained in the analysis of the standard fair-die game. For any λ belonging to a specific closed interval of validity of the analysis, we characterize the optimal (maximin) behavioral strategies of the two players, showing that, in general, they are not unique. However, for any fixed λ, the optimal probabilities of lying/doubting of the two players do not depend on the specific choices of their optimal strategies. Finally, we discuss possible future theoretical and empirical extensions of the analysis.

Abstract ID: ODS-099 Session: S10

Optimization and Problem Solving for TEAching of Mathematics

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Mathematics education is undergoing a significant process of transformation aimed at bringing the discipline closer to its applications. AIRO has been carrying out, for almost 20 years, effective training activities on Applied Mathematics topics, addressed to mathematics teachers and their students in high schools. For this reason, three years ago it established a Thematic Section called OPSTeaM (Optimization and Problem Solving for TEAching of Mathematics), which has so far operated in high schools of eight Italian regions, developing significant experiences through training courses and laboratory-based teaching activities. The approach adopted is that of Problem Modelling and Solving, typical of Operational Research. It is used to present and solve simple decision-making problems, related to transport, traffic, environment, healthcare, and all other socio-economic sectors. Problems and phenomena are modelled through analytical relationships, introducing concepts such as data, variables, equations, inequalities, and functions, leading progressively to the definition of curricular content in a gradual and engaging way for students. Course topics are presented in an alternative way, reversing the traditional teaching approach and reaching curricular concepts and definitions gradually, in an engaging manner. It is also important to guide students to understand the importance of data. In this way topics related to combinatorics and algorithmics can be introduced naturally, within the development of computational thinking required by curricular guidelines. This approach introduces students to topics of great contemporary relevance: Data Science and Machine Learning, as well as Artificial Intelligence and its impact on learning. The OPSTeam experiences have received highly positive feedback from both students and teachers. Building on this experience, AIRO plans to establish seminar-based training activities and dissemination events at regional and/or national level.

Keywords: Problem Solving, Problem Modelling, Teaching of Mathematics

Abstract ID: ODS-016 Session: S10

Optimizing Research Output Selection in the Italian VQR Process

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The Italian Research Quality Evaluation (VQR) 2020–2024 is the main national framework for assessing research performance in Italian academic institutions. Its aim is to identify institutional strengths and weaknesses and to support future strategic planning. The results are also intended to help universities recognize areas of excellence as well as critical issues requiring intervention. Within this framework, universities and departments must select and assign a fixed number of research outputs to their authors under formal constraints. The selected outputs are then subject to peer review. In this study, we focus exclusively on the selection phase, since universities and departments play no role in the subsequent review process.

The problem can be formally defined as follows. Given a set of researchers and publications, the task is to choose a fixed number of ⟨researcher, paper⟩ pairs, subject to lower and upper bounds on the number of papers assigned to each researcher, while ensuring that each paper is selected at most once at the department level and at most twice at the university level. Each pair is associated with a score based on bibliometric indicators related to both the paper and the author, and the objective is to maximize the total score. The evaluation process also includes some exceptions to these rules. In many cases, such exceptions can be handled a priori or incorporated by modifying the right-hand side of the model; however, a full treatment of these cases lies outside the scope of this work.

We prove that this paper selection problem is polynomial-time solvable by reducing it to the capacitated minimum-cost flow problem, and we show that its constraint matrix is totally unimodular.

Keywords: Research Quality Evaluation, VQR, Polynomial Reduction, Computational Complexity, Total Unimodularity

S11 – Quantum Optimization

Abstract ID: ODS-067 Session: S11

An Efficient Variational Quantum Algorithm for Solving the Generalized Assignment Problem

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This work addresses the challenge of solving the Generalized Assignment Problem (GAP)—a complex NP-complete optimization problem—using contemporary Noisy Intermediate-Scale Quantum (NISQ) devices, which are currently limited by low qubit counts and susceptibility to noise. While hybrid quantum-classical algorithms like the Variational Quantum Eigensolver (VQE) [2] are promising, they traditionally require a large number of qubits because every problem variable and slack variable (used to convert inequality constraints into equations) must be mapped to a qubit [1].

To mitigate these hardware limitations, and building on the studies on quantum variational optimization in [3] and [4], we propose VQGAP (Variational Quantum Generalized Assignment Problem), a method that decouples the qubits of the ansatz circuits from the problem's binary variables. With VQGAP, only the core assignment variables are mapped to qubits, while the residual budget variables (slack variables) are managed in the classical component of the hybrid algorithm. This design reduces both quantum circuit width and depth compared to standard VQE approaches. Moreover, some variants leveraging efficient encoding patterns and problem constraints, enable a logarithmic scaling in the required number of qubits, significantly optimizing the use of limited quantum resources.

The proposed method is assessed through experiments on the IBM Aer simulator, under both noiseless and noisy conditions. Preliminary results indicate that VQGAP performs comparably to standard VQE while requiring fewer qubits and shallower circuits. Overall, the proposed algorithm promises to offer a more efficient path for tackling real-world optimization problems on current and near-future quantum hardware [5].

Keywords: Quantum computing, Quantum optimization, General assignment problem

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Abstract ID: ODS-050 Session: S11

Hybrid Quantum Reservoir Computing: Memory and Entanglement for Classification and Forecasting

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We develop hybrid quantum-classical learning architectures based on Quantum Reservoir Computing and Quantum Extreme Learning Machines, addressing both chaotic time-series forecasting and image classification. By exploiting the high-dimensional structure of Hilbert space, these approaches generate expressive nonlinear feature maps while maintaining a simple training scheme restricted to a linear output layer. We introduce memory-augmented designs in which classical post-processing enhances temporal correlations, eliminating the need for repeated coherent input injections and enabling efficient modeling of multivariate dynamical systems. Applied to benchmark tasks—including Mackey–Glass, Lorenz-63, and reduced Navier–Stokes dynamics—our framework achieves extended prediction horizons and robust performance. For image classification, we combine dimensionality reduction, quantum encoding, and evolution under simple spin Hamiltonians, showing that quantum reservoirs systematically improve accuracy. We further identify a transition to high-performance regimes associated with the onset of entanglement. Notably, moderate and short-range entanglement is sufficient to enhance data embedding and separability, without requiring global complexity. These regimes remain compatible with efficient classical simulation. Our results establish hybrid quantum reservoir computing as a practical and scalable framework for enhancing learning performance beyond classical feature maps in near-term quantum settings.

Keywords: Reservoir computing, Quantum computing

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Abstract ID: ODS-123 Session: S11

Hypergraph clustering via quantum optimization

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Clustering is a fundamental task in network analysis and machine learning. By utilizing hypergraphs, we can naturally encode higher-order relationships among data points that standard graphs often miss. Classical approaches typically rely on spectral relaxations of combinatorial optimization problems; while efficient, these methods may lose information due to continuous approximations and rounding procedures. In this work,we propose a direct binary quadratic formulation of the hypergraph clustering problem based on the hypergraph Laplacian. The resulting model is expressed as a Quadratic Unconstrained Binary Optimization (QUBO) problem, making it natively suitable for quantum annealing. We evaluate our approach on six different benchmark datasets, comparing the results against ground truth labels using the Rand Index. Our findings demonstrate that the proposed formulation achieves performance comparable to classical methods on balanced datasets, while maintaining the discrete nature of the optimization problem.

