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# Practical deployment of real-time railway traffic management algorithms: impact of process meta-parameters

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## ► To cite this version:

Federico Naldini, Paola Pellegrini, Joaquín Rodríguez. Practical deployment of real-time railway traffic management algorithms: impact of process meta-parameters. ODS 2022, International Conference on Optimization and Decision Science, Prof. Fabio Schoen; GOL – Global Optimization Laboratory "Gerardo Poggiali" - UniFI, University of Florence, Italy; Airo - The Italian Association of Operations Research; DINFO (Dept. of Information Engineering, Università degli Studi di Firenze), Aug 2022, Firenze, Italy. pp.91. hal-04402651

**HAL Id: hal-04402651**

**<https://univ-eiffel.hal.science/hal-04402651v1>**

Submitted on 18 Jan 2024

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**ODS 2022**  
INTERNATIONAL CONFERENCE ON  
OPTIMIZATION AND DECISION SCIENCE  
FIRENZE (ITALY) August 30<sup>th</sup> - September 2<sup>nd</sup> - 2022

# ODS2022 – Book of abstracts

the ODS2022 Organizing committee

August 2022

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This book contains all of the abstracts accepted for presentation at the International Conference on Optimization and Decision Science, ODS2022, held in Florence from August 30<sup>th</sup> to September 2<sup>nd</sup>, 2022. The conference is organized within AIRO, the Italian Operations Research Society, with the support of DINFO (Dept. of Information Engineering, Università degli Studi di Firenze). The conference theme is open in the fields of operations research, optimization, problem solving and decision making, and their applications. A special focus is on the theme “Operations Research: inclusion and equity”.

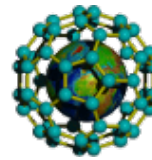
The book of abstracts contains over 230 contributions, 30 of which associated to papers accepted for publication in the AIRO Springer Series volume devoted to the conference. The contributions are organized into 5 parallel streams and about 35 sessions, 14 of which are invited sessions/streams. Four 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, namely the use of quantitative analytical methods to promote equality and equity, in the many facets that these terms may have. Abstracts are listed day by day, session by session.

The ODS 2022 Organizing Committee

## Acknowledgments

We sincerely thank all those who contributed to the realization of the conference, and in particular, the members in the Program Committee, those in the Organization Committee, and all of the DINFO PhD's and PostDocs, in particular, from GOL, the Global Optimization Lab, who have been invaluable in the organization of such a complex event.

The organization of ODS2022 gratefully acknowledges the Institutional support of DINFO, Dipartimento di Ingegneria dell'Informazione, Università degli Studi di Firenze and of AIRO, the Italian Association for Operations Research:



We also acknowledge the financial contributions from:



### Special acknowledgments

We tried, in many cases, to rely on the professional help from social cooperatives and not-for-profit organizations. We would like to thank them here and

to inform participants that part of their registration fees went to support the activities of these organizations.



Zenzero catering bio equo, for the coffee breaks



Flo concept, for the ODS2022 bags and backpacks



Istituto degli Innocenti, host for the first plenary and the welcome cocktail



Viviamo In Positivo VIP Firenze OdV, for the organization of the treasure hunt in Florence

## Invited Sessions

We also acknowledge the precious contributions of the organizers of Invited Sessions:

**AMUO** Advances in Multiobjective Optimization, organized by Marianna De Santis (Sapienza, Univ. di Roma), Pierluigi Mansueto (Univ. di Firenze)

**EQVA** Equilibria, variational models and applications, organized by Mauro Passacantando (Univ. di Pisa)

**GO** Global Optimization, organized by Fabio Schoen (Univ. di Firenze)

**HCM** Health Care Management, organized by Giuliana Carello (Politecnico di Milano), Elena Tanfani (Univ. di Genova)

**KNAP** Knapsack Problems, organized by Adam Letchford (Lancaster University), Laura Galli (Univ. Pisa)

**MLO4EMD** Machine learning-based optimization for extreme metamaterials design, organized by Andrea Bacigalupo (University of Genoa), Francesca Fantoni (University of Brescia), Giorgio Gnecco (IMT Lucca)

**MUOS** Multicriteria Optimization for sustainability, organized by Marianna De Santis, Lavinia Amorosi (Sapienza, Univ. di Roma)

**NODAI** Numerical optimization for data analysis and imaging, organized by Benedetta Morini, Simone Rebegoldi (Univ. di Firenze)

**NOML** Nonlinear Optimization and Machine Learning, organized by Matteo Lapucci (Univ. di Firenze), Marco Sciandrone (Sapienza Univ di Roma)

**OML** Optimization for machine learning, organized by Cesare Molinari, Vasilis Apidopoulos, Silvia Villa (MaLGa, DIMA, Università degli Studi di Genova)

**OPTSM** Optimization in Public Transport and Shared Mobility, organized by Andrea D'Ariano (Univ Roma Tre), Valentina Cacchiani (Univ. di Bologna)

**OOUTA** Optimization under Uncertainty: Theory and Applications, organized by Francesca Maggioni (Univ. di Bergamo), Patrizia Beraldi (Univ. Calabria)

**PRPI** Path and routing problems in industry, organized by Marco Locatelli (Univ. di Parma)

**RAVIEP** Recent Advances in Variational Inequalities and Equilibrium Problems, organized by Patrizia Daniele, Laura Scrimali (University Catania)

Special thanks to AIROyoung for the organization of the special session devoted to a selected group of PhD thesis presentations.

And a special thanks to Verizon Connect Italy for the support given to two female young researchers through the ODS2022/Verizon Connect prize.

## **OUUTA, Optimization under Uncertainty: Theory and Applications; Invited Session**

**TU 14:10 PM1 001**

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*Optimal ordering under a low-quality substitute in case of shortage and stochastic lead time*

Delivery lead time is becoming a key factor which uncertainty significantly affects supply chain performance. Empirical studies in different industries show that stock-out-based substitution is a common way to handle shortages. Notably, during the COVID-19 pandemic, the demand for medical supplies intensely increased, not only because of the fast spread of the infection but also because the related shortages of genuine products contributed to an increase in number of substandard medical products. In this work we consider a finite replenishment cycle in a humanitarian organization where (i) a high-quality material is characterized by a stochastic lead time, (ii) the demand during the replenishment cycle is known but it can be affected by last minute requests. Furthermore, in case of shortage, the high-quality material can be substituted with a low-quality material, but the substitute impacts the demand. Specifically, the demand increases due to the fact that the low-quality product wears out faster than the other product. The formulation involves continuous-time inventory depletion and associated purchase and inventory holding costs. The goal is to order the supplies so that to minimize the total cost of meeting the demand during the replenishment cycle. We formalize the analysis with the aid of a number of scenarios characterizing the cases when there is no need to substitute the high-quality products with the low-quality ones; when there exists a time point such that the high-quality products will be substituted with the low-quality products; and when the high-quality products will be substituted twice over the time horizon. All scenarios account for a last-minute demand. With the aid of these scenarios, we reduce the problem to minimizing a cost function consisting of two convex functions determined along two adjacent order quantity intervals thereby implying not-necessarily convex optimization.

**OUUTA, Optimization under Uncertainty: Theory and Applications; Invited Session**



**TU 14:30 PM1 001**

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*Pickup and delivery requests through a multi-company e-commerce  
platform*

Delivery services have been developed within the grocery and restaurant domain such as for non-food items with different platforms but the demand patterns and consumer behavior differ in the case of food and non-food products. A single e-platform serving a wide range of local businesses could provide the volume and smooth the non-stationary demand pattern typical of restaurant delivery. There is an opportunity for local brick-and-mortar companies to utilize such an e-platform, particularly if paired with a high level of customer service (professional shopper consultation, favorable return policy, etc.) to support shop local initiatives and stave off a retail apocalypse. A primary motivation for local businesses to join an e-platform is to compete with the distribution power of companies like Amazon [Mattioli, June 17 2021], even because the global COVID-19 pandemic has altered consumer behavior (perhaps permanently) and local brick-and-mortar stores may need to serve as showrooms (for in-person shopping) and/or dark stores (warehouses), with employees serving as salespeople and/or as order-pickers. Schrottenboer et al. [2021] examine a similar setting motivated by local delivery via bicycle. In our problem we assume that a third-party logistics (3PL) company receives the customer requests stochastically throughout the day and dispatches these requests to available vehicles, using a fleet of dedicated vehicles and a fleet of crowdsourced vehicles that arrives stochastically during the day by offering a known limited time availability. The incorporation of crowdshippers has implications on sustainability of city logistics by reducing the number of vehicles dedicated to deliveries. In the treatment of our problem, we consider two aspects of the logistical design of a delivery system: cost and service. Our formulation focuses on workforce costs as these represent a major component of operating costs. Along the service dimension, we focus on on-time delivery with particular modeling of time-dependent travel times. To represent the stochastic nature of the arrival of customer requests and of the availability of crowdshippers, we model the problem as a Markov decision process (MDP) over finite, discrete-time horizon and the solution approach is based on an approximate dynamic programming method.

[1] D. Mattioli. Shops join forces against amazon. The Wall Street

**OUUTA, Optimization under Uncertainty: Theory and  
Applications; Invited Session**

Journal, June 17 2021. [2] A. H. Schrotenboer, M. A. Broek, P. Buijs, and M. W. Ulmer. Fighting the e-commerce giants: Efficient routing and effective consolidation for local delivery platforms. arXiv preprint arXiv:2108.12608, 2021.

TU 14:50 PM1 001

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*Bounds for Multistage Mixed-Integer Distributionally Robust Optimization*

Multistage mixed-integer distributionally robust optimization (DRO) forms a class of extremely challenging problems since their size grows exponentially with the number of stages. One way to model the uncertainty in multistage DRO is by creating sets of conditional distributions (the so-called conditional ambiguity sets) on a finite scenario tree and requiring that such distributions remain close to nominal conditional distributions according to some measure of similarity/distance (e.g., phi-divergences or Wasserstein distance). In this talk, new bounding criteria for this class of difficult decision problems are provided through scenario grouping using the ambiguity sets associated with various commonly used phi-divergences and the Wasserstein distance. Our approach does not require any special problem structure such as linearity, convexity, stagewise independence, and so forth. Therefore, while we focus on multistage mixed-integer DRO, our bounds can be applied to a wide range of DRO problems including two-stage and multistage, with or without integer variables, convex or nonconvex, and nested or non-nested formulations. Numerical results on a multistage mixed-integer production problem show the efficiency of the proposed approach through different choices of partition strategies, ambiguity sets, and levels of robustness.

**OUUTA, Optimization under Uncertainty: Theory and Applications; Invited Session**

**TU 15:10 PM1 001**

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*A Robust Optimization Approach for Designing Renewable Energy  
Charging Stations*

We consider strategic and operational planning decisions arising in managing plug-in electric vehicle (PEV) charging stations. At a strategic level, we face the problems of both defining the optimal configuration of the energy system of a PEV charging station and of setting the optimal retail prices for PEV-charging energy. These decisions depend on the unknown values for the productivity of the renewable resources, for the number of PEV clients and for the wholesale prices. Based on the worst possible outcome for these random variables the PEV owner would like to make the best operational decisions regarding the quantity of supplementary energy to be produced. A similar problem has been considered in [1] where a bilevel robust optimization model is first formulated and then transformed into an equivalent single-level problem to be solved by a column-and-constraint-generation algorithm. We test the PEV charging station robust optimization formulation on a series of instances drawn from the literature.

[1] Bo Zeng, Houqi Dong, Ramteen Sioshansi, Fuqiang Xu and Ming Zeng, Bilevel Robust Optimization of Electric Vehicle Charging Stations with Distributed Energy Resources. *IEEE Transactions on Industry Applications*, 56 (5), pp. 5836-5847 [2] Manlio Gaudioso, Giovanni Giallombardo and Giovanna Miglionico, Minimizing Piecewise-Concave Functions Over Polyhedra. *MATHEMATICS OF OPERATIONS RESEARCH*, 43 (2), pp. 580597.

**OUUTA, Optimization under Uncertainty: Theory and  
Applications; Invited Session**

**TU 15:30 PM1 001**

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*Stochastic Programs with extreme behaviors-focused second stages: a Deterministic Equivalent Formulation*

A closed deterministic form of a two-stage Stochastic Programming (SP) problem is obtainable when the expected optimum of the second-stage problem can be analytically calculated. However, in practice, this is almost always impossible given the complexity of the multidimensional integral of such an expected value. In this work, we consider and formally define a large class of two-stage Stochastic Programs whose second-stage expected optimum is Decomposable into a finite number of expectations of Extreme Values (tsSP-DEV). Typical applications of tsSP-DEVs can be found, e.g., in location-allocation problems under allocation costs uncertainty. In a sense, a tsSP-DEV involves characteristics both from the classical SP paradigm and from the Robust Optimization one. In fact, the tsSP-DEV optimization perspective is still focused in making here-and-now decisions by also evaluating the expected value of an uncertain problem over all the possible future situations, but assuming that such a value can be obtained as a function of extreme future behaviors.

We show that a closed-form analytical expression of the expected second-stage optimum of any tsSP-DEV can be derived by exploiting some results coming from the Extreme Value Theory [1], and thus an equivalent deterministic version of the SP problem can be obtained. This can be done under the mild hypothesis that the involved uncertain data follow a Multivariate Extreme Value (MEV) distribution. The MEV family includes many common distributions, and some of them are of practical interest since they enable a modeling of the second-stage problem uncertainty structure through well-known and widely used Discrete Choice Models (e.g., Logit, Nested Logit, Cross-Nested Logit). Finally, a tsSP-DEV special case, named two-stage Stochastic Programs embedding Discrete Choice Problems (tsSP-DCP), is further defined. In a tsSP-DCP, the second stage consists of a sequence of independent Discrete Choice Problems (DCPs), each one triggered or weighted by the value of a specific first-stage variable. In this case, the deterministic equivalent problem results to be linear and thus further properties can be derived. This allows to well-approximate many realistic uncertain MILP problems by solving their deterministic versions [2].

We validate our approach through numerical experiments on common combinatorial optimization SP problems and compare its efficiency and effectiveness with respect to scenario-based paradigms.

**OUUTA, Optimization under Uncertainty: Theory and Applications; Invited Session**

- [1] D. McFadden (1978). Modelling the choice of residential location. A Karlquist et al., ed., Spatial interaction theory and residential location, 7596. North-Holland, Amsterdam. [2] E. Fadda, L. Fotio Tiotsop, D. Manerba, R. Tadei (2020). The stochastic multi-path Traveling Salesman Problem with dependent random travel costs. Transportation Science 54 (5), 1372-1387.

## HCM, Health Care Management; Invited Session

TU 14:10 PM1 002

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*The value of exploiting information in Logic-Based Benders Decomposition for chronic outpatients scheduling by Answer Set Programming*

Chronic patients living at home often need to take tests or receive treatments (health services in general) at hospital premises in a periodic way, as prescribed by well-assessed clinical pathways. In addition, due to increased life expectancy, the number of elderly patients having several Non-transmissible Chronic Diseases (NCDs) at the same time (comorbidities) is steadily growing; these patients must follow several clinical pathways at the same time, thus making health service synchronization of paramount importance to ensure system efficiency and patients satisfaction. A further source of complexity is due to timing conflicts potentially arising between health services: for example, a treatment with a certain drug may invalidate the results of a medical examination if the two health services are done too close in time. Therefore, an appointment schedule should obey several time constraints, such as predetermined service frequencies, beside complying with patient needs. Moreover, resource availability, regarding both personnel and devices at hospital care units, is limited, thus reducing the options for booking. This criticality has been further exacerbated by the current pandemic situation in which, at hospitals, resources have been devoted mostly to patients with high intensity care needs. Inevitably, this has had negative effects on the management of chronic patients: on the one hand, many screening or monitoring activities have been delayed, and in many cases cancelled; on the other hand, many patients have preferred to avoid attending hospitals for fear of becoming infected. For these reasons, it is estimated that the service demand for chronic patients will grow significantly in the near future. This suggests managing the scheduling of the clinical pathways of enrolled patients in a centralized manner. From the patient point of view, synchronizing different services reduces the number of accesses to the hospital or even avoids potential duplications that may arise when the same health service is present in different protocols. In this work, we provide a declarative approach to this challenging problem, encoding it in Answer Set Programming (ASP). Computational results show that when all of the constraints are given in one shot, the resulting monolithic approach soon fails to provide a feasible solution as the dimension of the problem grows. In order to

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improve the scalability of the monolithic approach, we propose a decomposition of the problem inspired by Logic-Based Benders Decomposition (LBBD), a technique that extends Benders decomposition principles to other formalisms, such as Constraint Programming. According to LBBD, a master problem and a set of independent sub-problems are iteratively solved until all subproblems admit a feasible solution. Master problem and subproblems efficiently communicate and exchange information to reduce the search space. The propagation of information from one subproblem to others is of key importance in the design of an efficient system. The computational experience will thus pursue two targets: first, we will show the impact on efficiency of using decomposition instead of the monolithic approach; second, we will compare several ways of propagating information. The decomposition algorithms as well as the monolithic approach will be tested on realistic instances.



**TU 14:30 PM1 002**

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*An approach to healthcare services decision-making using fuzzy ELECTRE III. An outpatient chemotherapy service application.*

Each day, healthcare institutions face the challenges of maintaining high-quality care and patient satisfaction while dealing with budget restrictions and a constantly increasing patient load. Oncology hospitals share the same struggle. An outpatient chemotherapy service is a complex care system that includes a multi-step process, complex procedures and interdisciplinary caregivers. Bringing changes and improvements need to be carefully considered and accepted by all stakeholders. In such a context, we propose a decision-making approach based on business process improvement (BPI) and multi-criteria decision making to help an oncology department in their reorganization. BPI is used as a tool to structure the decision-aid process, and to identify the stakeholders, the improvement solutions and the criteria to assess them. As there is some ambiguity in the stakeholders consensus on the improvement solutions, a fuzzy-ELECTRE III method is used. An online questionnaire is given to ten stakeholders to identify the relative importance of the improvement solutions over the selected decision criteria. Their preferences are assessed and the concordance, discordance and credibility matrices are built. We have decided to add the weights of stakeholders characteristics to the decision matrix to include the differences of perspectives and experiences. A sensitivity analysis is finally performed to study the impact of a change in the methods parameters. Results provide the priorities and the least preferred options for the outpatient services.

**TU 14:50 PM1 002**

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*A framework for at-home blood collection considering donor preferences*

In all health care systems, Blood Donation Supply Chains (BDSCs) play a fundamental role in several sectors, including hematology, trauma management and surgery. According to recent statistics (2019), the production of blood units for transfusion still falls short of satisfying the ever-increasing demand. This is due to a combination of factors, the main one being that blood can only be produced from human donors. Meeting demand has always been the main objective of the system, and several decision tools have been developed during the years to help reach it. However, during the COVID-19 pandemic, new and unexpected issues emerged. As blood drives were cancelled because of lockdowns and donors feared going to donations centers, shortages of units have increased dramatically. This is due to the lack of a direct channel between donors and blood banks. According to the Italian National Blood Center, in April 2020 the production of red blood cells was 36.4% less than the one of the previous year. At the same time, healthcare services are now moving towards a more decentralized paradigm. Considering these factors, in this work we consider an integrated framework to collect blood directly at the donors homes. To do so, we link the Blood Donation Appointment Scheduling (BDAS) and the Multi-Trip Vehicle Routing Problem with Time Windows (MTVRP-TW) problems in an organic way. Our approach consists of three planning phases: in the first one, we create possible time slots for donor appointments, with the aim of balancing the production of the different blood types, to ensure better manageable stock levels. Then, we turn these slots into real appointments, according to the received booking requests. Here, we compromise between the preferences expressed by calling donors and the requirements of the center, including scheduling and routing constraints. Lastly, a fleet of bloodmobiles is dispatched to perform the collection. The second and third phases are linked in such a way that the outcome of the former serves the purpose of helping the computation of the latter, providing an improved starting point. The proposed integrated framework is then tested and validated against data obtained from the most prominent Italian blood provider. We also prove the cost-effectiveness of the implementation of the proposed solution.

**HCM, Health Care Management; Invited Session**

TU 15:10 PM1 002

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*Patient Appointment Scheduling for Chemotherapy treatments*

The number of patients affected by cancer is expected to increase in the next years and, thus, the need for chemotherapy treatments will increase accordingly. We assume that chemotherapy treatments are delivered in an outpatient setting. Further we consider a cancer centre shared by different specialties where patients affected by different pathologies are treated. Managing the activities of shared cancer centres involves different decisions hierarchically linked (Lamè et al. 2016). First, at a strategic level, the capacity planning of the main resources involved must be determined. Then, at a tactical planning level, the available resources (such as beds, seats, nurses, clinicians, rooms for visit) must be allocated to the clinical specialties. At this stage the cyclic timetable determines the days when the different cancer groups are treated, referred to as Master Chemotherapy Planning (Carello et al. 2022). The clinician rostering over a mid-term planning horizon that covers the cyclic schedule must be determined, as well. Finally, at an operational level, the assignment and sequencing of patients needing chemotherapy must be determined for each day of a given planning horizon (Garaix et al., 2020). In this work, we focus on the operational level decision. We assume that the resources have been assigned to the pathologies, and that in each day the assignment of rooms to pathologies and clinicians is given. The set of days of the week in which patients can be treated, depending on their pathology, is therefore known as the solution of by ad hoc optimization models (Carello et al., 2022). The obtained weekly pattern repeats over a month. In this work, we consider the problem of assigning patients to days in the considered planning horizon. Further, we solve the appointment scheduling problem for each day. The problem can be seen as a multi-appointment scheduling problem (Marynissen and Demeulemeester, 2020) where we have to decide the starting time of each activity involved in the day hospital (in particular, oncologist visit and infusion delivery) for each patient. We consider different objectives using a patient centered approach aimed at maximizing the quality of the patient experience. We formulated the problem as a multi-objective optimization model and we tackle the problem by sequentially solving three ILP models, in a lexicographic multi-objective fashion. The models and solution procedure are tested on real data from an Italian hospital.

[1] Marynissen J., Demeulemeester E. (2020). Literature review on multi-appointment scheduling problems in hospital settings. *European Journal of Operational Research*, 272 (2), 407-419. [2] Carello, G., Landa,

P., Tànfani, E., Testi, A. (2022). Master chemotherapy planning and clinicians rostering in a hospital outpatient cancer centre. *Central European Journal of Operations Research*, 30, 159-187. [3] Lamè G., Jouini O., Stat Le Cardinal J. (2016). Outpatient chemotherapy planning: A literature review with insight from a case study. *IIE Transactions on Healthcare System Engineering*, 6(3), 127-139. [4] Garaix T., Rostami T., Xie X. (2020). Daily outpatient chemotherapy appointment scheduling with random deferrals. *Flexible Services and Manufacturing Journal*, 32(1), 129-153.

## Applications of OR; Contributed Session

TU 14:10 PM1 003

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*Evaluation of economic impacts for a demand response program  
within a sawmill*

In this paper, we propose an economic evaluation method for a typical sawmill in Quebec, Canada, which is considering participating in a Demand Response (DR) program such as that provided by Hydro-Quebec, the local electricity utility. In this method, the variation in costs associated with program participation is tracked, including unmet demand, inventory utilization, and electricity bill costs against potential revenues generated from participation in DR events. These are evaluated for different scenarios with a varying number of DR hours that could occur during winter. For this purpose, a suitable mathematical model was selected from the literature. Using real data collected between December 2019 and February 2020 and employing techniques based on demand shedding and demand shifting at the planning stage, the results revealed that participating in Hydro-Quebec's DR program is possible with limited backorder quantities. It was also shown that each additional production hour added to the weekly calendar, load shifting strategy, reduced costs by about 70%, in the case of 80 DR hours per winter season. Furthermore, a 0.44% cost reduction can be achieved for DR events of 16 hours by adding 2.5 hours per week of overtime to the production calendar (about C\$ 17,665.40 profit).

**TU 14:30 PM1 003**

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*A Branch and Cut algorithm for the Flying Sidekick Traveling Salesman Problem*

Last mile logistics (LML) is one of the most important and expensive part of the freight distribution process in a supply chain. LML role is not going to change in the future since we are observing an always increasing shift away from physical stores to digital shopping. In this context, the integration of new distribution technologies in the delivery systems, specifically drones, has been investigated by several companies to reduce the LML costs. The most promising delivery system, in terms of emissions and completion time reduction, consists of a truck and a drone operating in tandem for the parcel delivery to the customers. These new drone-based delivery systems have led to the definition of new and complex decision and optimization problems for which operations research methodologies represent a valuable support tool. In this context, several contributions have appeared in the last years providing ILP and MILP formulations for these kinds of problems. Nevertheless, these formulations suffer from dimensional drawbacks which make their solution impracticable even on small instances. In this work, we propose an exact approach for one of these problems, the flying sidekick traveling salesman problem (FS-TSP) [3]. It is a variant of the TSP where routing decisions are integrated with customer-to-drone and customer-to-truck assignment decisions and truck-and-drone synchronization constraints. The objective is the minimization of the time required to serve all the customers, considering drone payload capacity and battery power constraints. Big-M constraints to take into account the synchronization issue, are used by almost all the formulations proposed in literature [2]. In [1][4] the synchronization constraints are tackled in a column generation fashion. In this work a compact formulation without Big-M constraints is presented and solved by using a Branch and Cut approach. The proposed method has been experienced on a large set of benchmark instances. Computational results show that it either is competitive or outperforms the best exact approach present in literature for the FS-TSP.

**Applications of OR; Contributed Session**

**TU 14:50 PM1 003**

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Studi di Siena

*Real-time optimization for a Digital Twin of a robotic cell with human operator*

Digital Twins (DTs) can support the simulation, planning, and optimisation of the firms operations, but their adoption may be hindered by the role played by human operators. Indeed, differently from machines, human behaviours are largely characterized by nondeterministic nature, thus requiring that constant monitoring of the manufacturing system is accompanied by the development of real-time simulation and optimization algorithms. This paper presents the DT of a robotic cell for the manufacturing of Printed Circuit Boards (PCBs). The human operator oversees the management of the defective PCBs and the replenishment of the necessary materials for the cell but may also carry out some tasks otherwise performed by the robotic arm. The cell is autonomously optimized by the real time optimization algorithm keeping into account and adapting to the behaviour of the human operator. The optimization process guides the human operator by suggesting, without enforcing, the desired next moves. To deal with the uncertainty related to the human operator, we developed a simulation-optimization algorithm based on the Approximate Dynamic Programming framework. The algorithm evaluates the set of the available moves by simulating the behaviour of two independent agents (i.e., the robotic arm and the human operator) and selects the most promising moves for both these agents. Through an extensive experimental campaign and appropriate statistical analyses, we show how the productivity of the cell is scarcely affected by the behaviour of the human operator. These results may enrich the limited literature on DTs with human operators and provide useful insights to manufacturing companies interested in the implementation of robotic cells based on DTs.

**TU 15:10 PM1 003**

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Politecnico di Torino  
Manerba, Daniele, Università degli Studi di Brescia; Crainic, Teodor  
Gabriel, CIRRELT

*A time-space multi-network modelling approach for the Location-Transshipment Problem in Sychromodal Logistics*

We study the tactical planning problem of a Logistics Service Provider (LSP) that must secure contracts with transshipment terminals for many months of operational activities. During that period the LSP needs to manage many customers origin-destination shipments through different types of services. The objective of the LSP is to minimize the costs for contracting and using the terminals plus the service costs to transport, handle, and store commodities. In the context of synchronomodal logistics [1], we consider truck, rail, barge, and ship as available transport modes to perform long-haul shipments. An important synchronomodality feature considered in our work regards the shipments flow synchronization addressed by considering penalties for late collection, early delivery, and late delivery. We first define a new MILP formulation variant of the classical Hub Location Problem [2], namely the Location-Transshipment Problem with Synchronized Multi-Commodity Flows. Then, we further model the problem using a time-space multi-network in which the time dimension and the time-dependent parameters are hidden within time-space nodes and arcs [3]. Given this model, we present an economic analysis to assess how much a more flexible environment, like the one required in the implementation of synchronomodality, can affect operational costs. For this aim, we compare different types of instances in which some cost parameters vary depending on how much terminals and customers are flexible. Moreover, we present a solution method based on cutting-planes to overcome the computational limits of using a commercial solver as a black-box tool. We will present the validation of our modeling and solving methodology through an extensive computational campaign. Note that the modelling approach adopted could be relevant for other multi-periodic hub location problems.

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**Applications of OR; Contributed Session**



**TU 15:30 PM1 003**

**Carlo Filippi** `carlo.filippi@unibs.it`

Università degli Studi di Brescia

*On crowd-shipping using public transport: MILP model and empirical evaluation*

Crowd-shipping is a promising shared mobility service that involve the delivery of goods using non-professional shippers [1]. One of the main goals of crowd-shipping initiatives is to reduce congestion and pollution in city centers. However, in most crowdshipping initiatives, the crowd rely on private motorized vehicles and hence the environmental benefits could be small, if not negative. Conversely, a crowd-shipping service relying on public transport should maximize the environmental benefits. Motivated by this observation, our aim is to model a crowd-shipping service based on public transport and to assess the potential economic impact of using bus- or metro-based crowd-shipping coupled with a traditional home delivery service. We consider a shipper that must deliver packages to customers located in an urban area served by a metro service using two delivery modes: home delivery and crowd-shipping. Home delivery is carried out by vehicles that visit customer locations; crowd-shipping is carried out by metro commuters using lockers located at the stations and supplied by the vehicles. A customer is compatible with crowd-shipping if her/his home is sufficiently close to a metro station and the required parcel is fitted for lockers. In this case, she/he can be served either by home delivery or by crowd-shipping. Otherwise, the customer must be served by home delivery. Essentially, the carrier has to decide: which customers to assign to crowd-shipping among those compatible with this delivery mode; how many vehicles are necessary to perform the delivery tasks; how to route the vehicles. We allow two crowd-shipment rewarding schemes: either fixed (possibly null) or proportional to the size of the package. The decision criterion for the carrier is total cost minimization. The resulting problem includes characteristics of the VRP with Occasional Drivers [2] and the VRP with Transshipment and Delivery Options [3]. We derive a MILP formulation including restrictions on the availability of crowd-shippers, locker capacity, and vehicle capacity. The model is implemented using Python with Gurobi solver and a computational study based on the municipalities of Brescia and Milan is performed. We get insights on the economic advantages that a metro-based crowd delivery option may have for a carrier, and we point out possible modeling and algorithmic developments.

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occasional drivers. *European Journal of Operational Research*, 254(2), 472-480. [3] Vincent, F. Y., Jodiawan, P., Redi, A. P. (2022). Crowdshipping problem with time windows, transshipment nodes, and delivery options. *Transportation Research Part E: Logistics and Transportation Review*, 157, 102545.

## OPTSM, Optimization in Public Transport and Shared Mobility; Invited Session

TU 14:10 PM1 Auditorium A

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Roma Tre University, Department of Engineering  
Bigi, Federico, Department of Engineering, University of Luxembourg;  
D'Ariano, Andrea, Department of Engineering, Roma Tre University;  
Viti, Francesco, Department of Engineering, University of Luxembourg.

### *A MILP Model for the Wagon Shunt-in Shunt-out Problem in Rail Freight Transport*

The European Union plans to double the freight rail traffic by 2050, both to cut pollution emissions and to mitigate the congestion by shifting traffic from road to rail networks. One of the challenges is to minimize the high costs associated with the shunting yard operations (including the cost of wagon maintenance), while maintaining an acceptable level of service. Due to the complexity of the studied problems, shunting operations are usually managed based on practitioners' experience. In this context, we propose a MILP model for wagon placing-in and taking-out operations on outbound and inbound trains along with a multi-objective Dijkstra algorithm (MDA), in which each arc bears a multidimensional vector of cost attributes, to deal with scalability limitations. Our methodology aims to minimize the number of shunting operations and, consequently, both the operating costs and the emissions of shunting locomotives. The proposed mathematical model considers the number of shunts as well as weighted delay terms of outbound trains in the objective function, while rolling stock maintenance and composition constraints are related to wagons. We propose the linearization of several constraints as well as a pre-processing phase to deal with the assumptions related to the fixed size of inbound and outbound trains. The MDA, developed in Python, represents each inbound train as a directed graph by adding weights on its arcs calculated by using the multi-objective function of the model. The algorithm finds the MultiObjective Shortest Path (MOSP) from the first wagon requiring maintenance to the last one. This path gives information on the wagons that must be shunted. To test the effectiveness of our methodology, we have considered the 2020 train timetable for freight trains in the Bettemburg Eurohub Sud Terminal (Luxembourg) and we have assessed different KPIs, linked both to tactical and strategical objectives, such as efficient wagon fleet management, to assign a smaller wagon pool to the shunting yard. Computational results show how the criteria for choosing which wagons should be taken-out from the inbound train and should be inserted in the outbound train might significantly impact the various

**OPTSM, Optimization in Public Transport and Shared Mobility;  
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KPIs analyzed, in terms of time to shunt plus fixed and variable costs, that are related to depot costs and cost per shunt wagons availability in the shunting yard. The MILP model is used in the Antoine Project, financed by CFL (Société nationale des chemins de fer luxembourgeois), as an add-on tool to the Antoine event-based simulator. This simulator connects the MILP model with another mathematical model that, based on the shunting decisions resulting from the MILP model, exploits the potential of multiple placing-in policies.