Abstract ID: ODS-059 Session: S11

Quantum optimization based on cutting-plane methodology for the Traveling Salesman Problem

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The Traveling Salesman Problem (TSP) is a classical NP-hard combinatorial optimization problem [1]. A key challenge in its formulation is the exponential number of subtour elimination constraints (SECs). The cutting-plane procedure [2] addresses this issue by iteratively adding only the SECs required to obtain a Hamiltonian tour. Quantum approaches to the TSP include variational quantum algorithms (VQAs) [3] and quantum annealing (QA) [4], where SECs are either explicitly enforced or implicitly encoded through alternative formulations. However, due to current hardware limitations, only very small instances (up to four nodes) have been solved, limiting the practical applicability of these methods. In this work, we integrate the cutting-plane procedure into a QA framework to dynamically manage SECs during the solution process. We focus on the D-Wave platform, considering both direct execution on the quantum processing unit (QPU) and hybrid quantum–classical solvers. The proposed approach reduces the problem size by limiting the number of active constraints at each iteration, enabling the solution of larger instances. We evaluate the method on standard TSP benchmark instances. Our results show that problems with up to 10 nodes can be solved using direct quantum execution on the QPU, and up to 30 nodes using hybrid solvers, improving upon the current state-of-the-art.

Keywords: traveling salesman problem, quantum annealing, hybrid quantum–classical optimization, cutting-plane approach

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Abstract ID: ODS-108 Session: S11

School Network Optimization through innovative approaches: a case study of the Calabria region

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We address the School Network Reorganisation Problem in fragile and peripheral territories affected by demographic decline, limited accessibility, and socio-economic disparities. We propose a multi-criteria optimization model to identify efficient and socially sustainable school network configurations. The model determines which schools remain autonomous institutions and how the others should be aggregated, subject to regulatory, demographic, spatial, and organizational constraints. The objective function accounts for territorial equity by minimizing inter-municipal aggregations, territorial fragmentation, and aggregations involving socio-economically vulnerable areas. The framework integrates administrative school data, georeferenced information, and territorial vulnerability indicators. Computational experiments are conducted on the school network of the Calabria region under different policy scenarios. Results indicate that demographic-based optimization strategies tend to penalize peripheral municipalities, whereas the inclusion of territorial fragility indicators yields more balanced solutions that preserve accessibility and reduce territorial disparities. Current research developments include the integration of quantum optimization techniques to address large-scale and highly constrained school network reorganization problems.

Keywords: School Network Reorganisation, Public Service Optimization, Quantum Optimization

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S12 – Routing

Abstract ID: ODS-060 Session: S12

A Data-Driven State Exploration Policy in Dynamic Programming for ERCSPP

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One of the most successful approaches for solving the Elementary Resource Constrained Shortest Path Problem (ERCSPP) to optimality consists of using a dynamic programming (DP) algorithm combined with an iterative relaxation technique. Decremental State Space Relaxation (DSSR) [1] and *ng-path* relaxation [2] are well-established techniques in this context.

In DP algorithms, an effective policy for selecting the next state to extend among the open ones is crucial for performance.

In preliminary work, we showed that machine learning can be used to identify promising states in DP. In particular, a classifier trained to identify dominated states in a given DSSR iteration can accurately estimate the quality of the states generated in the subsequent iteration.

Building on this idea, we show that it is possible to efficiently integrate such a model into a state-of-the-art DP algorithm for the ERCSPP and use its predictions to define a data-driven state exploration policy, that aims to enhance a classical node-based policy. Although the approach is data-driven, it remains exact and does not require pre-existing training data.

We introduce new features for DP states that perform better than those available in the literature when used within the algorithm. We also propose a simple strategy to decide when to update the models during the solution process.

The algorithm has been implemented in the Pathwyse library [3] and evaluated on a dataset of multi-resource instances. Compared to the standard node-based policy, our approach reduces the number of explored DP states by 37% on average and improves runtime by 20% on sufficiently challenging instances.

Keywords: Data-Driven Optimization, Dynamic Programming, Machine Learning, Exact Methods

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Abstract ID: ODS-087 Session: S12

A new *MILP* Formulation for the Multimode Set Covering Problem

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Classical covering location models aim to guarantee accessibility to facilities while minimizing installation costs. However, these approaches usually assume a single facility type and neglect multi-purpose trips, where users combine different services within the same journey. In many real-world contexts, individuals require simultaneous access to multiple facility types, making the spatial interaction among services important for travel efficiency.

To address this limitation, we introduce the Multimode Set Covering Problem (MSCP), a new optimization framework integrating covering and clustering decisions. The MSCP extends the classical Set Covering Location Problem by considering multiple facility types and promoting compact multi-type service clusters, where cluster compactness is used as a proxy for routing efficiency, helping reduce detours in multi-purpose trips.

We propose two modeling approaches. In the first, each demand node must be covered by at least one facility of every required type within a predefined radius. Facilities also belong to compact service clusters, allowing users to access additional services through the cluster of the facility initially visited. Capacity constraints are enforced at the individual facility level.

The second approach adopts a centroid-based logic. Demand nodes are assigned directly to the closest active cluster centroid representing an integrated service hub, while facilities of different types are associated with the centroid to form the cluster. Accessibility and capacity are managed at the cluster level, leading to a different representation of multi-service trips.

For both formulations, we develop mixed-integer linear programming formulations and branch-and-cut procedures based on dynamically generated capacity inequalities. Computational experiments on realistic datasets show that the proposed approaches improve the spatial organization of services and reduce travel inefficiencies associated with multi-purpose trips.

Keywords: Facility Location, Set Covering, Clustering, Branch-and-Cut

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Abstract ID: ODS-027 Session: S12

A new systematic framework to analyse problem-based fairness in a static and dynamic context

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This work proposes a systematic framework to analyse fairness in optimisation problems where fairness cannot be captured solely by the utility function. The framework combines two complementary approaches: the *utility-based* approach [1] and [2], where the fairness can be harnessed using only the utility, and the *problem-based* approach [3], where the fairness can not be measured by the utility but it focuses on a specific characteristic of the problem.

We apply the framework to the Team Orienteering Problem with Service Times and Mandatory & Incompatible Nodes [4], an extension of the classical Team Orienteering Problem that includes service times, mandatory nodes, and physical and logical incompatibilities. Our analysis considers three stakeholder perspectives: service providers, customers, and workers. These perspectives correspond respectively to balancing route profits, quality of service, and workload through several objective functions specifically designed to guide the optimisation process towards a fair solution.

Computational results show that solutions obtained only considering efficiency can generate substantial unfairness for one or more stakeholders. In contrast, the proposed framework makes it possible to identify alternative solutions that achieve a better balancing between fairness and efficiency. We further extend the analysis to a dynamic setting and show that dynamism significantly increases the difficulty of preserving such a balancing, especially from the customer perspective. Overall, the paper provides a general methodology for systematically studying fairness in complex optimisation problems and illustrates its value in both static and dynamic contexts.

Keywords: fairness, stakeholders, systematic analysis, team orienteering problem

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Abstract ID: ODS-134 Session: S12

An incremental redesign approach towards solving the urban transit routing problem

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In existing models of the *urban transit network design problem*, the unrealistic assumption is usually made that an entire urban transit network should be designed anew or can be redesigned completely. Instead, the operator of such a network may prefer to improve an existing network design incrementally, in phases, in a bid to minimise the disruption that a complete redesign would cause to passengers. In this paper, we propose a novel modelling approach for establishing high-quality transit routes resembling a current reference set of routes to varying degrees, thereby providing a decision maker with transit network route design alternatives that may be implemented incrementally in phases. The objectives pursued are the simultaneous minimisation of the expected average passenger travel time and of a reference-route-to-design-route similarity measure. The model takes as input an origin-destination demand matrix for a specified set of vehicle stops, along with the corresponding road network structure, and a reference route set against which to compare alternative transit network designs in terms of similarity. It provides as output a set of trade-off solutions in terms of the aforementioned objectives.