**TU 14:30 PM1 Auditorium A****Federico Bigi** federico.bigi@uni.lu

University of Luxembourg  
Bosi, Tommaso, Roma Tre University; Pineda-Jaramillo, Juan, University of Luxembourg; Viti, Francesco, University of Luxembourg; D'Ariano, Andrea, Roma Tre University

*A MILP Model for the Wagon Shunt-in Problem in Multimodal Rail Freight Transport*

In a context where Europe aims to become climate-neutral by 2050, freight trains will play a key role in this transition. By now, almost 78% of goods are transported by road, with double the freight train traffic expected in the next 30 years to reach carbon neutrality. Looking at an already overcrowded network system, the optimization of shunting operations, defined as the movement of multiple rolling stocks inside a shunting yard, has already proved to be impactful in terms of costs to be sustained by the companies, especially due to outbound trains' delays and cancellations. Moreover, due to the problem's complexity, the shunting operations are usually managed by practitioners in a sub-optimal way. Our study aims to formalize the shunt-in problem, defined as the modality to choose and place rail-cars stored in the shunting yard inside an outbound train given a certain demand of wagons. This demand is obtained by the relative shunt-out problem, defined as the problem of choosing which wagons have to be extracted from an inbound train  $T$  when a new composition has to be created for the corresponding outbound train. The basic shunt-in problem can be modeled as an ILP, specifically as a general set-partitioning problem, with the objective of minimizing the time required to complete all the shunt-in operations. For this problem, we define two sets of wagons: the wagons inside the inbound train that must be replaced, and the rail-cars in the shunting yard that are suitable to be shunted in. Each wagon from the shunting yard can be placed inside the freight train with a specific cost and respecting the composition request for the wagon types of the outbound train. The ILP model is then extended to a MILP, proposing different shunt-in policies expressed by weighted objective functions, such as the minimization of the actual mileage of wagons chosen to be shunted in. The suitability of a wagon in the shunting yard is related to maintenance and category constraints. The MILP is then solved via CPLEX solver and injected as an input in an event-based simulation framework developed by University of Luxembourg. Several analyses are carried out for the validation of these models, exploiting the 2020 rolling stock schedule used by the Luxembourg National Railway Company with a particular focus on the Intermodal terminal - EuroHub Sud, a combined rail-road transport terminal located in Bettembourg, Luxembourg, analyzing KPIs in terms of Feasibility, Service Level and Operations performed, focusing especially on the wagon fleet and delay of outbound trains. Results

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show that different shunt-in policies can impact the overall percentage of delayed trains, number of wagons used and shunting operations to be performed.

**TU 14:50 PM1 Auditorium A****Anna Livia Croella** `annalivia.croella@uniroma1.it`Sapienza University of Rome  
Mannino, Carlo, SINTEF; Ventura, Paolo, IASI*Dynamic Discretization Discovery applied to train traffic re-scheduling*

Train scheduling is a critical activity in rail traffic management, both off-line (timetabling) and on-line (dispatching). Time-indexed formulations for scheduling problems are stronger than other classical formulations, like big-M. Moreover, they can be easily adapted to cope with complicating constraints and non-linear objectives. Unfortunately, their size grows usually very large with the size of the scheduling instance. As a consequence, time-indexed formulations are typically not fit to attack real-life instances of job-shop scheduling problems, especially when fast, online responses are required. Moreover, the approximation introduced by time discretization often leads to solutions which cannot be realized in practice. Dynamic Discretization Discovery (DDD), recently introduced by Boland for the continuous-time service network design problem, is a technique to keep at bay the growth of time-indexed formulations and thus response times and at the same time ensure the necessary modelling precision. Exploiting and extending the DDD paradigm, we develop a primal-dual approach to train dispatching and, more in general, to job-shop scheduling. The result is a restricted TI formulation and a procedure with running times comparable with the best alternatives presented in the literature on our real-life instances of train dispatching. Furthermore, the method implemented does not suffer by the approximation error introduced by a standard time discretization and seems to be very promising, not only in a railway context but, more generally, for the broader field of job-shop scheduling.

**TU 15:10 PM1 Auditorium A****Pierre Hosteins** pierre.hosteins@univ-eiffel.fr

University Gustave Eiffel

*Decomposition methods for an integrated rail-rail transshipment yard problem*

The optimised management of freight transshipment yards is a very complex problem resulting from the articulation of several difficult and intricate problems. Many yard resources must be scheduled, such as tracks, teams and cranes, so as to minimise the time required to load and unload containers on freight trains. Recently, a few works have tried to handle several transshipment yard subproblems within a single optimisation approach, particularly using mathematical programming. The work of Cichenski et al (2017) handles the separation of trains in bundles, the trains positioning on tracks and the placement of containers on outgoing trains. We propose to extend the MILP approach of Cichenski et al (2017) to consider the division of the tracks in different areas managed by the different cranes in order to take into account a more realistic objective function. Moreover, we propose to apply Benders Decomposition to the obtained MILP, after proving that many integer variables can be relaxed to continuous ones. Depending on the state of advancement, we will also discuss how to compare the obtained results with those of approaches which solve the respective subproblems sequentially, and how to integrate the remaining crane and shuttle cars scheduling problems.



**TU 15:30 PM1 Auditorium A****Bianca Pascariu** bianca.pascariu@uniroma3.it

Roma Tre University

Samà, Marcella, Roma Tre University; Pellegrini, Paola, Université Gustave Eiffel; D'Ariano, Andrea, Roma Tre University; Rodriguez, Joaquin, Université Gustave Eiffel; Pacciarelli, Dario, Roma Tre University

*Improving train punctuality by optimized train route selection in decision support systems*

The Train Routing Selection Problem (TRSP) is the combinatorial optimization problem of selecting the best train route alternatives, for each train in a rail network. Solving the TRSP aims to limit the number of rerouting variables of the train rescheduling problem, formalized as the real-time Rail Traffic Management Problem (rtRTMP) and intended to minimize train delays. In the TRSP, the benefit of using specific subsets of routes in the rtRTMP is assessed by considering estimations of costs due to scheduling decisions. The impact of TRSP solution on the rtRTMP has been analyzed in the literature by using RECIFE-MILP, a rtRTMP solver based on a MILP model formulation. In this paper, we propose the extension of the TRSP validity for the rtRTMP, regardless the specific model and solution approach used for the rtRTMP, and the objective function optimized. In addition to RECIFE-MILP, we consider for the rtRTMP the decision support system AGLIBRARY, developed at Roma Tre University, which solves an alternative graph model of the problem. We then propose the formulation in the TRSP of a selection of rtRTMP objectives functions, such as the minimization of the cumulative consecutive train delay, the train travel time, the number of delayed trains, and the maximum consecutive delay. We study the extent to which the TRSP effectiveness depends on the correlation between the TRSP and rtRTMP objective functions. The computational analysis is performed on a real case study: the line around the city of Rouen.

## MUOS, Multicriteria Optimization for sustainability; Invited Session

TU 14:10 PM1 Auditorium B

Lavinia Amorosi [lavinia.amorosi@uniroma1.it](mailto:lavinia.amorosi@uniroma1.it)

Sapienza University of Rome  
De Santis, Marianna, Sapienza University of Rome

*A criterion space search algorithm for bi-objective mixed integer linear programs*

In this talk, we focus on bi-objective mixed integer linear programming problems (BOMIP) presenting a new algorithm able to detect the complete non-dominated set. The design of this exact method is motivated by multi-objective mixed integer linear models arising from real world applications and the need of the complete exploration of their Pareto frontiers. In particular, we mention an application in the energy sector related to the management and sizing of a battery storage system. The algorithm works in the criterion space, alternating the resolution of single objective mixed integer linear problems and bi-objective linear problems. We prove that, after a finite number of iterations, a list of points and segments, containing the Pareto frontier, is generated. This list is filtered by a post-processing procedure in order to eliminate potentially dominated regions of the image set.

**TU 14:30 PM1 Auditorium B****Daniele Patria** daniele.patria@uniroma1.it

Sapienza, University of Rome  
De Santis, Marianna, Sapienza University of Rome; Eichfelder, Gabriele,  
TU Ilmenau; Warnow, Leo, TU Ilmenau

*Using Dual Bounds for Multiobjective Mixed Integer Quadratic Programming*

In this talk, we present an algorithmic framework for solving Multi-Objective Mixed Integer Convex Quadratic Programs (MOMICQP) with linear constraints. The framework is based on two phases. First, a branch-and-bound method is applied to detect promising integer fixings, that are needed to initialize the second phase, where the Pareto front of the (MOMICQP) is detected up to an according precision using the solver HyPaD. The branch-and-bound works by fixing subsets of variables to integer values. Lower bounds are computed by addressing the dual problems of the continuous relaxations of the restricted objective functions. A major advantage is that the expensive calculations are performed in a preprocessing phase so that the nodes in the branch-and-bound tree can be quickly enumerated. Suitable pruning strategies are presented. Experiments on biobjective instances and on instances with three objectives are shown.

**TU 14:50 PM1 Auditorium B****Justo Puerto** puerto@us.es

Universidad de Sevilla

Pozo, Miguel A, Universidad de Sevilla; Roldan, Ignacio, Universidad de Sevilla

*The biobjective minimum-cost Perfect Matching and Chinese Postman Problems*

This paper analyzes the biobjective versions of the perfect matching problem and the Chinese postman problem. We consider supported and non-supported non-dominated solutions of both problems resorting to scalarization methods and different two phase strategies. We also study the issue of finding the entire set of non-dominated solutions of the Chinese postman problem by solving the corresponding biobjective matching problems and prove that unlikely the single objective case, in general, this strategy does not provide the correct solution of the biobjective problem. We derive sufficient conditions that ensure under which conditions one can expect to solve the biobjective Chinese postman problem by solving matching problems. Extensive computational results are reported assessing the usefulness of our approaches.

**TU 15:10 PM1 Auditorium B****Marianna De Santis** mdesantis@diag.uniroma1.it

University of Rijeka, Faculty of Maritime Studies  
Luca, Benvenuti, DIAG, Università di Roma La Sapienza; Alberto,  
De Santis, DIAG, Università di Roma La Sapienza; Daniele, Patria,  
DIAG, Università di Roma La Sapienza

*Designing sustainable diet plans by solving a tri-objective 0-1 linear problem*

In this talk, we present a tri-objective 0-1 linear model, built to design nutritionally adequate and healthy diet plans, minimizing their environmental impact. The diet plans refer to two-week full-board menus for nursing homes and we consider the carbon, water and nitrogen footprints as conflicting objectives to be minimized. Energy and nutrient contents are constrained in suitable ranges suggested by the dietary recommendation of health authorities. In order to compute the non-dominated solutions of the tri-objective 0-1 linear model an algorithm that combines the epsilon-constrained method and suitably defined weighted sum scalarizations is devised. We analyze our method and prove that it is able to detect the complete Pareto front within a finite number of iterations. Results obtained on real world data are reported and discussed.

## **OUUTA, Optimization under Uncertainty: Theory and Applications; Invited Session**

**TU 16:30 PM2 001**

**Andrea Spinelli** andrea.spinelli@guest.unibg.it

Università degli Studi di Bergamo  
Maggioni, Francesca, Università degli Studi di Bergamo

*A Robust Optimization Model for Nonlinear Support Vector Machine*

In this contribution we present a novel optimization approach for Support Vector Machine (SVM), with the aim of separating two sets of points by means of a nonlinear decision boundary. Our approach extends the deterministic and linear predictor proposed in [1] to a nonlinear classifier by including a kernel function in the model. Moreover, we consider the case in which training data are plagued by uncertainty. To tackle the problem, we formulate a robust optimization model that generalizes the technique proposed in [2] to a class of uncertainty sets bounded by a  $p$ -norm and by including a nonlinear classifier [3]. The deterministic model and its robust counterpart reduce both to linear programs which can be shown to be computationally tractable. Preliminary numerical results on real-world datasets show the performance of the proposed approach.

[1] Liu, X., Potra, F.A., 2009. Pattern separation and prediction via linear and semidefinite programming. *Stud. Inform. Control* 18, 7182. [2] Faccini, D., Maggioni, F., Potra, F.A., 2022. Robust and distributionally robust optimization models for linear support vector machine. *Comput. Oper. Res.*, to appear. [3] Trafalis, T.B., Gilbert, R.C., 2006. Robust classification and regression using support vector machines. *Eur. J. Oper. Res.* 173, 893909.

**OUUTA, Optimization under Uncertainty: Theory and Applications; Invited Session**

**TU 16:50 PM2 001**

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DISMA, Politecnico di Torino

*Robust Approaches for a Two-Stage Assembly-to-Order Problem.*

Assembly to order is a production strategy where components are manufactured under demand uncertainty and end items are assembled only after demand is realized. Risk-neutral approaches aim to maximize the expected profit. However, this approach may fail if heavy-tailed or multimodal distributions are likely to generate significant disruptions or if the shrinking life of products is considered. Conversely, risk-averse models may tackle these problems. In the paper, we deal with an assembly-to-order problem, modeled as a two-stage stochastic linear programming problem considering the introduction of a classical risk measure from finance: the conditional value-at-risk. We examine the characteristics and the performance of the model by means of a large number of out-of-sample scenarios.

**TU 17:10 PM2 001**

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

Sara, Khodaparasti, Department of Mechanical, Energy and Management Engineering, University of Calabria

*Dynamic Pricing in the Electricity Retail Market: A Stochastic Bi-Level Approach*

This paper investigates the dynamic pricing problem in the retail market and propose a bi-level approach to define time-differentiated electricity rates which are announced with short advance. The pricing decisions are affected by the procurement plan that the retailer defines also exploiting the local energy system composed by Photovoltaic panels and a battery storage device. In the proposed bi-level formulation, the retailer acts as leader deciding first about the electricity rates, whereas the consumer acts as follower, reacting to the announced tariff changing the consumption pattern. To account for the inherent uncertainty affecting the main parameters entering the decision process a stochastic formulation is proposed. By exploiting the structure of the problem a single level reformulation is provided. Preliminary numerical results carried out on a real case study are presented and discussed.

**OUUTA, Optimization under Uncertainty: Theory and Applications; Invited Session**



## HCM, Health Care Management; Invited Session

TU 16:30 PM2 002

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*Mid term scheduling of medical staff at a hospital network by Answer Set Programming: a case study*

This study deals with a staff scheduling problem concerning physicians working at few hospitals belonging to a local area network. Due to the pandemic situation, these hospitals have been subject to several reorganizations in terms of both staff and services allocation. These changes have exacerbated previous strains to manually provide working schedules able to cover the service, meet legal requirements, and be perceived as a fair workload allocation. On the one hand, the problem shares the features of classical scheduling problems, i.e., a set of tasks, which repeat on a weekly basis, must be assigned to a set of workers according to a set of rules, possibly meeting a few criteria. On a regular basis, service can be covered without overtime. Since physicians get paid a fixed monthly salary, any feasible schedule has the same monetary cost for the administration. Therefore, the primary focus is not on cost rather than on feasibility. On the other hand, beside the challenges posed by feasibility constraints, fairness related issues sharply arise in the mid term. In fact, while working time is constrained by law, differences arise because of the kinds of tasks in the physician rosters. Since the variety of tasks is high and each physician has different skills, achieving fairness by simply rotating tasks among different people is not viable. In particular, there are no two identical professional profiles, so that a rotation is to be directly mapped on to specific individual. Moreover, because of this diversity, a priori there is no ideal workload threshold whose distance from may return a measure of fairness. Indeed, more elaborated attributes should be measured to make a comparison possible, taking into account also the spatial distribution of the activities. In our proposal, fairness is sought off by diversification in the short term and possibly achieved in the long one. To this aim, service must be scheduled over a mid term time period, such as few months, long enough to allow a certain degree of diversification within the schedule of each physician, as well as a fair distribution of the heaviest tasks (such as week end duties and night shifts) among all physicians. Long planning horizons, though, increase the problem size, which poses a challenge on the solution process performance. Moreover, beside compulsory requirements, many soft preferences are present (such as do not assign night shifts to older physicians). These tend to confine

HCM, Health Care Management; Invited Session

the returned solutions into a narrow field, which goes to the detriment of variety and, in turn, of fairness achievement. We propose to tackle the problem by Answer Set Programming, as it easily handles preferences and soft constraints. The aim is to provide the Hospital administration with a flexible tool that is easy to use and to customize, i.e., by fixing some shift assignment to someone or by changing priorities, to be leveraged for conflict resolution as well as to promptly react to sudden organizational changes. In the presentation we will focus on various modeling options regarding fairness representation, and how to enforce it over time. In particular, we will discuss a mathematical formulation for the objective function, which in the ASP environment is realized by way of soft constraints with different priority and weight, and will present results based on real data.

**TU 16:50 PM2 002**

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*The Ambulance Diversion phenomenon in an Emergency Department network: a case study*

The Emergency-Department (ED) overcrowding problem is regularly regarded as the main subject of many healthcare management-oriented studies. Such works are generally carried out by the means of a model of the patient-flow within a single ED, without considering the possibilities offered by the cooperation among EDs. In this article, such solution is examined and an ED network model is developed, focusing on the Ambulance Diversion problem. Then, the resulting Discrete Event Simulation (DES) model is studied employing a Simulation-Based Optimization (SBO) approach. Various scenarios are considered to analyze the first-aid network under different conditions, in order to obtain optimal operative performances without carrying unsustainable resource costs. As a case study, six EDs in the Lazio region of Italy were considered to build the network. The results show the obtained performances for each diversion policy, both in terms of patient waiting time and costs for the service providers. Moreover, a brand-new interface for the communication between the DES model and the Derivate-Free algorithm has been set up in our implementation, in order not to rely on external software.