Abstract ID: ODS-089 Session: S12

An Iterative LP-Based Approach for Joint Route and Departure-Time Optimization in Congested Networks

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Road congestion is shaped not only by route choices but also by departure times. We study a system-optimal route-and-departure assignment problem on a time-expanded highway network with exogenous background traffic. Given origin-destination requests, departure windows and feasible paths, the goal is to assign vehicles to path-departure options so as to minimize total system travel time while keeping local congestion under control.

We formulate a linear programming (LP) model based on discrete time snapshots and a piecewise-linear approximation of travel-time costs. An upper bound on the total flow in each arc time combination prevents unrealistic overloads. To avoid unfair treatment of travelers, we restrict alternatives to paths whose free-flow travel time exceeds that of the shortest path by at most a given threshold.

The formulation relies on estimated travel times, but the resulting assignment changes local congestion and therefore actual travel times, creating a circular dependency. We address this by embedding the LP model in an iterative procedure. Starting from free-flow travel times, each iteration solves the LP, updates travel-time estimates from the induced arc flows, recomputes feasible alternatives, and re-optimizes until the flow assignment and travel-time estimates are mutually consistent.

We test the approach on a realistic Northern Italy highway network over a two-day horizon, with synthetic origin-destination demand and calibrated background traffic. The optimized path-departure patterns consistently outperform earliest-departure and random-departure benchmarks, reducing both total system travel time and demand-weighted inconvenience. In the tested instances, only a few iterations are needed to reach a stable solution, spreading demand across departure times and routes and identifying persistent and time-varying patterns.

Keywords: Dynamic traffic assignment, Route and departure-time optimization, LP-based congestion control

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Abstract ID: ODS-068 Session: S12

Branch and cut algorithms for a Vehicle Routing Split Delivery problem with refilling constraints

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Keywords: Split Delivery, Agriculture, Branch&Cut

In this work, a variant of the Split Delivery Vehicle Routing Problem (SDVRP) arising from a practical application is considered, concerning field fertilization in viticulture. In the problem, a tractor equipped with a fertilizer spreader of limited capacity have to visit a set of fields, each with a known fertilizer demand. The refill of the spreader can only occur at a central depot, where fertilizer (i.e., nitrogen) is stored in discrete units (i.e., bags). The refilling constraints impose that when tank's spreader is empty, a full refill can be performed, by using exactly two bags of fertilizer, while, when the tank is not completely empty, only a partial refill is allowed, and only one fertilizer bag can be used to refill the tank. The rationale behind this refilling policy is that, when a fertilizer bag is open, the fertilizer not immediately used to refill the tank can not be stored and must be discarded.

The problem consists in processing each field possibly by multiple trips, in order to spread fertilizer over all the field. The objective is to design a set of concatenated routes in such a way that the total travel distance is minimized and the refilling constraints are respected.

The problem is modeled as a variant of SDVRP with a single vehicle (i.e., the tractor) that can travel multiple routes starting and ending at the depot, to satisfy the demand of nitrogen of each customer (i.e., field).

Exact Branch & Cut algorithms are proposed, based on the algorithmic framework presented in [1,2], taylored for the specific application. More precisely, (i) a new class of no-good cuts specifically designed for the problem is proposed, and (ii) a new two-edge model tailored for the problem is presented, employed to check whether a feasible solution of a relaxed formulation is also feasible for the problem.

Computational campaigns on real-world instances and on instances from the literature show the effectiveness of the proposed approaches.

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Abstract ID: ODS-055 Session: S12

Dynamic Programming for the Single Picker Routing Problem with Decoupling

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A fundamental problem in warehouse operations management is the routing of pickers who collect items in order to fulfill customer orders. The single-picker routing problem (SPRP) aims to minimize the distance traveled while ensuring all items are collected from designated locations. In many warehouses, pickers use carts to move through the aisles. We consider an extension of the SPRP in which a picker can temporarily leave the cart to collect a limited number of items on foot which is typically faster. The single-picker routing problem with decoupling (SPRP-D) therefore seeks a duration-minimal tour distinguishing between the picker and cart moving together and the picker moving alone. For single-block warehouses, the SPRP can be solved in linear time using dynamic programming [1]. Inspired by this type of model, we present the first dynamic programming formulation of the SPRP-D. If the picker's capacity on the subtours is given and fixed, the new dynamic program can be solved in linear time with respect to the number of aisles and pick positions. Computational experiments show that the dynamic programming approach is several orders of magnitude faster than all known exact solution approaches, which are based on mixed integer linear programming (MIP) models. Using a benchmark set of 800 instances, we empirically quantify the savings obtained by allowing decoupling. Additionally, we evaluate multiple variations of the proposed approach, each characterized by different restrictions when and where a picker may decouple from the cart.

Keywords: routing, dynamic programming, warehousing, picker routing, decoupling, exact algorithms, fixed parameter linear tractable

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Abstract ID: ODS-066 Session: S12

Equity-Aware Last-Mile Routing on Multigraphs

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Last-mile delivery generates high operational costs and uneven social externalities. While classical Vehicle Routing Problem models focus on travel time or distance, we introduce an equity-aware variant that also accounts for population exposure on residential streets.

The problem is defined on a directed multigraph $G = (V, A)$, where each arc $(i, j, p) \in A$ represents an alternative path between two customers, or between a customer and the depot. Each arc has a travel time t^p_{ij} and crosses a subset of residential streets. Given a feasible solution $\bar{x}$, with $\bar{x}^p_{ij} = 1$ if arc (i, j, p) is used and 0 otherwise, the exposure on street r is defined as $z_r(\bar{x}) = \omega_r \sum_{(i,j,p)\in A_r} \bar{x}^p_{ij}$, where ω_r is the population weight and A_r is the set of arcs crossing r. Equity is modeled through the k-sum criterion $\Theta_k(z(x)) = \sum_{h=1}^{k} z_{[h]}(x), x \in \mathcal{X}$, where $\mathcal{X}$ denotes the set of feasible routing solutions and $z_{[h]}(x)$ is the h-th largest component of the exposure vector. This measure, based on compact ordered-sum formulations [1,2], controls the impact on the k most affected streets, bridging worst-case protection and total exposure minimization.

We handle the bi-objective problem through an ϵ-constraint approach, minimizing exposure under a controlled increase in routing time. To solve large instances, we propose a Self-Adjusting Kernel Search variant [3], initialized with a high-quality TS–ALNS solution.

Computational results show that the proposed matheuristic outperforms Gurobi, while real-world tests confirm that large exposure reductions can be obtained with limited routing-time increases.

Keywords: Vehicle Routing Problem, Equity, k-sum optimization, Multigraph, Kernel Search, Last-mile delivery

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Abstract ID: ODS-022 Session: S12

Modeling Network Congestion under Demand Uncertainty Using Wardrop Principles[1]

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We address the problem of determining the worst-case congestion in a multi-commodity traffic network subject to demand uncertainty. The scope is to conduct a traffic management analysis under uncertain travel demands. We assume that the users of the traffic network act according to the Wardrop principles. Hence, the resulting model can be seen as bilevel problems with a single leader and multiple followers. We consider different models of the uncertainty in the travel demands: ellipsoidal uncertainty; budgeted uncertainty; and the hose polyhedron. Single-level mixed-integer nonlinear reformulations of the congestion models are derived and an extensive computational study is performed, considering the Sioux Falls network and networks from the SNDlib. Insights into the impact of different congestion measures and uncertainty models on the resulting worst-case congestion are provided.

Keywords: Traffic networks, Wardrop principles, Bilevel optimization, Mixed-integer nonlinear optimization

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Modelling a Vehicle Routing Problem with Dynamic Requests and Perishable Goods

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In real-world logistics, operational information is rarely fully known in advance. As highlighted in [1], predicting real-world conditions is difficult because many real-world variables are uncertain. A classic example is the retail sector, where customer demands are often split between static requests known in advance and dynamic orders revealed during route execution [2]. In such scenarios, it is necessary to carefully assess whether new service requests can be served within existing operational constraints. Furthermore, given the significant carbon footprint of transportation activities, reducing routing emissions is crucial [3]. This problem becomes even more complex when managing perishable goods, which suffer from gradual quality degradation depending on time and temperature exposure [4]. To address these challenges, we propose a mathematical formulation for a Vehicle Routing Problem with perishable goods and dynamic demands, ensuring that delivered products maintain a strict quality threshold. Specifically, service requests can only be fulfilled if product quality remains above a minimum acceptable level. Building upon the model presented in [5], the proposed formulation aims to minimize unserved requests, environmental impact, and overall routing costs.

Keywords: Dynamic VRP, Perishable Products, Product Quality, Carbon Emissions

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Abstract ID: ODS-111 Session: S12

Solving the Vehicle Routing Problem with Private Fleet and Common Carrier using a bilevel programming approach

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We address the problem of a delivery company that must serve a set of customers located in an urban area by managing a private fleet of vehicles and outsourcing deliveries to a common carrier. Since the carrier operates independently and has its own routing constraints, its rational reaction to the company's offers must be explicitly considered. We model this interaction through a Stackelberg game framework, formulating the problem as a bilevel Vehicle Routing Problem with Private fleet and Common Carrier. At the upper level, the delivery company (leader) minimizes its costs by deciding the optimal bundle of customers to outsource, which dictates a volume-based echelon compensation. At the lower level, the carrier (follower) maximizes its profit by accepting or rejecting the proposed bundle.

To solve the problem, we propose an algorithmic framework based on a Branch-and-Cut procedure applied to the High-Point Relaxation reformulation of the bilevel model. Within this framework, the leader's proposals and the follower's rational reactions are systematically evaluated. Finally, we present and discuss an extensive computational analysis on test instances to evaluate the overall performance of the proposed Branch-and-Cut approach and the impact of different cutting strategies.

Keywords: vehicle routing, common carrier, bilevel optimization

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Abstract ID: ODS-063 Session: S12

The value of monitoring occupation and booking electric recharging stations

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Keywords: Electric Vehicles, Routing, Approximate Dynamic Programming

Electric Vehicles (EVs) represent a viable alternative to traditional combustion vehicles for reducing emissions in the logistics sector. However, a key challenge with EVs is their need for en-route recharging, particularly in mid-haul logistics, where the distances traveled often exceed the driving range of medium-duty EVs. This work addresses the Electric Vehicle Routing Problem with Time Windows (E-VRPTW), which involves a fleet of EVs with limited cargo capacity tasked with serving customers within specified time windows. We consider a stochastic setting, with uncertainty in travel time, energy consumption, and waiting time at recharging stations. This latter source of uncertainty depends on how busy the stations are and can be particularly troublesome when few chargers are available and demand is high. This issue has been addressed by companies operating charge points through digital tools that provide information on station occupancy and, in more advanced cases, allow users to reserve a charging time slot in advance. In this work, we study the economic value of these features using a Markov Decision Process framework and considering three settings: a baseline case with no information on station occupancy, a setting where real-time occupancy levels are available, and a setting where occupancy can be monitored and charging slots can also be reserved. We develop solution methodologies tailored to each setting and compare these configurations in terms of total cost, evaluating all pairwise differences to quantify the economic value of having occupancy information only, of having both information and reservation capabilities, and of operating without any support on station usage.

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S13 – Scheduling

Abstract ID: ODS-023 Session: S13

A Knowledge Transfer-Based Genetic Programming Hyper-Heuristic for Dynamic Task Scheduling of Geostationary Satellites

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To address challenges in dynamic task scheduling for GEO observation satellites—random task arrivals, high environmental uncertainty, and stringent real-time demands—this paper proposes a knowledge transfer-based genetic programming hyper-heuristic algorithm (KT-GPHH). Bursty tasks have unknown arrival times and urgent response windows, making traditional offline scheduling inadequate, while online learning suffers from cold-start and slow convergence.

KT-GPHH integrates evolutionary computation with a knowledge transfer mechanism. It comprises three core modules: a multi-objective GP evolution module generating non-dominated priority heuristics; a two-state heuristic simulation and evaluation module emulating real-time decisions; and a knowledge transfer module that transfers historical knowledge via elitist deduplication, feature contribution extraction, and guided initialization to accelerate convergence. The framework designs 12 feature terminals across four dimensions (task attributes, satellite states, environmental features, coordination features). Non-dominated sorting and crowding distance optimize total profit and total completion time.

Experimental results on 30 dynamic instances show that KT-GPHH significantly outperforms both the version without knowledge transfer and the MO-GPEA algorithm. The Hypervolume metric improves by 8.7% on average, better extreme solutions are obtained in the low completion time region, and convergence speed increases by approximately 40%. The Wilcoxon rank-sum test confirms statistical significance ($p < 0.05$). By mitigating the cold-start problem via knowledge transfer, KT-GPHH provides a robust and efficient solution for online GEO satellite task scheduling.

Keywords: Geostationary Earth orbit satellite, dynamic task scheduling, genetic programming hyper-heuristic, knowledge transfer, multi-objective optimization

Abstract ID: ODS-020 Session: S13

Column Generation for Large Scale LEO Hybrid Constellation Collaborative Scheduling

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This paper investigates large-scale LEO hybrid constellation cross-domain collaborative scheduling, which arises from hybrid constellations combining remote sensing and communication satellites via inter-satellite links (ISL) for global observation data transmission. Unlike conventional constellation scheduling, this problem features two key challenges: the strong coupling between imaging decisions and data routing, and dynamic topology constraints caused by satellite mobility, rendering the problem NP-hard.

To address these challenges, we first propose a Time-Expanded Graph model that transforms the dynamic scheduling problem into a static network flow, enabling efficient shortest-path solving in $O(|V| + |E|)$ time. Based on this, we design a path-based Column Generation (CG) framework to avoid exponential path variable enumeration, and re-solve the resulting integer program with Gurobi for integer recovery. Five acceleration mechanisms are incorporated: A* heuristic pricing for efficient path search, column caching with deduplication to avoid redundant columns, bound-based pruning for selective task re-pricing, parallel pricing using multi-threading, and K-alternative path diversification to enhance solution diversity.

Experiments on real TLE data from Celestrak (Planet Dove and Starlink satellites) with 136 remote sensing and 1,321 communication satellites over a 60-minute planning horizon demonstrate that the proposed approach outperforms baseline algorithms. The LP relaxation yields integer-optimal solutions directly (zero fractional flows), enabling efficient integer recovery without branch-and-price. On 100 tasks, CG achieves zero optimality gap vs. Gurobi, while Gurobi fails due to memory overflow (340M variables). On 796 tasks, CG achieves 73% task completion rate within 49s. Moreover, the performance advantage of CG grows with problem scale, validating its scalability. Ablation confirms A* pricing and pricing filter drive efficiency gains.