## Applications of OR; Contributed Session

TU 16:30 PM2 003

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Morandi, Valentina, University of Brescia; Speranza, M. Grazia,  
University of Brescia

*Designing optimal paths in large crowded events*

There are several practical situations where the number of people simultaneously allowed in a specific area needs to be limited over time below a predefined threshold. This is often related to safety reasons, or the physical capacity of the venue. Well-known examples are shopping malls, theme parks, large expositions, and international events. In such situations, providing directions to people regarding where and when to go, as well as tracking where people are over time, can help to avoid overcrowding and provide people with a better and safer experience. Note that this has been a critical issue during the pandemic caused by the SARS-CoV-2 virus. In this talk, we present the Crowd Avoiding Routing (CAR) problem, which we define as follows. We consider a multi-period setting defined over a finite planning horizon. The planning horizon is discretized into a number of equally spaced time periods, each corresponding to, e.g., one minute, ten minutes, or one hour. We consider an environment where a set of physical points is given. We assume that this set comprises one entry point, one exit point, and a set of locations that provide a service. Examples of the latter are shops available in a mall, attractions in a theme park, or pavilions in a large exposition. Each of such locations is associated with a fixed capacity and a predetermined service time. We are given a set of requests, where each request is associated with a weight, a preferred start time, a maximum time available for the visit, and a set of desired locations. The weight of a request represents the amount of capacity consumed if that request visits a location. We assume that it is not mandatory to visit all the desired locations associated with a request, but a selection can be made if the capacity of some locations is not sufficient to accommodate simultaneously all requests. We also allow that a request stands in line before entering a location if the capacity available of the latter is not sufficient. In such a case, the request stands in line until a sufficient number of other requests, whose service started previously, leave the location. The CAR problem calls for determining an optimal set of coordinated paths, one per each request, so that the total number of desired locations not selected and the total time spent queuing is minimized. The main constraints of the problem are that the length of each path, that includes the travel, service, and queue times, must not be larger than the maximum time available of the associated request; and that, at any time period, the capacity of each location cannot be violated. Based

Applications of OR; Contributed Session

on a time-space network representation, we cast the CAR problem as a Mixed-Integer Program (MIP) and introduce a set of valid inequalities to strengthen the mathematical formulation. Computational experiments are given where the MIP is solved by means of a general-purpose solver on a set of instances generated by the authors. We discuss the computational effectiveness of the valid inequalities proposed, and present some insights on the potential benefits that can be achieved by using the solutions of the CAR problem as a tool to support decision-making processes.

**TU 16:50 PM2 003****Martina Luzzi** `martina.luzzi@unical.it`Department of Mechanical, Energy and Management Engineering,  
University of Calabria

Guerriero, Francesca, Department of Mechanical, Energy and Management Engineering, University of Calabria; Macrina, Giusy, Department of Mechanical, Energy and Management Engineering, University of Calabria; Triki, Chafi, Department of Engineering for Innovation, University of Salento, Lecce, Italy

*An auction mechanism in restaurant business*

An auction is a popular sales practice, in which every potential customer, called bidder, expresses an offer, named bid, for a particular product that is usually sold to the person who offers the highest price, (i.e., the winner of the auction). Although the auction mechanism is currently applied in many fields including procurement, luxury goods, electricity, art and rare collectibles, public-works contracts and sale of natural-resource rights, there are still some business where auction could be applied in an innovative and profitable way. In this study we focus on the application of auction mechanism, through a web platform, to the restaurant business. In particular, we propose some optimization models and strategies, aimed at winners determination and revenue maximization. Different types of auction mechanisms, like first price auctions, second price auctions and dynamic auctions, are implemented and tested. In addition, we consider several features of the restaurant business, such as the possibility to combine more tables to allocate larger groups of customers and the duration of the meal, hence, considering the tables as a renewable resource. Preliminary computational results have shown that the application of auction strategies to restaurant business is an effective way to achieve revenues.

[1] Guerriero F., Miglionico G., and Olivito F. "Strategic and operational decisions in restaurant revenue management." *European Journal of Operational Research* 237.3 (2014): 1119-1132. [2] Talluri Kalyan T., and Van Ryzin Garrett J. *The theory and practice of Revenue Management*. Springer (2004). [3] Triki C. "Using combinatorial auctions for the procurement of occasional drivers in the freight transportation: A case-study." *Journal of Cleaner Production* 304 (2021): 127057.

**TU 17:10 PM2 003**

**Veronica Mosca** veronica.mosca1996@libero.it

University of Calabria  
Guerriero, Francesca, University of Calabria; Matteucci, Massimiliano, PAC 2000A Conad Group

*Optimising the order picking process: CONAD case study*

The order picking is one of the most expensive and laborious operation in a warehouse. Optimising the picking activities involves several aspects that could be improved, such as the packing, layout design, storage assignment, zoning, batching, and routing. In this work we address the problem of optimising the picking activities of an existent warehouse of PAC 2000A CONAD (Consorzio Nazionale Dettaglianti) group. CONAD is an Italian cooperative system of entrepreneurs which operates the largest supermarket chains in Italy, and PAC 2000A is its biggest cooperative. After analysing the current process adopted by the company, and outlining the best practices, we focus on the re-optimisation of the process, proposing several strategies aiming at providing more efficient and effective picking solutions.

**Applications of OR; Contributed Session**

**TU 17:30 PM2 003**

**Petra Groelj** University of Ljubljana, Biotechnical Faculty  
Tjaa, midovnik, University of Ljubljana, Biotechnical Faculty

*Decision makers weights of importance based on the projection measure in DEMATEL*

EMATEL (Decision Making Trial and Evaluation Laboratory) is a method for identifying and evaluating the relationships between factors in a complex system, divided into cause and effect factors. Digraphs can help visualize the direction and strength of the relationships, while influence matrices represent them numerically. The results of the analysis of the interdependence between factors can be represented by the causal diagrams. A group of experts with different knowledge and experience should be involved in decision-making to better grasp all the important aspects of complex real world problems and to solve them satisfactorily. To improve the decisions, different importance of decision makers (DMs) should be taken into account. Subjective weights based on experts positions and objective weights based on different mathematical methods are two different approaches used in applications. In order to successfully manage the differences in DMs opinions that can lead to difficulties in the decision-making process, objective methods based on the similarity of DMs opinions are one way to assign importance weights to DMs. Although there are many studies that use the group DEMATEL, most assume that DMs are equally important. In order to contribute to more satisfactory and powerful group decision making, we present a new approach to derive objective weights of DMs in DEMATEL. It is based on the projection method that considers the distance and angle between two vectors. Its generalization to the matrices can be a suitable distance measure between two matrices representing the opinions of DMs. Although several projection measures have been proposed in the literature, we show that they are not suitable for DEMATEL. We present a new DProj method adapted for DEMATEL influence matrices. Larger DProj values indicate higher similarity between matrices. Based on DProj, we define the importance weights of DMs, with larger weights indicating greater closeness between DMs opinions and promoting higher agreement between DMs. To validate DProj-DEMATEL, some examples from the literature are given. To compare the results from the literature with the results of DProj-DEMATEL, the normalized Manhattan distance between the individual and group influence matrices is measured. The results show that DProj-DEMATEL is suitable for use in applications.



## OPTSM, Optimization in Public Transport and Shared Mobility; Invited Session

TU 16:30 PM2 Auditorium A

Majid Soolaki M.Soolaki@westminster.ac.uk

University of Westminster

Gurtner, Gérald, University of Westminster; Bolic, Tatjana, University of Westminster; Delgado, Luis, University of Westminster

*New mathematical model for extended arrival management capabilities*

The Extended arrival management (E-AMAN) concept is based on starting the arrival traffic sequencing earlier than is the case by the arrival management (AMAN). The E-AMAN extends the horizon at which to start sequencing from the airport terminal area further upstream, to enable more smooth traffic management through speeding up, or slowing down arriving flights. Current application of E-AMAN at Heathrow, with the horizon at 350NM reduces delay, operational costs, CO<sub>2</sub> emission and smooths delivery of arrival traffic to the runways. Here we propose an E-AMAN model that extends to 500NM. More specifically, the model incorporates three horizons: Tactical Horizon (100NM), Command Horizon (500NM), and Data Horizon (600NM). When a flight enters Data Horizon, the flight intentions are sent to the E-AMAN. When a flight enters Command Horizon, the optimizer is run to find optimal slot for that flight at the runway. Compared to previous optimisation processes, the E-AMAN takes into account the cost of delay and fuel for the airline instead of delay alone, and uses information on the distribution time of arrival to manage uncertainty (e.g. due to wind). Based on the optimal slot assigned, the E-AMAN issues a command to the flight, that can be to maintain initial speed, to speed up, or to slow down. It also assigns minutes of holding if delay cannot be absorbed during cruise. We will present some evidence of the efficiency of the optimisation process, in particular compared to a baseline scenario where the E-AMAN takes only delay into account and no uncertainty. We will show how this efficiency changes in different conditions, in particular relative to wind uncertainty.

**OPTSM, Optimization in Public Transport and Shared Mobility;  
Invited Session**

**TU 16:50 PM2 Auditorium A****David Garcia-Heredia** garciaherediad@ryanair.com

Ryanair Labs

Alonso-Ayuso, Antonio, Universidad Rey Juan Carlos; Laguna, Manuel,  
University of Colorado Boulder; Molina, Elisenda, Universidad Com-  
plutense de Madrid*Metaheuristic algorithm for the Air Traffic Flow Management prob-  
lem*

One of the biggest challenges that the global air traffic industry is currently facing is the saturation of the airspace and airports. That is, the mismatch between capacity (number of flights that want to be operated) and demand (what can be operated attending to safety conditions).

On a daily basis, this saturation problem mainly arises because of short-term factors such as weather, which can negatively affect flight conditions. When saturation issues are detected, the current practice is to modify the flight plan of some aircraft a few hours before their execution. That way, all the scheduled flights can proceed at the expense of some of them suffering some delay or having to fly a longer route. These modifications are included in what is denoted as Air Traffic Flow Management (ATFM).

Thus, the ATFM problem is about proposing the reschedule of some flights a few hours before their execution so: 1) the overall cost is minimized and, 2) safety (capacity) conditions are respected in airports and air sectors at all times.

To that end, we present here an integer programming formulation that permits MIP solvers to tackle large ATFM instances within minutes. The formulation is based on 4D graphs, resulting in most of the constraints being facets of the polytope. The decisions considered to modify the flight plans include ground and air delays, changes in the speed of the aircraft, and alternative routes.

For the largest instances arising in practice, we present a parallelizable matheuristic algorithm. The algorithm, capable of providing near-optimal solutions within minutes, consists of three phases: (1) generation of feasible solutions, (2) combination of solutions, and (3) solution improvement. In the three phases, the structure of the mathematical formulation proposed is largely exploited.

A large computational experience, which shows the goodness of the formulation and algorithm proposed, is presented.

Optimization in Public Transport and Shared Mobility 2 - Airline Op-  
timization

**TU 17:10 PM2 Auditorium A****Guglielmo Lulli** `guglielmo.lulli@unimib.it`

University of Milano-Bicocca &amp; Lancaster University management School

De Giovanni, Luigi, university of Padova; Lancia, Carlo, University of Milano-Bicocca

*Solving the European Air Traffic Flow Management Problem*

The air traffic industry is a strategically important sector of the overall world economy. Although air travel is currently one of the economy's sectors most affected by the COVID-19

epidemic, there is a general agreement among experts that the sector will recover. Indeed, all the major R & D programmes for modernizing the air transport systems around the world are continuing with their plan and long-term objectives, and perhaps even reinforcing the focus on resilient and network-based operations. One of the cornerstones of these initiatives is the implementation of the ICAO Trajectory Based Operations concept. Moreover, in the attempt of better satisfying airspace users' business objective and enabling a more collaborative decision-making environment in the air traffic flow management decision process, the concept of trajectory preference has been widely discussed.

In this talk, we present a novel data-driven optimization approach for air traffic flow management (ATFM). The proposed approach allows resolving demand-capacity imbalances while considering airspace users preferences. The model assigns a feasible 4D trajectory and a possible ground delay to each flight. The proposed approach has been tested on instances extracted from the Eurocontrol data repository. With more than 32000 flights considered, we solved the largest instances of the ATFM problem available in the literature in short computational times that are reasonable for practical application. As a by-product, we highlight the trade-off between preferences and delays as well as the potential benefit of the proposed approach.

The proposed approach has the potential of becoming the main engine of air traffic flow management tools.

**TU 17:30 PM2 Auditorium A****Luigi De Giovanni** luigi.degiovanni@unipd.it

Dipartimento di Matematica 'Tullio Levi-Civita' - Università di Padova  
Lulli, Guglielmo, Lancaster University Management School and Di-  
partimento di Informatica Sistemistica e Comunicazione - Università  
degli Studi di Milano Bicocca

*Data-driven kernel search for trajectory based air traffic flow man-  
agement*

In the Air Traffic Flow Management (ATFM) problem, we want to assign a flight plan to each scheduled flight, taking both the network manager's and the airspace users' perspectives into account: on the one side, safe operations and efficient use of airspace are required, on the other side, we have to consider the airspace users flying preferences [1]. In this talk, we explicitly consider routes' preference into account and, to this aim, we propose a trajectory based ATFM modeling framework, where a set of alternative flight plans is directly extracted from air traffic data repositories by means of data analytics. We thus build consistent trajectory option sets (in the spirit of [2]) and, moreover, we learn the preference of each flight for each option [3]. We propose an assignment formulation for the ATFM, where binary variables select a trajectory option and a delay for each flight, constraints limit total delays and airspace congestion, and the objective function maximizes airspace users preferences. Realistic daily instances lead to prohibitively large Integer Linear Programming models, and we consider kernel search inspired matheuristics: they solve a sequence of models restricted to a suitable variable subset and, at each iteration, a kernel of variables is expanded by a further bucket. We compare different implementations where buckets are a-priori defined based on a linear relaxation, or they are dynamically determined by machine learning techniques. In particular, a tree classifier, trained on reduced-size instances, selects the next bucket by considering features of the candidate variables, the current solution and the search state. Preliminary computational results show that appropriate configurations of the methods are able to solve realistic daily instances within limited optimality gap and acceptable running times.

[1] Dal Sasso, V., Djeumou Fomeni, F., Lulli, G., Zografos, K.: Incorporating stakeholders priorities and preferences in 4D trajectory optimization. *Transportation Research Part B* 117:594609, 2018. [2] Estes, A.S, Ball, M.O.: Alternative Resource Allocation Mechanisms for the Collaborative Trajectory Options Program (CTOP). In *Thirteenth USA/Europe Air Traffic Management Research and Development Seminar*, 1-9, 2019. [3] Lancia, C., De Giovanni, L., Lulli, G.: Data analytics for trajectory selection and preference-model extrapolation in the European airspace. In: *The OR2018 Proceedings*. Springer, 1-7, 2018.

**OPTSM, Optimization in Public Transport and Shared Mobility;  
Invited Session**

## AMUO, Advances in Multiobjective Optimization; Invited Session

TU 16:30 PM2 Auditorium B

Marco Boresta marco.boresta@uniroma1.it

Sapienza Università di Roma / IASI-CNR  
Giovannelli, Tommaso, Lehigh University; Lucidi, Stefano, Sapienza  
Università di Roma; Roma, Massimo, Sapienza Università di Roma

*Multi-objective simulation-based optimization using a machine learning-based mathematical programming model*

We present a novel approach to solving a multi-objective simulation-based optimization problem that employs Artificial Neural Networks (ANN) to approximate the objective function whose values are obtained by running a simulation model. This method involves replacing such objective function with a metamodel with the structure of a Multilayer Perceptron, allowing the use of gradient-based methods to solve the optimization problem. The Pareto Frontier is then generated by solving a series of single-objective problems, with the objective function obtained as a weighted combination of the different conflicting objectives.

We test this approach on a real problem for the Emergency Department (ED) of a large Italian hospital which is significantly affected by the phenomenon of overcrowding: the ED of Policlinico Umberto I in Rome, Italy, one of the largest EDs in Europe. We compare its performance to that of a globally convergent Derivative-Free (DF) method on the same data and with the same budget of function evaluations. The results are encouraging, demonstrating that the ANN approach has several advantages over the DF approach, such as a significant reduction in computation time, the generation of a Pareto Frontier with more distinct, better distributed points, and higher robustness to changes in the problem statement.

**TU 16:50 PM2 Auditorium B****Giampaolo Liuzzi** liuzzi@diag.uniroma1.it

DIAG - Sapienza

Giovannelli, Tommaso, Lehigh University; Lucidi, Stefano, Sapienza Univ. di Roma; Rinaldi, Francesco, Univ. di Padova

*A derivative-free approach to mixed integer constrained multiobjective nonsmooth optimization*

In this work, we consider multiobjective optimization problems with both bound constraints on the variables and general nonlinear constraints, where objective and constraint function values can only be obtained by querying a black box. Furthermore, we consider the case where a subset of the variables can only take integer values. We propose a new linesearch-based solution method and show that it converges to a set of stationary points for the problem. For what concerns the continuous variables, we employ a strategy for the estimation of the Pareto frontier recently proposed in the literature and which takes advantage of dense sequences of search directions. The subset of variables that must assume discrete values are dealt with using primitive directions appropriately modified to take into account the presence of more than one objective functions. Numerical results obtained with the proposed method on a set of test problems and comparison with other solution methods show the viability and efficiency of the proposed approach.