Keywords: LEO Hybrid Constellation, Inter-Satellite Link, Collaborative Scheduling, Column Generation

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Abstract ID: ODS-072 Session: S13

Mathematical Models and a Decision Support System for a Multi-Project Scheduling and Staffing Problem

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This study addresses the integrated multi-project scheduling and staffing problem, a critical task in project-based contexts, where heterogeneous human resources are assigned across concurrent projects with the aim of ensuring timely completion, balanced workloads and efficient use of specialized skills.

We model this as a Preemptive Resource-Constrained Multi-Project Scheduling Problem with multi-skilled continuous resources [1]. The model determines (i) each task's schedule and (ii) worker assignment to each task over time. These decisions are subject to precedence constraints, resource limits, and skill compatibility, ensuring all task workloads are met. The objective minimizes a weighted sum of project tardiness, coordination effort measured by the number of workers per task, and penalties for soft constraint violations related to worker and customer preferences.

Given the NP-hard nature of the problem, we propose three mixed integer linear programming (MILP) formulations with different time granularities to balance model accuracy and computational tractability. All models are embedded in a user-friendly web-based Decision Support System (DSS) that integrates data acquisition, optimization, and visualization. Additionally, the DSS includes a rescheduling model to handle disruptions by updating the current plan while limiting deviations.

The approach is validated on real-world instances with up to 100 resources and planning horizons of 18 months. Results show that the weekly granularity achieves the best trade-off between accuracy and computational effort, solving most instances to proven optimality in 5 minutes and confirming the effectiveness of MILP-based methods for real-world scheduling and staffing decisions.

We acknowledge financial support from the European Union – NextGenerationEU, through BI-REX Competence Center and the Italian Ministry of Enterprises and Made in Italy, project PRISMA (CUP C89H25000020001).

Keywords: Project scheduling, Project staffing, Decision Support Systems, Resource Constrained Project Scheduling Problem.

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Abstract ID: ODS-161 Session: S13

Optimizing Predictive Maintenance Scheduling under Remaining Useful Life Constraints through MILP formulations

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The maintenance of complex systems is increasingly relying on predictive frameworks to improve safety and operational efficiency. This paper addresses a predictive maintenance scheduling problem for a set of critical assets, where Remaining Useful Life (RUL) estimations are integrated into the maintenance planning process together with operational constraints, including machine availability windows, limited maintainer capacity, and technological precedence relations. The proposed framework models degradation-related failure risk through time-dependent coefficients associated with the execution time of maintenance interventions. These coefficients are derived from a Gaussian-based representation of the uncertainty affecting the actual RUL of each asset and are used to estimate the expected down time generated by unexpected failures occurring before the planned intervention. The resulting optimization problem simultaneously accounts for intervention earliness, expected unplanned downtime due to failures, and downtime generated by planned maintenance activities through a single weighted objective function. To tackle the problem, we develop two Mixed-Integer Linear Programming formulations: an event-based model and a time-indexed model. Computational experiments are conducted to evaluate the proposed formulations in terms of solution quality and computational tractability.

Abstract ID: ODS-077 Session: S13

Reliable Sub-Tree Scheduling of Wireless Sensor Networks with Partial Coverage

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We introduce and study the *reliable sub-tree scheduling of wireless sensor networks with partial coverage* (Rel-STSWSN-PC). Let $G = (V, E)$ be a graph. Each edge $e \in E$ has k costs $c_e^1, \ldots, c_e^k$, and each vertex $v \in V$ has a *working probability* p_v. Given $0 \leq B \leq 1$, a solution to the Rel-STSWSN-PC is a spanning k-forest with trees $T_1, T_2, \ldots, T_k$ satisfying the *reliability condition*: for all $j \in \{1, 2, \ldots, k\}$ there is $w \in V(T_j)$ such that $\prod_{v \in P_{uw}} p_v \geq B \quad \forall u \in V(T_j)$, where P_{uw} is the unique path between u and w. The goal is to find a solution minimizing the *communication cost* $\sum_{j=1}^{k} \sum_{e \in E(T_j)} c_e^j$.

A solution corresponds to the scheduling of a wireless sensor network (WSN) over k time slots: graph vertices (resp. edges) represent sensors (resp. links); the link costs vary across time slots; tree T_j indicates the active sensors and links of time slot $j \in \{1, 2, \ldots, k\}$. The motivation is to extend the WSN lifetime by allowing partial coverages (only sensors corresponding to $V(T_j)$ consume their battery in time slot j); furthermore, the reliability condition ensures that, with high probability, each active sensor communicates with a specific active sensor chosen as gateway, possibly through other sensors acting as relays.

We show that feasibility testing and single time slot optimization of the Rel-STSWSN-PC are NP-hard. We model the problem with two MILPs: a compact formulation and one involving exponential families of constraints, namely infeasible-path and cut constraints. A branch-and-cut algorithm based on the exponential model solves instances of realistic size. To reduce the optimality gaps of unsolved instances we use two primal heuristics, based on variable neighborhood search and integrated in the branch-and-cut algorithm. When $B = 0$, the Rel-STSWSN-PC boils down to a WSN scheduling problem introduced in [1], and later studied in [2,3]. We show that our branch-and-cut approach outperforms state-of-the-art methods for such problem.

Keywords: Wireless Sensor Network, Branch-and-Cut, Variable Neighborhood Search

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Abstract ID: ODS-133 Session: S13

Spatio-Temporal Crop Scheduling in a Rotary Greenhouse with Hexagonal Shelves

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In controlled environment agriculture, spatio-temporal resource optimization is needed to achieve high productivity, especially in systems with reconfigurable or mobile components. This paper presents ageometry-sensitive, mixed-integer linear programming (MILP) formulation of crop scheduling in a high-density cultivation system made up of a rotary greenhouse design with hexagonal shelves and radially expanding crop envelopes, even if the principles of the formulation also apply to a more general class of circular, shelf-based designs. A multi-stage heuristic search is proposed as well to explore the solution space efficiently and construct high-quality, feasible production schedules in the case of large problem instances, which make it difficult to solve the MILP formulation. We show that the physical layout of the facility, including a tradeoff between inter-shelf distances and boundary clearances, is a crucial determinant of the optimal crop allocation strategies. The framework provides a quantitative basis for strategic planning by exposing the operational tradeoff between maximizing total production, which is usually dominated by small- and fast-growing crops, and accommodating high value or staple crops that require more space and time. The paper presents a rigorous optimization framework that bridges high-level production goals and hardware-level feasibility, and offers a useful tool for the design, analysis, and implementation of next-generation automated agricultural systems.

Abstract ID: ODS-164 Session: S13

Tropical optimization for Scheduling

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Tropical optimization is a branch of mathematics based on tropical algebra, where addition and multiplication are replaced by maximum (or minimum) and addition. It is grounded in semirings with idempotent addition and is widely used in operations research, especially for project scheduling. Its main advantage is the compact representation of synchronization phenomena and optimal paths. However, its use for deriving compact QUBO formulations remains limited, despite its potential for classical and quantum optimization methods.

S14 – Sustainability

Abstract ID: ODS-101 Session: S14

A Mixed Integer Linear Programming Approach to Limit Urban Sprawl in Vienna

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Urban sprawl, i.e., the expansion of towns and cities into dispersed low-density, car-dependent settlements, is a critical issue of urban growth. Sprawl increases distances, sparsifies service networks, and harms transportation efficiency [4], leading to poor social and environmental outcomes. The state-of-the-art metric Weighted Urban Proliferation (*WUP*) [2] enables measuring sprawl, yet planning strategies have failed to prevent it. To date, contributions of operations research to land use decision-making have been limited in number and fragmented in purpose, and Kumar et al. [3] are the only ones that addressed urban sprawl.

In this work, we propose a novel Mixed-Integer Linear Programming (MILP) approach to make optimal land use decisions in an urban setting that minimize urban sprawl. The city is represented as a grid of cells with given land use and intensity. The objective is to make feasible land-use assignments that minimize transformation costs and maximize inter-cell suitability, while ensuring that demand for housing and jobs is met. Urban sprawl is modeled either as a constraint or an objective. A key novelty is the use of the *WUP* metric in this context. Being a multi-variated, hard-to-capture spatial phenomenon, the computation of *WUP* itself is demanding, therefore we suitably decompose and linearize it.

We validate our model using data of the city of Vienna, for which detailed information on land use, population, jobs, and sprawl is available for all years from 1984 to 2018 [1]. Experimental results show the potential of our approach to limit urban sprawl, while ensuring the sustainability of urban growth. Moreover, they highlight future growth strategies for Vienna and can be used to assess past planning choices. Finally, our model is transferable to other urban areas for which data on built-up surface, population, and jobs are available.

The WU Anniversary Fund of the City of Vienna is acknowledged.

Keywords: Mixed Integer Linear Programming, Land Use Decision-Making, Urban Sprawl

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Abstract ID: ODS-071 Session: S14

Forecasting Residential Mortgage Default: The Role of Energy Efficiency

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We investigate the role of building energy efficiency in forecasting residential mortgage default using a large-scale dataset of 531,974 European mortgage loans sourced from the European DataWarehouse across nine countries over the period 2021–2025. Using Energy Performance Certificate (EPC) ratings as a proxy for energy efficiency (EE), we document a negative and monotonic relationship between energy performance and default risk through survival analysis and logistic regression. We then assess the predictive value of EPC information within a machine-learning benchmarking framework covering ten classification algorithms, in which EE ranks among the top predictors across models, confirming its economic relevance beyond traditional credit risk variables.

Abstract ID: ODS-034 Session: S14

How to compare the environmental and financial efficiency of companies from multiple economic sectors?

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This study evaluates the joint financial and environmental efficiency of 422 European companies across 23 sectors (2014–2022), focusing on greenhouse gas (GHG) emission performance. Using a robust conditional input-oriented BCC Data Envelopment Analysis (DEA) model, the research incorporates outlier-resistant order-m estimation (Cazals *et al.*, 2002) and a conditional framework (Daraio and Simar, 2005) that accounts for sectoral emission intensity as an external environmental factor. GHG emissions are transformed into "emission savings" based on sector-specific worst-case intensities, enabling cross-sector comparability. Separability tests confirm that emission intensity significantly affects the efficient frontier, justifying the conditional approach. A limitation is the high number of efficient units produced by the method, likely due to the environmental variable being constant within sectors, suggesting directions for methodological refinement.

Keywords: Financial and environmental efficiency, GHG emissions, Order-m robust DEA, Conditional DEA

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Abstract ID: ODS-160 Session: S14

Optimization algorithms for the price clustering problem with disjoint clusters and bounded centroids

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The price clustering problem requires to partition a set of items into clusters so that each item is sold at the price associated with its cluster instead of its original price, while satisfying a constraint on the minimum total revenue obtained. The objective is to minimize the difference between the original price and the cluster price for each item. In this paper we consider a variation of the price clustering problem in which the price ranges of the clusters must be disjoint and the cluster prices are constrained to lie within the price range of the items in each cluster. We present effective optimization algorithms and related computational results.

S15 – Topics in Combinatorial Optimization

Abstract ID: ODS-036 Session: S15

A DP-based Exact Method for the Submodular Knapsack Problem

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Research Questions and Challenges. We study the *Submodular 0–1 Knapsack Problem* (SKP), a generalization of the well-known 0–1 Knapsack Problem that calls for selecting a maximum-profit subset of items from a set of items, each featuring a profit, a nominal weight, and a submodular weight, while satisfying a knapsack-capacity constraint defined by a submodular function. In particular, we focus on the special case where this submodular function is the square root function. Most studies provide heuristic algorithms for the SKP. As to exact methods, the state of the art encompasses a second-order cone programming formulation, as well as two additional approaches. Our research challenge is to develop a new exact method for the SKP and achieve superior computational efficiency compared with existing methods.

Methodology and Results. We propose a new exact method, based on dynamic programming, that exploits dominance rules, completion bounds, and two primal heuristics. We consider two benchmark sets derived from the literature and compare our approach with the state of the art through an experimental evaluation. Results show that our exact method outperforms the state of the art by significantly decreasing the average solve time.

Importance and Implications. The SKP is related to the Chance Constrained Knapsack Problem, the Robust Knapsack Problem, and the Distributionally Robust Chance Constrained Knapsack Problem. With certain assumptions on weight distributions or uncertainty/ambiguity sets, these problems can be reduced to or approximated by the SKP. Consequently, our exact method applies to these problems and their applications in diverse domains such as facility location, telecommunication network, and portfolio selection.

Keywords: submodular functions, dynamic programming, exact methods, knapsack problems

Abstract ID: ODS-106 Session: S15

An improved primal algorithm for the assignment problem

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The assignment problem [3] is one of the most classical and widely used graph optimization problems in mathematical programming and operations research. Given n origins and n destinations, with cost c_{ij} for assigning origin i to destination j, the objective is to find a minimum-cost one-to-one matching. Despite its simple statement, the assignment problem remains a key computational primitive, appearing both as a direct model in applications and as a subproblem in more complex combinatorial optimization problems.

We present an exact primal algorithm for the assignment problem, extending and refining the algorithm presented at ODS2025 [1]. Starting from a feasible assignment, the method iteratively improves the current solution by searching for negative-cost cycles in a suitably defined graph containing only a limited and dynamically selected set of arcs. The search is based on a tailored use of Bellman–Ford-type distance relaxations, embedded in a graph structure specifically designed for fast updates and efficient cycle detection.

The resulting approach combines an efficient exploration of the solution space with an algorithmic design that tackles the computational bottlenecks of core graph operations and arc filtering for dense assignment instances. We compare the proposed method with established exact algorithms for the assignment problem, including auction, cost-scaling, and shortest augmenting path approaches [2,4,5]. Computational results show that the proposed algorithm is competitive with the best available solution methods.

Keywords: Assignment problem, exact algorithms, combinatorial optimization, graph algorithms

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Abstract ID: ODS-130 Session: S15

Convex Hulls for Non-Convex Mixed-Integer Quadratic Programs in the McCormick Space

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We consider non-convex mixed-integer quadratic programs (MIQP) in which all variables are explicitly bounded. A classic approach, due to McCormick, introduces additional variables that represent squares or products of the original variables, and uses these to construct a linear programming relaxation of the MIQP. We consider the convex hull of feasible solutions for the approach of McCormick, explore conditions under which the convex hulls are polyhedral, and present results concerned with their dimension.