**TU 17:10 PM2 Auditorium B****Gabriele Eichfelder** gabriele.eichfelder@tu-ilmenau.deTechnische Universität Ilmenau  
Leo, Warnow, Technische Universität Ilmenau*A new approach to solve multi-objective mixed-integer convex optimization problems*

We propose a new numerical method for solving multi-objective mixed-integer convex optimization problems. The algorithm determines a covering of the whole set of nondominated solutions which is the image set of efficient solutions, also known as Pareto frontier. It works mainly in the image space and can thus handle larger numbers of variables.

In multi-objective mixed-integer convex optimization multiple convex objective functions need to be optimized simultaneously while some of the variables are only allowed to take integer values. We present an approach to compute an enclosure of the nondominated set of such optimization problems by calculating lower and upper bound sets. For obtaining this covering, we decompose the multi-objective mixed-integer convex optimization problem into several multi-objective continuous convex optimization problems, which we refer to as patches. Then, we iteratively compute and improve enclosures of the nondominated sets of those patches to finally combine them to obtain an enclosure of the nondominated set of the multi-objective mixed-integer convex optimization problem with a certain width as quality guarantee. Additionally, we introduce a mechanism to reduce the number of patches that need to be considered in total by using linear relaxations.

**TU 17:30 PM2 Auditorium B****Pierluigi Mansueto** pierluigi.mansueto@unifi.itUniversity of Florence  
Lapucci, Matteo, University of Florence*A Quasi-Newton Approach for Large Scale Multi-Objective Optimization*

We propose a Limited Memory Quasi-Newton method for large scale unconstrained multi-objective optimization. The algorithm approximates the combinations of the objective functions Hessians through positive definite matrices, whose formula is similar to the one of the L-BFGS method for scalar optimization. By means of a Wolfe line search, our method is well defined even for non-convex optimization problems. We compare the performance of the proposed algorithm with other state-of-the-art Newton and Quasi-Newton approaches, showing its effectiveness and strengths with respect to the competitors.



## Keynote

**TU 19:00 PM3 Museo degli Innocenti**

**Anna Nagurney** nagurney@isenberg.umass.edu

Isenberg School of Management, University of Massachusetts Amherst,  
(U.S.A.)

*Labor and Supply Chain Networks: It's All About People*

The COVID-19 pandemic, climate change, conflicts and wars have dramatically illustrated the importance of labor in supply chain networks in numerous economic sectors, from agriculture to healthcare. In this talk, I will discuss our research on the inclusion of labor in supply chains both in optimization and game theory frameworks to elucidate the impacts of disruptions of labor in terms of availability as well as productivity on product flows, prices, and the objective functions of organizations, both profit and nonprofit ones. I will also highlight what can be done to ameliorate negative impacts and will discuss the power of setting appropriate wages on supply chain links from production and transportation to storage and the ultimate distribution to points of demand. The use of international migrants to alleviate shortages will be discussed and the impacts of the war on Ukraine on global supply chains. The inclusion of labor in blood service supply chains in healthcare and in humanitarian organization models for disaster preparedness and response will also be highlighted. I will conclude with some of our experiences in influencing policy in the pandemic.

**Keynote**

## EQVA, Equilibria, variational models and applications; Invited Session

WE 10:00 AM1 001

Valerio Giuseppe Sasso `sasso.1808011@studenti.uniroma1.it`

Roma Tre University  
Lorenzo, Lampariello, Roma Tre University; Simone, Sagratella,  
Roma Tre University

### *Nonsmooth Hierarchical Multi Portfolio Selection*

We focus on the case of a financial service provider having to manage different clients accounts via assigning them to multiple managers. In this multi-agent scenario, we introduce sparsity-enhancing terms in the objectives of both clients and managers. The resulting decision problem can be modeled as a hierarchical GNEP that is Jointly-Convex with nonsmooth objectives. We study the main theoretical properties of this multi-agent problem, and show that it is solvable under mild conditions.

**WE 10:20 AM1 001**

**Mauro Passacantando** mauro.passacantando@unipi.it

Department of Computer Science, University of Pisa  
Raciti, Fabio, Department of Mathematics and Computer Science,  
University of Catania

*A finite convergence algorithm for solving network games with strategic complements and bounded strategies*

We propose a new algorithm for solving a class of network games with strategic complements and bounded strategies. The algorithm is based on the sequential solution of linear systems of equations and we prove that it finds the Nash equilibrium of the game after a finite number of iterations. The new algorithm is then applied to a social network model of juvenile delinquency which has been investigated recently, where we also consider random perturbations of some data. Preliminary numerical results show the efficiency of the algorithm.

**WE 09:00 AM1 001**

**Francesco Caruso** francesco.caruso@unina.it

University of Naples "Federico II"  
Maria Carmela, Ceparano, University of Naples "Federico II"; Jacqueline, Morgan, University of Naples "Federico II" and CSEF

*A general method for selecting subgame perfect Nash equilibria in two-player Stackelberg games*

Two-player Stackelberg games may have multiple Subgame Perfect Nash Equilibria (henceforth SPNEs), especially when the optimal reaction of the follower to any choice of the leader is not always unique. In this presentation we investigate the issue of selection of SPNEs in two-player Stackelberg games by exploiting perturbations of the payoff functions of the game. To achieve such a goal, since the limit of "perturbed" SPNEs is not necessarily an SPNE of the initial game even for classic perturbations, first we show how to produce an SPNE starting from a sequence of SPNEs of perturbed games. This result allows to define a general selection method for SPNEs that can accommodate various behaviors of the players. More precisely, under mild assumptions on the data of the game we prove that perturbations relying on a Tikhonov regularization, on an adverse-to-move behaviour and on an altruistic behaviour fit the general method and we present the specific selection results associated to such perturbations. On the one hand, as regards to the Tikhonov regularization and the adverse-to-move behaviour, we extend or recover the results showed by Morgan and Patrone [Advances in Dynamic Games, 2006] and by Caruso, Ceparano and Morgan [Dyn. Games Appl., 2019]. On the other hand, concerning the altruistic behaviour, we present a new specific selection method for SPNEs based on the slightly altruistic approach introduced by De Marco and Morgan [J. Optim. Theory Appl., 2008] for simultaneous-move games. Finally, we illustrate by examples that the general method carried out under the three different "behaviours" just mentioned can select different SPNEs.

**EQVA, Equilibria, variational models and applications; Invited Session**

**WE 09:20 AM1 001**

**Giandomenico Mastroeni** giandomenico.mastroeni@unipi.it

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Pellegrini, Letizia, Department of Economics, University of Verona, Via Cantarane, 24, 37129 - Verona; Peretti, Alberto, Department of Economics, University of Verona, Via Cantarane, 24, 37129 - Verona, Italy

*A decomposition method for a linear problem with complementarity constraints*

We consider a linear programming problem in which a complementarity type constraint is considered in addition. The complementarity constraint in the feasible region causes the lack of the classic properties that are usually important to obtain the standard optimality conditions, as convexity and constraint qualifications. To overcome this difficulty, we propose a decomposition method of the given problem in a sequence of parameterized linear problems, that aim to force complementarity. Once we obtain an optimal solution of one of the parameterized problems, exploiting duality results, we are able to generate a suitable cut that allows us to eliminate a set of parameterized problems which are not worthwhile to be considered. The procedure continues until there are no further parameterized problems to be considered or until a feasible value of the objective function is sufficiently close to some lower bound for the optimal value. We present an example of application of the proposed technique and some computational experiments.

**EQVA, Equilibria, variational models and applications; Invited Session**

**WE 09:40 AM1 001**

**Annamaria Barbagallo** `annamaria.barbagallo@unina.it`

Department of Mathematics and Applications R. Caccioppoli", University of Naples Federico II  
Serena Guarino, Lo Bianco, Department of Agricultural Sciences, University of Naples Federico II

*A general Cournot-Nash equilibrium principle and applications to the COVID-19 pandemic*

The paper deals with the study of an oligopolistic market equilibrium problem in which each firm produces several commodities and both production and demand excesses occur. The equilibrium definition is presented by means of a general Cournot-Nash equilibrium principle. Such a condition is characterized by a tensor variational inequality. Hence, the existence and uniqueness of equilibrium solution can be established by using theoretical results on tensor variational inequalities.

## KNAP, Knapsack Problems; Invited Session

WE 10:00 AM1 002

Ulrich Pferschy [ulrich.pferschy@uni-graz.at](mailto:ulrich.pferschy@uni-graz.at)

University of Graz  
Scatamacchia, Rosario, Politecnico di Torino

*On a knapsack game*

Given a standard 0-1 knapsack problem, we consider the following sequential game played by two players A and B in consecutive rounds. As in a subset sum game previously considered in the literature, the items are partitioned between the two players. In each round both players submit simultaneously one of their items to a neutral decider who chooses the more efficient item (w.r.t. profit to weight ratio) and packs it into the knapsack. The losing item can be resubmitted in a later round. We are looking for a strategy of one player, say B, who aims to maximize the total profit of its packed items, when the item set is known. It can be shown that for an arbitrary strategy of A, every strategy of B may perform arbitrarily bad. However, if A follows a list strategy, i.e. submits items according to a fixed ordering (omitting the submission of items that would violate the capacity constraint), then we can show that the best response of B will always be a list strategy of items sorted in decreasing order of efficiencies. If also the list of A is sorted in decreasing order of efficiencies, then the computation of the submitted items for such an optimal response strategy of B can be done by an Integer Linear Programming (ILP) model or by a pseudopolynomial time dynamic program. A dynamic program can also be given for the more general case of an arbitrarily sorted list of A. However, in polynomial time not even a response with constant approximation ratio can be reached. The problem seems to be more difficult, if the losing item of every round is permanently discarded.

**WE 10:20 AM1 002****Laura Galli** laura.galli@unipi.it

Dipartimento di Informatica, Università di Pisa  
Giulia, Ansuini, Dipartimento di Matematica, Università di Pisa;  
Antonio, Frangioni, Dipartimento di Informatica, Università di Pisa;  
Giovanni, Nardini, Dipartimento di Ingegneria dell'Informazione, Università di Pisa;  
Giovanni, Stea, Dipartimento di Ingegneria dell'Informazione, Università di Pisa

*Bi-dimensional Assignment in 5G Periodic Scheduling*

We consider a scheduling application in 5G cellular networks, where base stations serve periodic tasks by allocating conflict-free portions of the available spectrum, in order to meet their traffic demand. The problem has a combinatorial structure featuring bi-dimensional periodic allocations of resources. We consider four variants of the problem, characterized by different degrees of freedom. Two types of formulations are presented and tested on realistic data, using a generalpurpose solver.



**WE 09:00 AM1 002**

**Iskander Aliev** `alievi@cardiff.ac.uk`

Cardiff University

*Sparse integer points in knapsack polyhedra and beyond*

We will overview recent results on the sparsity of integer points in the standard form knapsack polyhedra. Specifically, let  $P$  be a knapsack polyhedron, defined by a linear equation  $ax=b$ , where  $x$  is nonnegative and the vector  $a$  is integer. Suppose that  $P$  contains integer points. We are interested in estimating the minimum size of the support of an integer point in  $P$ . When  $P$  is a polytope, we establish a surprising transference result that links the sparsity with distances of integer points to the vertices of  $P$ . Perhaps unexpectedly, known bounds are weaker for unbounded knapsack polyhedra.

**KNAP, Knapsack Problems; Invited Session**

**WE 09:20 AM1 002**

**Adam Letchford** a.n.letchford@lancaster.ac.uk

Lancaster University  
Galli, Laura, University of Pisa

*Cutting Planes for the Multiple Knapsack Assignment Problem*

The Multiple Knapsack Assignment Problem (MKAP) was introduced by Kataoka and Yamada in 2014. In the MKAP, we have  $m$  knapsacks and  $n$  items. The  $i$ th knapsack has a capacity  $c_i$ . The  $j$ th item has a profit  $p_j$  and a weight  $w_j$ . Moreover, the set of items is partitioned into  $r$  subsets or classes. Each knapsack can contain items from at most one class. The objective is to assign each knapsack to a class, and to select a set of items of maximum total profit, such that the total weight of the items assigned to any given knapsack does not exceed the capacity of that knapsack.

The MKAP has applications in the purchasing of goods and their subsequent transportation by air, rail or water. It includes the multiple knapsack problem and the assignment problem as special cases. We derive several families of cutting planes (i.e., strong valid linear inequalities) for the MKAP. We also present some exact and heuristic separation routines for them. Some encouraging computational results are also presented.

**WE 09:40 AM1 002**

**Alberto Locatelli** `alberto.locatelli@unimore.it`

University of Modena and Reggio Emilia  
Cacchiani, Valentina, Alma Mater Studiorum University of Bologna;  
Iori, Manuel, University of Modena and Reggio Emilia; Martello, Silvano, Alma Mater Studiorum University of Bologna

*Knapsack problems - An Overview of Recent Advances*

A systematic research on the knapsack problem and its many variants started in the Fifties. It produced, over the next fifty years, an impressive number of scientific results, making this field a very relevant area of combinatorial optimization. The two seminal books devoted to this area, by Martello and Toth in 1990 and by Kellerer, Pferschy, and Pisinger in 2004, include in total about 700 bibliographic entries. In this presentation, structured in two parts, we cover the developments appeared in this field after the publication of the latter volume, until Summer 2021.

Part I is devoted to problems whose goal is to optimally assign items to a single knapsack. Besides the classical knapsack problems (binary, subset sum, bounded, unbounded, change-making), we review problems with special constraints (setups, multiple-choice, conflicts, precedence, sharing, compartments) as well as relatively recent fields of investigation, like robust and bilevel problems. Part II covers multiple, multidimensional (vector and geometric), and quadratic knapsack problems, but also presents a succinct treatment of online and multiobjective knapsack problems.

The two parts are based on over 450 different papers, mostly appeared after 2004, the publication year of the latter of the two classical books specifically dedicated to these topics. Recent research has produced a good number of new exact algorithms, but there is still room for improvement on many problem variants. The publication dates of most reviewed articles (over 70% of the articles in the bibliography appeared in the last decade) indicate that all the main variants and generalizations of these problems still undergo intensive analysis and hence are attractive research areas to researchers interested in pursuing investigations in this fascinating area.

**KNAP, Knapsack Problems; Invited Session**

## **NODAI, Numerical optimization for data analysis and imaging; Invited Session**

**WE 10:00 AM1 003**

**Cesare Molinari** [cecio.molinari@gmail.com](mailto:cecio.molinari@gmail.com)

UNIGE

Mathurin Massias, Lorenzo Rosasco, Silvia Villa, Cristian Vega

*Iterative regularization for convex regularizers*

Iterative regularization exploits the implicit bias of an optimization algorithm to regularize ill-posed problems. Constructing algorithms with such built-in regularization mechanisms is a classic challenge in inverse problems but also in modern machine learning, where it provides both a new perspective on algorithms analysis, and significant speed-ups compared to explicit regularization. In this talk, we propose and study the first iterative regularization procedure able to handle biases described by non smooth and non strongly convex functionals, prominent in low-complexity regularization. Our approach is based on a primal-dual algorithm of which we analyze convergence and stability properties, even in the case where the original problem is unfeasible. The general results are illustrated considering the special case of sparse recovery with the  $l_1$  penalty. Our theoretical results are complemented by experiments showing the computational benefits of our approach.

**WE 10:20 AM1 003****Simone Rebegoldi** `simone.rebegoldi@unifi.it`Università di Firenze  
Stefania, Bellavia, Università di Firenze; Natasa, Krejic, University  
of Novi Sad; Benedetta, Morini, Università di Firenze*Stochastic trust-region methods with subsampling for finite-sum minimization problems*

We propose some novel stochastic first-order trust-region methods with function and gradient approximations for solving finite-sum minimization problems. At each iteration, the proposed methods approximate the function and the gradient by sampling, employing adaptive sample sizes that may vary from one iteration to the other. The core idea of these methods lies in the definition of an appropriate merit function, which combines the subsampled objective function with a measure of the distance of the sample size from its maximum value. The trust-region step is indeed accepted or rejected according to whether a sufficient decrease condition on the aforementioned merit function holds or not. We investigate the convergence in probability of these methods, showing that the gradient converges to zero with probability one under some appropriate probabilistic requirements on the function and gradient estimates. Furthermore, we provide some worst-case complexity results to achieve a certain accuracy in the gradient norm. We also report numerical results on nonconvex binary classification problems, which confirm that the proposed algorithms achieve an adequate accuracy way before the maximum sample size is reached, and without requiring a problem-dependent tuning of the involved parameters.

**WE 09:00 AM1 003****Elena Morotti** elena.morotti4@unibo.it

Università di Bologna  
Davide, Evangelista, University of Bologna, Italy; Elena Loli, Piccolomini, University of Bologna, Italy

*A new converging approach for learnt optimization with applications to imaging*

Image processing and image reconstruction are active research fields that have been recently revolutionized by the advent of convolutional neural networks, as deep learning-based schemes often yield superior results than classical optimization approaches. However, their ability to actually compute the inverse problem solution is still discussed in the literature. This talk presents a new scheme, called RISING, embedding deep learning tools in an optimization approach. Numerical results and theoretical aspects will be discussed, showing that RISING preserves the convergence properties of iterative solvers and also exploits the accuracy and flexibility of data-driven approaches, while fitting constraints due to large-scale problem applications.

**WE 09:20 AM1 003**

**Margherita Porcelli** `margherita.porcelli@unibo.it`

University of Bologna  
Domitilla, Brandoni, University of Bologna; Valeria, Simoncini, University of Bologna

*A spectral PALM algorithm for Dictionary Learning*

Dictionary Learning (DL) is one of the leading sparsity promoting techniques in the context of image classification, where the "dictionary" matrix  $D$  of images and the sparse matrix  $X$  are determined so as to represent a redundant image dataset. The resulting constrained optimization problem is nonconvex and non-smooth, providing several computational challenges for its solution. To preserve multidimensional data features, various tensor DL formulations have been introduced, adding to the problem complexity. We present a new alternating algorithm for the solution of the DL problem both in the matrix and tensor frameworks; in the latter case a new formulation based on Tensor-Train decompositions is also introduced. The new method belongs to the Proximal Alternating Linearized Minimization (PALM) algorithmic family, with the inclusion of second order information to enhance efficiency. The numerical performance of the new method will be discussed on the image classification of several benchmark datasets.

**WE 09:40 AM1 003**

**Monica Pragliola** monica.pragliola@unina.it

University of Naples Federico II  
di Serafino, Daniela, University of Naples Federico II

*Automatic parameter selection for the TGV regularizer in image restoration under Poisson noise*

We address the image restoration problem under Poisson noise corruption. The Kullback-Leibler divergence, which is typically adopted in the variational framework as data fidelity term in this case, is coupled with the second-order Total Generalized Variation (TGV<sup>2</sup>). The TGV<sup>2</sup> regularizer is known to be capable of preserving both smooth and piece-wise constant features in the image, however its behavior is subject to a suitable setting of the parameters arising in its expression. We propose a hierarchical Bayesian formulation of the original problem coupled with a Maximum A Posteriori estimation approach, according to which the unknown image and parameters can be jointly and automatically estimated by minimizing a given cost functional. The minimization problem is tackled via a scheme based on the Alternating Direction Method of Multipliers, which also incorporates a procedure for the automatic selection of the regularization parameter by means of a popular discrepancy principle. Computational results show the effectiveness of our proposal.



## **OPTSM, Optimization in Public Transport and Shared Mobility; Invited Session**

**WE 10:00 AM1 Auditorium A**

**Marcella Samà** `marcella.sama@uniroma3.it`

Roma Tre University  
Meloni, Carlo, Sapienza Università di Roma; Pranzo, Marco, Università di Siena

*Risk evaluation considering uncertain dwell times of real-time Railway Traffic Management solutions*

While trains travel in railway networks, disturbances may arise and corrective decisions to minimize delay propagation may be necessary to solve conflicting track requests. This problem is known in the literature as the real-time Railway Traffic Management Problem (rtRTMP) and its solutions represent plans of operations that minimize delay propagation due to unexpected disturbances. However, uncertainty may still affect such plans and their expected quality. We propose a new approach for assessing the risk of onset or worsening of delays associated to an rtRTMP solution when dwell times are uncertain and only an interval representation of them is known to the scheduler. To this aim, the Conditional-Value-at-Risk of the maximum train delay is adopted as risk index. We address both modeling and computational issues, developing and testing a graph-based model to use with an innovative numerical method to obtain a real-time risk evaluation for rtRTMP solutions. The proposed approach is applied on a real case study analyzing the effects of uncertainties of different severity. Promising computational results enable to use the methodology to deal with the rtRTMP taking into account the uncertainty on the involved activities and the risk attitude of the decision-makers at operational level.

**OPTSM, Optimization in Public Transport and Shared Mobility;  
Invited Session**

**WE 09:00 AM1 Auditorium A****Lorenzo Castelli** `castelli@units.it`

University of Trieste  
Brugnara, Irene, University of Trieste; Pesenti, Raffaele, University  
Ca' Foscari of Venice

*A distributed market mechanism for an efficient and equitable resource assignment*

Air traffic resources consisting in airports and airspace volumes have a limited capacity in terms of number of aircraft that can enter the resource in a given period of time. The factor determining capacity is the amount of traffic that can be safely handled by air traffic controllers.

In the current European Air Traffic Flow Management (ATFM) system, when an imbalance between traffic demand and available capacity is foreseen in an airport or airspace volume, the Network Manager can impose an ATFM regulation, which limits the rate of aircraft that can enter the regulated resource in a given period of time. This ATFM measure is achieved by delaying the departure of flights from their origin airport. ATFM delays are imposed to flights through an ATFM slot, a 15-minute tolerance time window that flights have to comply with for departure. In the case a flight is subject to multiple regulations, the delay on the most constraining regulation is applied.

In the current system, ATFM slots are assigned to flights according to a First Come First Served (FPFS) principle. Since ATFM delays represent a cost for airlines, remarkable cost savings are possible by considering a different assignment of ATFM slots which takes into account the different impact that delays have on costs for airlines.

We introduce a model which extends the concept of ATFM slot to the concept of time window, allowing to effectively deal with a network of interacting regulations. The model aims at minimising the total cost of delay of a time window assignment to flights and is based on an integer programming problem. It consists in a market-based mechanism between flights and the Network Manager to trade time windows, which fulfill the properties of individual rationality (every participating airline has a non-negative profit from the mechanism) and weak budget-balanced (the mechanism requires no external subsidisation). Equity is guaranteed by considering the FPFS assignment as an endowment guaranteed to all flights and allocated for free.

The proposed market mechanism can be implemented in a distributed manner which prevents the disclosure of confidential information by airlines, and is based on the Lagrangian relaxation of the integer optimisation problem, solved through the subgradient algorithm.

We present some computational experiments conducted to test the model on some real instances of air traffic data.

**WE 09:20 AM1 Auditorium A****Valentina Morandi** VALENTINA.MORANDI1@UNIBS.IT

Università degli Studi di Brescia  
Enico, Angelelli, Università degli Studi di Brescia; Maria Grazia,  
Speranza, Università degli Studi di Brescia

*Optimization models for fair horizontal collaboration in demand-responsive transportation*

The advances in information and communication technology are changing the way people move. Companies that offer demand-responsive transportation services have the opportunity to reduce their costs and increase their revenues through collaboration, while at the same time reducing the environmental impact of their operations. We consider the case of companies, offering a shared taxi service, that are involved in horizontal collaboration and present mixed integer linear programming (MILP) models for the optimization of their routes that embed constraints aimed at balancing the workload exchange. These constraints bound the imbalance in terms of travelled time and/or served customers to be less than thresholds agreed in advance by the companies. We also present a heuristic algorithm for the solution of the MILP models. The computational results show the good performance of the heuristic and the benefits, to each company, of the collaboration.

**WE 09:40 AM1 Auditorium A**

Recipient of the Verizon Connect Italy grant

**Marta Leonina Tessitore** `marta.tessitore@uniroma3.it`

Roma Tre University

Sartor, Giorgio, SINTEF; Mannino, Carlo, SINTEF; Samà, Marcella, Roma Tre University; Pacciarelli, Dario, Roma Tre University

*Identifying Railway Timetable Fragility*

In dense railway traffic, the delay of a single train may propagate in a domino effect over the entire network. During the last decade, several approaches have been proposed to measure and improve timetable robustness. Robustness usually refers to the timetables ability to restore punctuality following disturbed traffic situations and therefore prevent delays from spreading over the network. Existing robustness measures, however, are not always useful for perfectly understanding how the robustness of a timetable could be increased. The challenge we are trying to tackle is therefore to identify the weaknesses of a timetable, i.e., the sections of each train schedule that are more likely to generate knock-on delays. In order to do this, we developed a MILP model that computes the maximum delay a train can incur in each section of its schedule such that all trains will still arrive at their final station on-time. We define a section of a schedule as fragile if this maximum allowed delay is less than a few minutes. The model considers the optimal dispatching of trains rather than using a simulation tool based on heuristic algorithms as it is common in robustness related work. The model is based on the work of Lamorgese and Mannino (2015) for practical real-time train scheduling, which employs an exact decomposition approach combined with a row-generation scheme. This newly introduced concept of fragility is complementary to that of robustness, in the sense that it can help route planners identify which parts of a timetable to focus on for reducing knock-on delays. We test this approach on real-life scenarios from a busy railway line in Norway.

[1] Lamorgese, L., Mannino, C., 2015. An Exact Decomposition Approach for the Real-Time Train Dispatching Problem. *Operations Research*, 63(1), 48-64 [2] Lusby, R. M., Larsen, J., Bull, S., 2018. A Survey on Robustness in Railway Planning. *European Journal of Operational Research*, 266(1), 1-15

**OPTSM, Optimization in Public Transport and Shared Mobility;  
Invited Session**

## Global Optimization; Invited Session

WE 10:00 AM1 Auditorium B

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Benedetto, Manca, Dip. Matematica and Informatica, Universita  
degli Studi di Cagliari; Pierre-Louis, Poirion, RIKEN Center for  
Advanced Intelligence Project, Tokyo, Japan; Antoine, Oustry, LIX  
CNRS Ecole Polytechnique, Institut Polytechnique de Paris

*Random projections for semidefinite programming*

Random projections can reduce the dimensionality of point sets while keeping approximate congruence. Applying random projections to optimization problems raises many theoretical and computational issues. Most of the theoretical issues in the application of random projections to conic programming were addressed in [1]. This paper focuses on semidefinite programming.

**WE 09:00 AM1 Auditorium B****Filippo Pecci** `f.pecci14@imperial.ac.uk`Imperial College London  
Stoianov, Ivan, Imperial College London*A global optimization framework for resilient water distribution networks*

Resilience and sustainability are key objectives for critical infrastructure systems, which society relies upon for water, energy, and food supply. Optimization has the potential to play a vital role in supporting the design and operation of next generation infrastructure systems, improving resilience, reducing CO<sub>2</sub> emissions, and efficiently integrating renewable energy sources. The complexity of these large interconnected systems has grown to the level that modelling and optimization are needed to improve their resilience and sustainability in face of climate change, urbanisation, and fast growing population.

This is especially relevant for optimal design-for-control of nonlinear network systems, where the flow through the network is driven by a potential, and the potential loss across a link is a nonlinear function of the flow rate. These optimization problems combine continuous decision variables (e.g. pipe flow rates), with discrete decision variables (e.g. location of control actuators). Together with nonconvex constraints modelling systems dynamics, they result in large-scale Mixed Integer Nonlinear Programs (MINLPs). Despite significant progress in optimization algorithms and availability of computational power, it is still not possible to solve most MINLPs that arise when considering large and complex nonlinear network systems.

Water distribution networks (WDNs) are critical infrastructure facing unprecedented challenges due to increasing water demand, climate change, and more stringent economic and environmental constraints. The main operational objectives for water utilities include the reduction of water leaks, and the reduction of probability of pipe bursts. These objectives are achieved through pressure management, which is implemented by installing and operating pressure control valves. To benefit from advances in technological, modelling, and control solutions, it is necessary to simultaneously optimize both valve locations and their operational settings. The problem of optimal placement and operation of pressure control valves in WDNs belongs to the framework of optimal design-for-control of non-linear network systems. Hence, it poses significant computational challenges to optimization solvers.

The results reported in this work show that off-the-shelf global optimization solvers can fail to compute feasible solutions for this optimal design-for-control problem. Therefore, we propose a tailored branch and bound algorithm relying on polyhedral relaxations of the potential loss constraints, optimization-based bound-tightening, and heuristics to gen-

erate good quality feasible solutions with bounds on their level of sub-optimality. The developed algorithm is implemented to optimally place and operate PCVs to minimize different operational objectives, including Average Zone Pressure (AZP) and Pressure Variability with the Zone (PVZ). The tailored branch and bound algorithm enables the joint optimization of location and operational settings of pressure control valves in WDNs. This allows water utilities to implement integrated and efficient schemes for pressure management, in order to minimize leakage and probability of pipe bursts. Finally, we discuss further work and possible extensions to the framework of multiobjective optimization and water quality management.

**WE 09:20 AM1 Auditorium B****Immanuel Bomze** `immanuel.bomze@univie.ac.at`University of Vienna  
Rinaldi, Francesco, Univ.Padova; Zeffiro, Damiano, Univ.Padova*Fast Cluster Detection in Networks by First Order Optimization*

Cluster detection plays a fundamental role in the analysis of data. In this paper, we focus on the use of  $s$ -defective clique models for network-based cluster detection and propose a nonlinear optimization approach that efficiently handles those models in practice. In particular, we introduce an equivalent continuous formulation for the problem under analysis, and we analyze some tailored variants of the FrankWolfe algorithm that enable us to quickly find maximal  $s$ -defective cliques. The good practical behavior of those algorithmic tools, which is closely connected to their support identification properties, makes them very appealing in practical applications. The reported numerical results clearly show the effectiveness of the proposed approach.



**WE 09:40 AM1 Auditorium B****Marco Locatelli** marco.locatelli@unipr.itUniversità degli Studi di Parma  
Consolini, Luca, Università degli Studi di Parma*Sharp and fast bounds for the Celis-Dennis-Tapia problem*

In the Celis-Dennis-Tapia (CDT) problem a quadratic function is minimized over a region defined by two strictly convex quadratic constraints. Recently, it has been proved that the problem can be solved in polynomial time. However, all known polynomial-time algorithms are computationally expensive, since the degree of the polynomial in the complexity results is rather high. Moreover, differently from other quadratic problems such as the classical trust region problem or the trust region problem with an additional linear inequality, no exact convex relaxation for the CDT problem is known.

In this work we re-derive a necessary and sufficient optimality condition for the exactness of the dual Lagrangian bound (equivalent to the Shor relaxation bound in this case). Starting from such condition, we propose to strengthen the dual Lagrangian bound by adding one or two linear cuts to the Lagrangian relaxation. Such cuts are obtained from supporting hyperplanes of one of the two constraints. Thus, they are redundant for the original problem, but they are not for the Lagrangian relaxation. For the case of a single cut we also propose a procedure to detect the best possible cut, i.e., the one delivering the best possible bound. Interestingly, such best bound is computationally equivalent to the SOC-RLT bound proposed in [1], although up to now we do not have a theoretical proof of equivalence.

The computational experiments show that the new bounds are effective and require limited computing times. In particular, one of the proposed bounds is exact for all but one of the 212 hard instances of the CDT problem presented in [1].

[1] S.Burer, K.M. Anstreicher, Second-order-cone constraints for extended trust-region subproblems, *SIAM J. Optim.*, 23(1), 432–451 (2013)

## **RAVIEP, Recent Advances in Variational Inequalities and Equilibrium Problems; Invited Session**

**WE 11:30 AM2 001**

**Maria Bernadette Donato** mbdonato@unime.it

Department of Economics, University of Messina  
Villanacci, Antonio, Department of Economics and Management,  
University of Firenze

*Variational inequalities, maximal elements and economic equilibrium problems*

Our main goal is to provide conditions under which the solution sets to a maximal problem and to a generalized variational inequality problem coincide and are nonempty. In choice theory, individual actors are assumed to have preferences on a set of alternatives, i.e., a binary relation on a choice set. Individuals choose a subset of the choice set using such preferences. The preference relation is often assumed to be transitive and complete. In the present talk, we consider the case of preferences without completeness and transitivity. In this context, the individual look for an element in the choice set which is not strictly preferred by any other element in the set, i.e., a maximal element. The way we use to find maximal elements is to follow a variational inequality approach. Finally, we apply the obtained results to get a proof of the existence of equilibria in general equilibrium models.

**RAVIEP, Recent Advances in Variational Inequalities and  
Equilibrium Problems; Invited Session**

**WE 11:50 AM2 001**

**Daniele Sciacca** [daniele.sciacca@unipa.it](mailto:daniele.sciacca@unipa.it)

University of Catania  
Colajanni, Gabriella, University of Catania; Daniele, Patrizia, University of Catania; Nagurney, Anna, 2Department of Operations and Information Management, Isenberg School of Management, University of Massachussets, Department of Electrical and Computer Engineering, University of Hartford

*Disaster Management with UAVs and 5G technology: a Three-Stage Stochastic network-based Optimization Model*

In a disaster situation, whether natural or man-made, slow-onset or sudden-onset, an efficient and efficacious management is paramount and can assist in the saving of lives, the reduction of pain and suffering, and the protection and restoration of infrastructure. 5G technology and Unmanned Aerial Vehicles (UAVs) have emerged as powerful tools for disaster management which allow service providers and decision-makers to restore connectivity and provide much needed services in disaster areas. In this talk, we propose a three-stage stochastic optimization model in which each of the three stages represents a phase of disaster management: the preparedness, the response, and the recovery/reconstruction phase. Furthermore, managers need to consider multiple disaster scenarios with different probabilities of occurrence so as to be able to minimize the potential losses. The optimization model is based on a multi-level network made up of users and devices on the ground, which require 5G services, the controller UAVs, which handle requests for services, and a fleet of UAVs, which execute the services. The proposed model allows providers to satisfy service requests (favoring those with higher priority) while minimizing the overall cost and by determining the optimal flows and the optimal management of additional resources. A variational formulation of the proposed optimization model, ensuring the existence of a solution, and a numerical example, validating the effectiveness of the proposed model, are provided.