Abstract ID: ODS-024 Session: S15

Revisiting Johnson's rule for minimizing makespan in the two-machine flow shop scheduling problem

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We consider the two-machine flow shop scheduling problem with the objective of minimizing the makespan, commonly denoted by $F2 \mid\mid C_{\max}$. A set $J = \{1, \ldots, n\}$ of jobs must be processed on two machines M_1 and M_2 in this order. Job j requires a processing time $p_{1,j}$ on M_1 and $p_{2,j}$ on M_2. All jobs are available at time 0, each machine can process at most one job at a time, and preemption is not allowed. It is well known that there always exists an optimal schedule that is a permutation schedule and can be obtained by Johnson's rule [4]. This rule first schedules the set A of jobs such that $p_{1,j} \leq p_{2,j}$ in nondecreasing order of $p_{1,j}$, then the set B of jobs such that $p_{1,j} > p_{2,j}$ in nonincreasing order of $p_{2,j}$, and runs in $O(n \log n)$ time and $O(n)$ space.

As noted in [5], in addition to schedules obtained by Johnson's rule, "the class of optimal schedules appears to be hard to characterize and data dependent." Motivated by this observation, several studies (see [1, 2, 3]) have focused on the generation of equivalent optimal solutions. In this work, we investigate general conditions under which the $F2 \mid\mid C_{\max}$ problem can be solved optimally in $O(n)$ time. More specifically, we prove that a simple procedure running in $O(n)$ time allows one to determine whether a full sort can be avoided and, correspondingly, whether an optimal solution can be computed in linear time. In this case, the procedure also identifies a large set of equivalent optimal sequences.

We also provide a probabilistic analysis for instances with uniformly distributed processing times, showing that linear-time complexity is guaranteed with probability lower bounded by $1 - 10^{-3}$ for instances of size $n = 100$ and by $1 - 10^{-9}$ for instances of size $n = 200$. Computational tests indicate that, for standard uniform distributions and instance sizes $n = 1000, 10000$, and 100000, an optimal solution is always obtained in linear time.

Keywords: two-machine flow shop scheduling, Johnson's algorithm, linear time complexity

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Abstract ID: ODS-025 Session: S15

The Quadratic Multiple Knapsack Problem with Setup: Models and Algorithms

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In the *Quadratic Multiple Knapsack Problem* (QMKP), introduced by Hiley and Julstrom (1) in 2006, one is given a set of *knapsacks*, each having a prefixed *capacity*, and a set of *items*, each characterized by a *profit* and a *weight*, in addition, each *pair* of items provides a *pairwise profit* if both items are selected for the same knapsack. The objective of the QMKP is to select a maximum profit family of disjoint sets of items (one set for each knapsack) such that the global weight of the items selected in each set does not exceed the capacity of the corresponding knapsack.

In the *Knapsack Problem with Setup* (KPS), introduced by Chajakis and Guignard (2) in 1994, and in the *Quadratic Knapsack Problem with Setup* (QKPS), introduced by Galli et al. (3) in 2025, where a single knapsack is considered, the items are partitioned into *classes*, and the items of a class can only be selected if the corresponding class is activated. Activating a class requires both a *setup cost* (to be subtracted from the global profit) and a *setup reduction* of the knapsack capacity.

The subject of this talk is the *Quadratic Multiple Knapsack Problem with Setup* (QMKPS), which "naturally" combines the QMKP and the QKPS, and where it is assumed that each class can only be activated for a single knapsack, whose capacity is correspondingly reduced. Several *linear formulations* are presented, and dominances among them are investigated. Effective deterministic *matheuristic algorithms*, based on the optimal solution of Integer Linear Programming (ILP) models, are also proposed. Computational results, showing the good performance of the proposed formulations and algorithms, are reported.

Keywords: Combinatorial Optimization, Mathematical Models, Quadratic Multiple Knapsack Problem, Setup Constraints, Matheuristic Algorithms

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AYDA – AYDA

Abstract ID: ODS-170 Session: AYDA

Research in the Era of AI: Opportunities, Challenges, and New Frontiers

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Artificial Intelligence (AI) is changing the way scientific research is carried out and the way we teach and train new generations of researchers. Tasks that used to be slow and largely manual, from reviewing the literature to writing code and drafting papers, can now be supported by AI tools, while data-driven methods are increasingly present across many stages of the research process. This panel session brings together researchers, educators, and practitioners to discuss how these developments are changing the way we produce, validate, and disseminate knowledge.

The discussion will span three connected dimensions. First, *how we do research*: generative models and large language models (LLMs) are speeding up literature review, hypothesis generation, code writing, and even model formulation, while data-driven methods increasingly complement classical exact and heuristic approaches to optimization. Second, *how we publish and evaluate*: AI-assisted writing, automated peer review, and concerns around reproducibility, authorship, transparency, and research integrity are challenging established academic practices and leading communities to reconsider their standards. Third, *how we teach and train the next generation*: students now learn, code, and solve problems alongside AI tools, raising important questions about which skills remain essential, how to preserve critical thinking and methodological rigor, and how to encourage responsible use rather than uncritical dependence.

The aim of the panel is not to provide definitive answers, but to open a discussion on the opportunities that AI offers to the research and academic community, the risks it introduces, and the new questions it raises for how we work, publish, and teach. Together, these reflections will help us think about how research and education may evolve in the coming years, and how we can make good use of these tools while preserving rigor, critical thinking, and integrity.

Keywords: Artificial Intelligence, Operations Research, Machine Learning, Research Integrity, Higher Education

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Abstract ID: ODS-174 Session: AYDA

Chronicles on Metaheuristic Optimization: Components, Applications, and Large Language Models

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Metaheuristics have become a standard approach for solving combinatorial optimization problems that lie beyond the reach of exact methods, delivering strong solutions in practice. Their empirical study and reliable application, however, remain fragmented, shaped more by benchmark competition than by a genuine pursuit of understanding. This leaves four gaps. First, we can rarely explain why these methods succeed. Second, the tools built to study them seldom generalize beyond benchmark problems, making their use on new ones unreliable. Third, the literature keeps multiplying isolated problem variants rather than consolidating them. Fourth, Large Language Models (LLMs) raise a related question: as they become increasingly integrated into optimization, how they actually behave in this role remains largely unexplored.

This thesis addresses these challenges in four complementary directions. First, at the component level, we analyze the internal mechanisms of classical methods such as Tabu Search and Simulated Annealing, showing how adaptive control mechanisms can reproduce tuned performance without manual calibration. Second, focusing on real-world benchmarking, we study the Oven Scheduling Problem: we derive theoretical lower bounds, design Simulated Annealing and Large Neighborhood Search algorithms, and use statistical and visual analysis to reveal how instance features and search trajectories drive performance. Third, we address the proliferation of problem variants by consolidating isolated formulations of the Home Healthcare Routing and Scheduling Problem into a unified framework, providing open tools for instance generation and analysis, and general-purpose algorithms that match or exceed specialized methods. Fourth, we systematically map LLM applications in optimization and probe how they reason about combinatorial problems: they prove unreliable at extracting problem features explicitly, yet their internal representations predict the best solver as accurately as handcrafted features.

Taken together, these contributions offer a coherent account of how metaheuristic optimization methods can be analyzed, unified, and extended, providing both conceptual clarity and practical tools for understanding and solving complex decision problems.

Keywords: Combinatorial optimization, Metaheuristics, Local search, Empirical analysis, Large language models, Oven scheduling problem, Home healthcare problem, Scheduling problem.

Abstract ID: ODS-171 Session: AYDA

On data & decision-making: perspectives from healthcare applications considering representativeness and analytical scope

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Despite the growing availability of data, decision-makers in healthcare are often forced to rely on incomplete or low-quality information when making critical decisions: data are often partial, collected for purposes unrelated to decision-making, or are otherwise insufficient to describe the behaviour of the system under study. This Dissertation examines how quantitative decision-aiding methods, drawn from both operations research and data science, can be selected and integrated to improve healthcare decision-making in practice.