**RAVIEP, Recent Advances in Variational Inequalities and Equilibrium Problems; Invited Session**

**WE 12:10 AM2 001**

**Sergio Grammatico** s.grammatico@tudelft.nl

Delft University of Technology

*Generalised Nash equilibrium seeking under partial information*

We consider the generalised Nash equilibrium (GNE) problem under partial-decision information, i.e., where each player can only observe the decisions of its neighbours, while its cost function possibly depends on the actions of some other players. For this class of equilibrium problems, we study fully distributed, proximal-point and projected-pseudo-gradient algorithms. Finally, we discuss the numerical performance of our algorithms that can be accelerated via over-relaxation and inertial schemes.

**WE 12:30 AM2 001**

**Jacqueline Morgan** morgan@unina.it

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*Viscosity solutions in multi-leader-common-follower games*

Two-stage games with multiple leaders having pessimistic behavior and one common follower are considered. These games may fail to have pessimistic solutions, even if the leader payoffs are linear and the optimal reaction of the follower to the leaders strategies is unique. In a suitable class of such games, approximate and viscosity solutions are introduced and are proven to exist under appropriate conditions, in line with the results obtained by the authors in *J. Optim. Theory Appl.*, 173 (2017) for one-leader-one-follower games with a pessimistic leader, also called weak Stackelberg games or pessimistic bilevel optimization problems.

## Finance; Contributed Session

WE 11:30 AM2 002

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Universitat Politècnica de València  
Ana García-Bernabeu (UPV), José Vicente Salcedo (UPV), David  
Pla-Santamaria (UPV)

*A preference directions-based approach to integrate sustainability in portfolio selection*

This contribution develops a new proposal to include investor preferences in both the efficient frontier estimation and the decision-making phase using the concept of preference directions. In the optimization phase of a portfolio selection problem, sustainability criteria or ESG criteria are integrated as a third objective using the elitist algorithm ev-MOGA. The advantage of this algorithm is that it generates a uniformly distributed efficient surface. By including the third objective the problem of determining the preferred portfolio is transported to the space of three dimensions. In this context, the investor's optimal portfolio is the most preferred risk/return/ESG trade-off in the mean-variance-ESG surface. To include the investor's preferences in the optimal portfolio construction process, two ways can be chosen: (i) A priori: the optimization problem is redefined at the efficient surface estimation stage by including the preference directions without the need to modify the algorithm; (ii) A posteriori: at the decision-making stage the preference directions change the way the Euclidean norm (distance between the ideal and the frontier) is calculated. As a result, the region of interest is reduced and refocused in a way that facilitates decision-making for the investor. Keywords: Sustainable investments, Decision-maker's preferences, Multiobjective optimization, MOEAs.

Finance; Contributed Session

**WE 11:50 AM2 002**

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*A mathematical model to locate Services of General Economic Interest*

Services of General Economic Interest (SGEI) are services of public interest whose provision is ruled by public authorities to guarantee accessibility levels for users and fair competition among service providers. Therefore, locating SGEI in a given territory implies the definition of adequate criteria driving the decision-making process. In this context, Facility Location Models (FLMs) can play a crucial role as a decision support tool to simulate regulatory frameworks and identify practical solutions. In this work, we propose a mathematical model for the location of such services, including constraints about users spatial accessibility while considering a dispersion criterion to ensure fair market competition. We apply the model to a real problem concerning the locations of pharmacies in the city of Pamplona (Navarre, Spain). The obtained results show the capability of the model to produce meaningful scenarios that can support the definition of appropriate regulatory frameworks.

**Finance; Contributed Session**

**WE 12:10 AM2 002****Ana Garcia-Bernabeu** [angarber@upv.es](mailto:angarber@upv.es)

Universitat Politecnica de Valencia  
Adolfo, Hilario-Caballero, Universitat Politecnica de Valencia; José Vicente, Salcedo, Universitat Politecnica de Valencia; Francisco, Salas-Molina, Universitat Politecnica de Valencia

*Approaches to ESG - Integration in Portfolio Optimization using MOEAs*

Against a backdrop of growing collective awareness of sustainability, the financial sector plays a key role in aligning financial flows with a path towards sustainable development. In this research, we focus on the process of integrating environmental, social, and governance (ESG) criteria, which will lead to a better reorientation of investments towards socially and environmentally useful projects. With this aim, we approach the ESG-Integration problem in portfolio selection using a recently proposed evolutionary multiobjective optimization procedure called evMOGA. This new approach significantly improves over exact methods and allows a better assessment of financial and ESG criteria tradeoffs. As an application example, we compute the M-V-ESG non-dominated surface for ESG motivated investors who want to assess the tradeoffs among the three criteria.



## NODAI, Numerical optimization for data analysis and imaging; Invited Session

WE 11:30 AM2 003

Ambra Catozzi [ambra.catozzi@unipr.it](mailto:ambra.catozzi@unipr.it)

Università degli Studi di Parma  
Benfenati, Alessandro, Università di Milano

### *Bacterial Colonies Segmentation via Variational Approaches*

Digital image processing can be a crucial tool to automate and improve the analysis of plate culture of microorganisms, such as bacteria, molds and fungi. After taking a sample from the investigated environment, the main objective is to study its development within a specific growth medium in potential colonies. The number of plates to examine is usually large, hence the costs in terms of time and resources grows fast; we propose to combine image segmentation techniques with mathematical tools, such as the Mumford-Shah or Blake-Zisserman functionals (see Numerical minimization of a second-order functional for image segmentation, M. Zanetti, V. Ruggiero. M. Miranda, 2016), for the development of an automatic colonies detector. A possible dataset is composed of RGB images of plates; a pre-processing phase on the original data enables to crop the uninteresting parts of an image and to enhance the contrast without losing any significant information or properties, reducing the computational time. Thus, a variational approach enables to highlight the edges in the image, by identifying colonies of microorganisms with respect to the whole plate. Furthermore, the performance of the proposed approach is evaluated on a set of real images with respect to state-of-the-art techniques (see A comprehensive review of image analysis methods for microorganism counting: from classical image processing to deep learning approaches, J. Zhang et al., 2021). Session: "Numerical optimization for data analysis and imaging" [NODAI].

NODAI, Numerical optimization for data analysis and imaging;  
Invited Session

**WE 11:50 AM2 003**

**Francesco Colibazzi** francesco.colibazzi2@unibo.it

University of Bologna  
Lazzaro, Damiana, University of Bologna; Morigi, Serena, University of Bologna; Samorè, Andrea, University of Bologna

*Learning regularized Gauss-Newton methods*

We consider variational networks for a class of nonlinear-ill-posed least squares inverse problems. These problems are addressed by regularized Gauss-Newton type optimization algorithms where the regularization is learned by a neural network. Two different data-driven approaches will be investigated. First, we present a learned-regularizer integrated into an unrolled Gauss-Newton network. As an alternative approach, we derive a proximal regularized quasi-Newton (PRQN) method and we unfold the PRQN into a deep network which consists of a cascade of multiple proximal mappings. Therefore the proximal operator is learned directly through a variable metric denoiser network. As a practical application, we show how our methods have been successfully applied to solve the parameter identification problem in elliptic PDEs, such as the nonlinear Electrical Impedance Tomography inverse problem.

**WE 12:10 AM2 003**

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UNIMORE

Porta, Federica, UNIMORE; Ruggiero, Valeria, UNIFE; Trombini, Ilaria, UNIPR

*A line search based proximal stochastic gradient algorithm with dynamical variance reduction for finite-sum optimization problems*

Many optimization problems arising from machine learning applications can be cast as the minimization of a regularized finite-sum. When dealing with large-scale machine learning issues, the computation of the full gradient of the finite-sum functional can be prohibitively expensive. For this reason, proximal stochastic gradient methods have been extensively studied in the optimization area in the last decades. It is well known in the literature that a proper strategy to select the hyperparameters of the method (i.e., the set of parameters a-priori selected) and, in particular, the steplength and the mini batch size is needed to guarantee convergence properties and good practical performance. In this work we develop a proximal stochastic gradient algorithm which is based on two main ingredients: the steplength is automatically selected by means of a proper line search procedure and the variance of the stochastic gradients is dynamically reduced along the iterative procedure through an adaptive subsampling strategy. No need of periodical full gradient computation is required. An extensive numerical experimentation in training a binary classifier highlights that the proposed approach appears robust with respect to the setting of the hyperparameters and competitive compared to state-of-the-art methods.

**WE 12:30 AM2 003**

Recipient of the Verizon Connect Italy grant

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DIMA, Università di Genova - Lab I3S, UCA CNRS INRIA  
Estatico, Claudio, DIMA Università di Genova; Calatroni, Luca,  
Lab I3S UCA CNRS INRIA

*Iterative regularisation and modular-proximal algorithms in  $L^{p(\cdot)}$  spaces for imaging problems*

Solving imaging inverse problems by means of a variational approach requires some crucial choices: the modelling of the data-fidelity term whose structural form depends on the noise statistics, the use of a suitable regularisation (penalty) term typically promoting sparsity of the solution in some sense, and, when the formulation is given in an infinite-dimensional framework, the solution space. The latter choice is often overlooked due to the technical challenges it poses w.r.t. to the underlying metric and topological properties. However, it might have a critical effect on the quality of the computed solution due to its ‘implicit’ regularisation properties. We focus our attention on the non-standard choice of variable exponent Lebesgue spaces  $L^{p(\cdot)}$  as solution spaces. Such Banach spaces are defined in terms of a point-wise variable exponent inducing a specific shift-variant norm and intrinsic space-variant properties. Choosing  $L^{p(\cdot)}$  as a solution space corresponds to promote a spatially adaptive solution smoothness. We first show how this modelling improves the accuracy of the reconstructions with respect to standard  $L^2$  and  $L^p$  spaces with a constant exponent  $p \in (1, 2)$  by considering at first the so-called dual method, e.g. an iterative regularisation (Landweber) algorithm suited to the Banach spaces scenario, minimising the data term.

We then consider more complex, structured, problems, defined in terms of the sum of a smooth and convex fidelity, and a proper, l.s.c., convex, typically non-smooth penalty. Optimisation problems of this form are frequently encountered in signal and image processing and usually tackled with forward-backward splitting algorithms, where a gradient descent step w.r.t. the smooth part is alternated with a proximal step associated to the non-smooth part. The use of analogous strategies for minimising composite functionals in  $L^{p(\cdot)}$  is more challenging since due to the Banach setting, which requires the use of new definition of both gradient and proximal steps due to the lack of the Riesz identification between the solution space and its dual. To do so, we propose a proximal gradient algorithm where the gradient step is performed in the dual space and the proximal step, rather than depending on the natural but non-separable  $L^{p(\cdot)}$  norm, is defined in terms of its separable modular function, which allows for the

**NODAI, Numerical optimization for data analysis and imaging;  
Invited Session**

efficient computation of algorithmic iterates, and by means of a Bregman-like distance, which is more suitable to the Banach space geometry rather than the usual  $L^2$ -norm. We analyse the algorithms convergence rate in function values, showing its dependence on the smoothness of both the functional and the space. Some numerical tests highlight the flexibility of the space  $L^{p(\cdot)}$  for exemplar deconvolution and mixed noise removal problems are reported, showing improved reconstruction accuracy, faster convergence speed and reduced computational costs of the proposed algorithm in comparison with analogous ones defined in standard  $L^p$  spaces.

## OPTSM, Optimization in Public Transport and Shared Mobility; Invited Session

WE 11:30 AM2 Auditorium A

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COSYS-ESTAS Université Gustave Eiffel  
Pellegrini, Paola, COSYS-LEOST Université Gustave Eiffel; Rodriguez, Joaquin, COSYS-ESTAS Université Gustave Eiffel

*Practical deployment of real-time railway traffic management algorithms: impact of process meta-parameters*

Railway traffic is often afflicted by unforeseen perturbations causing so-called primary delays. As a result, impacted trains utilize some track sections later than planned. This may impact neighboring trains in that may not be allowed to proceed at their planned speed due to the onset of conflicts triggering restrictive signals. The consequent unplanned slow-downs or stops may cause delay propagation, as secondary delay. Dispatchers can counteract this by quick and effective train re-timing, re-routing and re-ordering decisions. In the literature, this is known as the real-time Railway Traffic Management Problem (rtRTMP). RECIFE-MILP is an optimization algorithm for the rtRTMP that may be used as a decision support tool for dispatchers. In the literature, the impact of rtRTMP algorithms on traffic is seldom assessed considering an actual possible deployment framework. This can be done considering a railway simulator to replace reality and using an optimization algorithm for making traffic management decisions. To further increase the realism of the assessment, a closed-loop framework can be set up, in which optimization is repeated periodically to take into account the actual traffic state as time evolves. In this work, we assess the performance of RECIFE-MILP when used in closed-loop with a state-of-the-art railway simulator named OpenTrack. We consider various infrastructures modeled microscopically, real timetables and realistic traffic perturbations. In particular, we perform a sensitivity analysis on the most relevant closed-loop meta-parameters, to understand their impact on the quality of the traffic management decisions implemented over time. For example, we vary the time horizon concerning the decisions to be taken and the frequency at which a new rtRTMP solution is to be computed. The results show how the best meta-parameter configuration depends on the characteristics of the case study considered.

**OPTSM, Optimization in Public Transport and Shared Mobility;  
Invited Session**

**WE 11:50 AM2 Auditorium A****Giorgio Sartor** `giorgio.sartor@sintef.no`

SINTEF

Kloster, Oddvar, SINTEF; Luteberget, Bjørnar, SINTEF; Mannino, Carlo, SINTEF; Schulz, Christian, SINTEF

*Large-scale real-time dispatching in the Greater Oslo area*

We present the results of a 4 year project aimed at developing a prototype for large-scale real-time dispatching in the Greater Oslo area, which includes all lines incident to Oslo central station up to a 100 km radius. The prototype was developed in collaboration with Bane NOR, the Norwegian railway infrastructure manager, which also provided us with real-time information about train positions and timetables. The underlying algorithm is based on a MILP approach introduced in Lamorgese and Mannino (2015), then extended in Bach et al. (2019), and here extensively updated to support the additional complexity of the Greater Oslo area. It combines an exact micro-macro decomposition approach with a sophisticated column-and-row-generation scheme. The model is able to consider almost every action a human dispatcher is able to perform, such as rerouting in stations, overtakes, and slow-downs. And it takes into consideration almost all operational constraints, including safety margins, platform lengths, slopes, train weight, etc.

The prototype consists of a decision support tool available via web GUI to train dispatchers seated at Oslo. The tool receives real-time information about the current traffic situation and displays the optimal future schedules for all trains for the next 6 hours through an interactive train graph. Dispatchers are allowed to interact with the tool by providing specific constraints or preferences, and therefore test what-if scenarios. For example, if a platform in a station is not available for the rest of the day due to a signal failure, the algorithm is able to adapt and recompute all future schedules in a matter of seconds.

**WE 12:10 AM2 Auditorium A****Xiajie Yi** xiajie.yi@railenium.eu

IRT Railenium

Marlière, Grégory, Univ. Gustave Eiffel; Pellegrini, Paola, Univ. Gustave Eiffel; Rodriguez, Joaquin, Univ. Gustave Eiffel; Pesenti, Raffaele, Università Ca Foscari Venezia

*Coordinated perturbation management in railway traffic*

Due to perturbations (i.e., an unexpected, degraded operation, technical failures, etc), a common problem faced by traffic controllers is that timetables for trains are not necessarily operated as they were initially planned. This paper deals with a coordinated train rerouting and rescheduling problem to minimise the impact of such a perturbation, e.g., to minimise delay propagation. This problem is often faced by traffic controllers at regional railway control centres. The problem of efficiently rerouting and rescheduling trains is known in the literature as real-time Railway Traffic Management Problem (rtRTMP). Typically, the railway network is divided into non-overlapping control areas. Regional control centres coordinate several control areas, and a coordinator manages each control centre. In this contribution, we call a track connecting between two control areas a border section. If a multiple track line connects two control areas, we represent them as multiple border sections. Besides, a border section can be traversed in either one or two directions. In many control centres, the real-time railway traffic management is organised into two decision levels. At a higher level, a coordinator makes decisions on the overall network making abstraction of operational details. At the lower level, a dispatcher manages train schedules and routes in his own control area to fit with coordinator decisions. Indeed, to optimise the overall system performance and ensure decision coherence, the coordinator may impose constraints to dispatchers. We hereby refer to the problems tackled at the lower and higher levels as dispatching and coordination problems, respectively. As far as we are aware, only few papers focus on the coordination of traffic management across different control areas. In this study, we propose an iterative algorithm to solve the coordinated traffic management problem in networks including multiple control areas.