The work is organized around two interconnected dimensions: data representativeness, defined as the extent to which available data adequately describe a given behaviour of the system, and analytical scope, which distinguishes explicit analytics (which returns descriptive information, i.e. forecasting) and implicit analytics (that yield directly actionable outputs, i.e. prescriptive modelling). Positioning problems within the resulting two-dimensional space yields fuori broad classes of decision-making approaches, of which three are addressed in this work: i) OR, ii) data science, and iii) their integration. The fourth, expertise-based decision-making is not addressed, as it relies on neither data nor quantitative methods.

This framework is populated by nine studies conducted across the doctoral programme, three per quadrant: in the first, a scenario-based disruption/restoration surgery scheduling framework, a primary care network design under approximated demand data, and a home blood collection logistics model translationally informed by historical records; in the second, a sentiment analysis from the public discourse to encourage blood donation, a large-scale ECG-based risk stratification study for screening programs, and a machine-learning-informed surgical planner for arteriovenous fistulae; in the third, robust surgery scheduling with an implementor-adversary machine learning-informed formulation, and two studies introducing simulated machine learning, a novel methodology for evaluating the predictive performance a model must achieve to justify its adoption.

The resulting methodological perspective links data characteristics, analytical requirements, and decision-making needs, offering researchers and practitioners a means of assessing when data-driven, optimization-based, or hybrid approaches are warranted, countering the temptation to treat data science as a silver bullet, and grounding decision-making in healthcare in what data representativeness requires, rather than in what data happen to be available.

Keywords: Healthcare; Machine learning; Robust optimization

Abstract ID: ODS-173 Session: AYDA

Combinatorial models and algorithms for resource allocation problems in healthcare management and logistics

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Scheduling problems represent a fundamental challenge across a wide range of domains, from industrial production to healthcare management. Their complexity arises not only from the intricate nature of the decisions involved but also from the presence of competing objectives and constraints. This thesis addresses several scheduling problems, with particular attention to real-world problems and the practical applicability of the proposed solutions.

The first chapter focuses on two healthcare management problems. The first study proposes a collaborative decision support system for elective surgery planning that combines clustering techniques with an integer linear programming (ILP) model to optimize operating room utilization while preserving surgeons' autonomy in patient selection. Validated using one year of real hospital data, the proposed approach achieves performance comparable to, or better than, current practice, improving resource utilization while satisfying capacity and waiting-time constraints. The second study develops an ILP model to support the allocation of healthcare services within Community Houses, evaluating the match between territorial demand and service capacity. The model provides a flexible framework for allocating healthcare personnel and identifying resource imbalances, thereby promoting both efficiency and equity.

The second chapter investigates the preemptive Resource-Constrained Project Scheduling Problem with time-varying resource availability. The study formulates a bicriteria problem, aiming to minimize both makespan and the number of preemptions through three time-indexed ILP models. Computational experiments on benchmark instances and a real-world information technology project show that a limited number of preemptions is generally sufficient to achieve most of the potential reduction in makespan, offering an effective compromise between project efficiency and managerial complexity.

The final chapter studies scheduling problems on machines subject to unrecoverable breakdowns, where failures permanently interrupt production and prevent the completion of subsequent jobs. Two problem variants are analyzed, involving job sequencing and job selection under different failure assumptions, with the objective of maximizing expected profit. In addition to developing optimization models, the chapter investigates the computational complexity of these problems, providing new theoretical insights into scheduling under machine unreliability.

Keywords: Combinatorial Optimization; Scheduling; Decision support systems.

Abstract ID: ODS-172 Session: AYDA

Advancing Supply Chain Inventory Management through Mathematical and Deep Reinforcement Learning Approaches

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The increasing complexity of modern supply chains, driven by Industry 4.0 principles and advances in artificial intelligence, has created a growing need for adaptive, data-driven supply chain management strategies. In this context, deep reinforcement learning (DRL) has emerged as a promising alternative capable of directly learning effective policies by interacting with simulated supply chain environments.

This thesis explores the potential of DRL to improve supply chain inventory management (SCIM) across diverse structural attributes and operational factors, focusing on three primary research objectives: 1) evaluating the performance of state-of-the-art DRL algorithms in two-echelon systems subjected to stochastic and seasonal demand, varying numbers of product types and warehouses, and different lead times; 2) developing a hybrid heuristic that combines DRL with multi-stage (MS) stochastic programming to mitigate computational complexity while accounting for production limits; and 3) assessing the applicability and interpretability of DRL in a real-world pharmaceutical supply chain characterized by perishability, production yields, batch limits, lead times, and lost sales under non-stationary demand.

The first study demonstrates that DRL, particularly the proximal policy optimization (PPO) algorithm, consistently outperforms base-stock and (s, Q)-policies in capacitated two-echelon systems. PPO effectively handles increasing complexity, scales across large state-action spaces, and achieves training times comparable to traditional inventory policies. The second study introduces a hybrid heuristic in which DRL determines long-horizon production planning while MS stochastic programming optimizes short-term logistics decisions. This combined approach results in robust, computationally tractable solutions that outperform both standalone methods. The third study focuses on a pharmaceutical supply chain and evaluates PPO with the order-up-to policy and one of its variants based on projected inventory levels. All three policies surpass human-driven policies in minimizing costs under complex conditions, while providing managerial insights and interpreting the impact of costs and lost sales in relation to ethical and legal constraints.

Furthermore, the open-source SCIMAI-Gym Python library, developed as part of this research, provides a flexible simulation environment that encourages further experimentation, collaboration, and practical implementation.

Keywords: Supply Chain Inventory Management, Deep Reinforcement Learning, Stochastic Programming.

Sponsors – Artelys Italia

Abstract ID: SP-001 Session: Sponsors

Artelys Knitro: An interactive tutorial

Enrico Bettiol[1] , Hannes Van Overloop[1]

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This session combines a brief introduction to Artelys Knitro with an interactive tutorial focused on its practical use on nonlinear optimization. Following a short overview of the solver's algorithmic capabilities and supported problem classes, attendees will participate in a hands-on exploration of some nonlinear optimization examples. Live demonstrations will showcase the formulation and solution of nonlinear optimization models with Artelys Knitro, providing practical insights into model formulation, solver behavior, and real-world applications.

Keywords: Artelys Knitro, tutorial, nonlinear optimization

Session Index

Author Index

ODS 2026 1726 Comic Strip

Giacomo Venier and Fortunato*

Giacomo Venier, one of the characters featured in the humorous comic strips that follow, is the protagonist of a series that has been published for several years and has received a fair amount of appreciation.

He is a hapless, penniless ladies' man, forever trying to make ends meet in eighteenth-century Venice. Even so, Venier does his best to live the life of a gentleman – albeit a lazy, work-shy one – with ambitions of moving in high society. Always on the lookout for his next romantic conquest, and something of an aspiring hedonist, he seizes every promising opportunity life throws his way. More often than not, however, his efforts land him in situations that can only be described as absurd.

The stories are made all the more entertaining by Fortunato, his loyal servant, gondolier and general handyman. He frequently finds himself having to rescue his "Sior Paròn" – his master – from trouble, despite rarely, if ever, being paid for his services.

In the two comic strips that follow, Giacomo Venier crosses paths with ODS 1726, with consequences you can discover for yourselves.

There is little left for us to add, except to wish our readers a few minutes of good fun.

The Authors

* *Editor's note: Venier is a very common last name in Venice and is also the name of an ancient and prominent Venetian noble family, while Fortunato literally means "Lucky" in English.*

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