**WE 12:30 AM2 Auditorium A****Joaquin Rodriguez** joaquin.rodriguez@univ-eiffel.frUniversité Gustave Eiffel  
Ferrari, Alessandro, Università di Udine; Sobieraj Richard, Sonia,  
Université Gustave Eiffel; Pellegrini, Paola, Université Gustave Eiffel*Train-based instance reformulation in real-time Railway Traffic Management*

Railway timetables are designed to allow smooth traffic operations. Nonetheless, when unexpected events occur delays may arise, and timetables may have to be modified to limit their propagation: trains may be rerouted or may have to respect specific passing orders in critical parts of the network. The real-time Railway Traffic Management Problem (rtRTMP) is the problem of minimizing the impact of unexpected events through rerouting and rescheduling. In the literature, several optimization algorithms have been proposed for tackling the rtRTMP (Cacchiani et al., 2012). In its classic representation, an instance of this problem includes information on the network topology, the timetable, and the expected traffic perturbation. Depending on network topology and train characteristics, a large number of alternative routes may be available for each train, and this typically has a negative impact on the performance of rtRTMP algorithms. In this work, we propose and assess a novel way for modeling instances aiming to allow algorithms to better deal with large numbers of rerouting possibilities. The novel modeling is based on a train-based instance reformulation. The motivation for this decomposition is the observation that train alternative routes often partially overlap. In the novel modeling, we split single trains with several partially overlapping routes into multiple trains with shorter and non-overlapping routes. The multiple trains deriving from a single split one are modeled as different trains performed by the same rolling-stock. Hence, algorithms will impose the route of each train to depart where the route of the previous train arrives, and departure and arrival times to be coherent. For example, consider a network including three stations with four platforms each, and a single track connecting stations. A train allowed to stop at any of these platforms will have 64 alternative routes. Of these routes, 16 will overlap in the first part as they will be passing through the first platform at the first station. Three disjoint sets of overlapping routes can also be defined for the other three platforms at the first station. In the novel modeling, we split this train into four new ones: the first goes from the origin to the first station, the second from the first to the second station, and so on. The first train will have four alternative routes, one reaching each platform. The second train will have 16, to connect each platform of the first station to each platform of the second. The third and the fourth trains will have 16 and 4 routes respectively. In a thorough experimental analysis

**OPTSM, Optimization in Public Transport and Shared Mobility;  
Invited Session**

based on French case studies with different network and timetable characteristics, we assess the impact of the train-based instance reformulation when solving instances through RECIFE-MILP (Pellegrini et al., 2015), a state-of-the-art rtRTMP algorithm. We show that the novel modeling never worsens the algorithm performance and strongly improves them in instances with specific characteristics.

[1] V. Cacchiani, D. Huisman, M. Kidd, L. Kroon, P. Toth, L. Veelen-turf and J. Wagenaar, 2014. An overview of recovery models and algo-rithms for real-time railway rescheduling. *Transp. Res. Part B Methodol.* 63, 1537. [2] P. Pellegrini, G. Marlière, R. Pesenti, and J. Rodriguez, 2015. RECIFE-MILP: an effective MILP-based heuristic for the real-time railway traffic management problem. *Intelligent Transportation Systems, IEEE Transactions on*, 16(5):26092619.

## Teaching Session

### WE 11:30 AM2 Auditorium B

**Roberto Musmanno** Department of Mechanical, Energy and Management Engineering  
Gianpaolo Ghiani, Univ del Salento; Gibert Laporte, HEC Montréal (Canada)

#### *Introduction to Logistics Systems Management with Microsoft Excel and Python Examples*

We present the updated new edition of the award-winning introductory textbook on logistics system management. It provides an in-depth introduction to the methodological aspects of planning, organization, and control of logistics for organizations in the private, public and non-profit sectors. Based on the authors extensive teaching, research, and industrial consulting experience, this classic textbook is used in universities worldwide to teach students the use of quantitative methods for solving complex logistics problems. Fully updated and revised, the third edition places increased emphasis on the complexity and flexibility required by modern logistics systems. In this context, the extensive use of data, descriptive analytics, predictive models, and optimization techniques will be invaluable to support the decisions and actions of logistics and supply chain managers. Throughout the book, brand-new case studies and numerical examples illustrate how various methods can be used in industrial and service logistics to reduce costs and improve service levels. The book:

- includes new models and techniques that have emerged over the past decade;
- describes methodologies for logistics decision making, forecasting, logistics system design, procurement, warehouse management, and freight transportation management;
- includes end-of-chapter exercises, Microsoft Excel files and Python computer codes for each algorithm covered;
- includes access to a companion website with additional exercises, links to video tutorials, and supplementary teaching material. Introduction to Logistics Systems Management with Microsoft Excel and Python Examples - Third Edition remains an essential textbook for senior undergraduate and graduate students in engineering, computer science, and management science courses. It is also a highly useful reference for academic researchers and industry practitioners alike.

**WE 11:45 AM2 Auditorium B****Eugenia Taranto** `eugenia.taranto@unict.it`

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Gabriella, Colajanni, Department of Mathematics and Computer Science, University of Catania, Viale Andrea Doria 6, 95125 Catania, Italy; Alessandro, Gobbi, Department of Mechanical and industrial Engineering, University of Brescia, Via Branze 38, 25123 Brescia, Italy; Marinella, Picchi, IIS Antonietti, Via Paolo VI, 3, 25049, Iseo, Italy; Alice, Raffaele, Department of Computer Science, University of Verona, Strada Le Grazie 15, 37134 Verona, Italy

*Operations Research at high school: its impact on modelling skills and beyond*

Operations Research (OR) is a branch of applied mathematics usually taught at the university level. Anyway, in recent years, various initiatives have been developed to introduce OR to secondary school students [1]. In addition to these initiatives, since March 2021 we have been carrying out the teaching experimentation ROAR (Real Applications of Operations Research), a three-year project consisting of three teaching units, designed for three-year secondary school students. In particular, we already tested the first teaching unit in a Grade-10 class. We completely reported the design and the implementation of this first part in [2, 3]. In this contribution, we intend to focus more on the results of these experiments, with an emphasis on the didactical aspects. The Grade-10 class worked in collaborative mode, divided into groups of 4-5 students. During the several activities, they were asked to formalise several optimization problems with two or more variables, by applying Linear, Integer, Binary, or Mixed Integer Programming. They also computed the optimal solutions of these problems by using digital technologies, such as GeoGebra and the add-in Solver of Microsoft Excel. All the meetings of the experiment were video-recorded. By watching these videos, it was possible to reconstruct the modelling processes implemented by the students, by using the modelling cycle described in [4]. Specific modes of action of peer collaboration [5] and discrete techno-mathematical fluency [6] also emerged. Moreover, an initial and a final questionnaire were administered to the students, in order to be able to analyse a possible evolution of their competences from the entrance to the end of the experiment. Qualitative and quantitative analysis on all collected data show first how it is appropriate to include OR and its typology of problems in regular school mathematics lectures. Secondly, how modelling and problem-solving skills, developed through OR, can be fostered by implementing a collaborative way of working, also by making use of digital technologies. Last but not least, how such activities can have a positive impact on students understanding and appreciation of OR as well as mathematics in general.

**Teaching Session**

- [1] Raffaele, A., Gobbi, A.: Teaching Operations Research Before University: A Focus on Grades 912. *SN Oper. Res. Forum* 2, 13 (2021).
- [2] Colajanni, G., Gobbi, A., Picchi, M., Raffaele, A., Taranto, E. (2021). Teaching OR before University: the ROAR Experience (Part I). Book of Abstracts of the 50th Annual Meeting of AIRO Italian Operations Research Society, pp. 186-187. Roma, Italy.
- [3] Colajanni, G., Gobbi, A., Picchi, M., Raffaele, A., Taranto, E.: An Operations Research based Teaching Unit for Grade 10: The ROAR Experience, Part I. *INFORMS Transactions on Education* (2022). To appear.
- [4] Kaiser, G., Bracke, M., Göttlich, S., Kaland, C. (2013). Authentic complex modelling problems in mathematics education. Educational interfaces between mathematics and industry (pp. 287-297). Springer.
- [5] Weinberger, A., Stegmann, K., Fischer, F., Mandl, H. (2007). Scripting argumentative knowledge construction in computer-supported learning environments. Scripting computer-supported collaborative learning (pp. 191-211). Springer.
- [6] Jacinto, H., Carreira, S. (2017). Mathematical problem solving with technology: The techno-mathematical fluency of a student-with-GeoGebra. *International Journal of Science and Mathematics Education*, 15 (6), 1115-1136.

**WE 12:00 AM2 Auditorium B****Claudio Sterle** `claudio.sterle@unina.it`

University "Federico II" of Naples - Department of Electrical Engineering and Information Technology  
Boccia, Maurizio, University "Federico II" of Naples - Department of Electrical Engineering and Information Technology; Masone, Adriano, University "Federico II" of Naples - Department of Electrical Engineering and Information Technology; Sforza, Antonio, University "Federico II" of Naples - Department of Electrical Engineering and Information Technology

*OPS4Math project: teaching optimization and problem solving at Secondary Schools*

Nowadays, the teaching of science, technology, engineering and mathematics, i.e., the so called STEM disciplines, represents a relevant topic of discussion given their boosting role for the economic growth of any developed and developing country. Several initiatives have been implemented worldwide to foster students interest towards STEM disciplines. These initiatives are based on the awareness that mathematics is essential for scientific and technological advancement: it trains to reasoning and reflection, stimulates logical capabilities and intuition, improve investigation attitude. Most of them recognize also that mathematical problem solving represents an effective way to support teachers and students in their teaching and learning activities, respectively. However, most of these initiatives are more focused on teaching mathematics for problem-solving rather than teaching mathematics through problem solving. Thus, they do not reflect directly in actions devoted to the insertion of problem solving in school curricula, thus confirming the mismatch between the mathematics education provided by school and university and the required problem-solving skills. This work is aimed at presenting a project providing a contribution in filling this gap. It is devoted to the presentation OPS4Math Optimization and Problem Solving for Teaching of Mathematics, a training project for Secondary School teachers organized by the University Federico II of Naples, financed by Italian Ministry of University and Research (D.D. 1662 del 22.10.2020), and supported by Campania Regional Education Office. The project driving idea, resembling the teaching mathematics through problem solving approach, consists in operating a reversal of the didactic perspective in classical curricula: starting from phenomena/problems to introduce concepts of data, variables, relationships and functions in an appealing way, providing new materials for mathematic teachers of Secondary School. We present project organization, structure and aims, to give useful hints for its replication at national and international level.

**Teaching Session**

**WE 12:15 AM2 Auditorium B****Alessandro Gobbi** `alessandro.gobbi@unibs.it`

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*Teaching OR before University: the ROAR Experience (Part II)*

Ricerca Operativa Applicazioni Reali (ROAR, i.e., Real Applications of Operations Research) [1, 2] is a three-year learning path for secondary school students, also inspired by a few similar initiatives which disseminate Operations Research (OR) before university level [3]. ROAR relies on active learning and constructionism [4], by offering examples and problems closely connected with students everyday life or with the Italian reality. The implementation of ROAR started in Spring 2021 as a three-year project-work fitting into a Percorso per le Competenze Trasversali e l'Orientamento (Path for Transversal Skills and Orientation), activated at the scientific high school IIS Antonietti in Iseo (Brescia, Italy). We reported the design, the implementation, and the results of the first teaching unit addressed to Grade 10 in [2]. In this talk, we describe how we carried out a teaching experiment of the second unit to the same students (now Grade 11), from January to April 2022. In particular, we show how we introduced graph theory and network applications, by starting from real situations and problems, such as social and transportation networks. Similar to the previous unit, we relied on collaborative learning (by dividing the students into groups), and the use of digital technologies. Differently, in this second unit, we focused on solving problems by applying both mathematical modelling and algorithms. Thus, we introduced the students to well known procedures, such as Kruskals and Dijkstras algorithms, but we also discussed the mathematical models of the Shortest Path Problem and the Travelling Salesman Problem. Moreover, we assigned a challenge to the groups as a final project, by applying competitive learning [5, 6] to increase students motivation and engagement. In particular, we asked them to find a solution for three instances of a Vehicle Routing Problem concerning the home delivery of groceries from a hypothetical supermarket chain. The groups had one month to submit their best solutions found, computed by developing their own heuristic algorithms and/or applying any tools or techniques we taught them during these two teaching units of ROAR. We analyse the results and feedback received from both students and teachers. Finally, we anticipate some topics of the third and

**Teaching Session**

last teaching unit of ROAR, addressed to Grade 12, that we will conduct in Autumn 2022 with the same students.

[1] Colajanni, G., Gobbi, A., Picchi, M., Raffaele, A., & Taranto, E. (2021). Teaching OR before University: the ROAR Experience (Part I). Book of Abstracts of the 50th Annual Meeting of AIRO Italian Operations Research Society, pp. 186-187. Roma, Italy. [2] Colajanni, G., Gobbi, A., Picchi, M., Raffaele, A., Taranto, E.: An Operations Research based Teaching Unit for Grade 10: The ROAR Experience, Part I. INFORMS Transactions on Education (2022). To appear. [3] Raffaele, A., Gobbi, A.: Teaching Operations Research Before University: A Focus on Grades 9-12. SN Oper. Res. Forum 2, 13 (2021). [4] Papert, S.: Constructionism: A New Opportunity for Elementary Science Education. MIT, Media Laboratory, Epistemology and Learning Group (1986). [5] Johnson, D.W., Johnson, R.T., Holubec E.J. (1986). Circle of Learning: Cooperation in the classroom. Edina MN: Interaction Book Company. [6] Cohen, E.G. (1994). Restructuring the classroom: Condition for productive small groups. Review of Educational Research, 64(1): 1- 35.



**WE 12:30 AM2 Auditorium B****Daniela Ambrosino** ambrosin@economia.unige.itUniversity of Genova  
Sciomachen, Anna, University of Genova*Projects for getting a taste of problem solving and mathematics in high school*

The University of Genova, in particular, the Department of economics and business studies (DIEC) is going on the realization of paths related to the POT (Piani di Orientamento e Tutorato) thanks to a project ScopriTalento. This project is coordinated by the University of Torino, and other four Italian Universities are involved in it. The aim of the project ScopriTalento is to direct students in the search for their skills and abilities. The idea is to use new and active teaching methods. Project works are used in the projects that involve a group of students either of the same class as in the project Explora or of different classes as in the Summer school. The Explora project is for students in the third class of the high school. Tutors, university students, prepared to work in the classroom permit to operate with a peer to peer education. Tutors meet students and teach them the basic information for understanding the organization of companies operating in the market. Then a second meeting is organised in the company, that usually presents a problem to solve. Coming back to school, the students- helped by tutors- analyse the problem and try to solve it by using the more adequate tool. In our case, we stress the importance of well understanding the problem, the decisions to take and the main aim of guiding the decision-maker. We propose decision theory and simple operation research approaches, we learn them to represent the problem in spreadsheet excel and to find a solution, a good solution. In the last meeting, students and tutors prepare a video for the company, students propose a solution. The summer school project concerns the realization of a summer school with the aim of presenting to the students some concepts related to the companies' organizations and some instruments useful to solve problems for being competitive in the market. Some labs are proposed, and a team game is organized. Each team can choose its preferred field. At the end of summer school, each team presents its work and a winner is identified by the teachers. Some examples of the activities realized by students will be presented.

**Teaching Session**

## Keynote

**WE 14:30 PM0 Auditorium A**

**Dimitris Bertsimas** dbertsim@mit.edu

MIT, Sloan School of Management, Cambridge, MA (U.S.A.)

*HAIM: Holistic AI for Medicine*

Artificial intelligence (AI) systems hold great promise to improve healthcare over the next decades. Specifically, AI systems leveraging multiple data sources and input modalities are poised to become a viable method to deliver more accurate results and deployable pipelines across a wide range of applications. In this work, we propose and evaluate a unified Holistic AI in Medicine (HAIM) framework to facilitate the generation and testing of AI systems that leverage multimodal inputs. Our approach uses generalizable data pre-processing and machine learning modeling stages that can be readily adapted for research and deployment in healthcare environments. We evaluate our HAIM framework by training and characterizing 14,324 independent models based on MIMIC-IV-MM, a multimodal clinical database (N=34,537 samples) containing 7,279 unique hospitalizations and 6,485 patients, spanning all possible input combinations of 4 data modalities (i.e., tabular, time-series, text, and images), 11 unique data sources and 12 predictive tasks. We show that this framework can consistently and robustly produce models that outperform similar single-source approaches across various healthcare demonstrations (by 6-33%), including 10 distinct chest pathology diagnoses, along with length-of-stay and 48-hour mortality predictions. We also quantify the contribution of each modality and data source using Shapley values, which demonstrates the heterogeneity in data modality importance and the necessity of multimodal inputs across different healthcare-relevant tasks. The generalizable properties and flexibility of our Holistic AI in Medicine (HAIM) framework could offer a promising pathway for future multimodal predictive systems in clinical and operational healthcare settings.

**Keynote**

**RAVIEP, Recent Advances in Variational Inequalities and Equilibrium Problems; Invited Session****WE 15:40 PM1 001****Sofia Giuffrè** [sofia.giuffre@unirc.it](mailto:sofia.giuffre@unirc.it)DIIES, Mediterranea University of Reggio Calabria  
Attilio, Marcianò, DIIES, Mediterranea University of Reggio Calabria*On the equivalence between constrained variational problems*

The talk deals with nonlinear monotone variational inequalities with gradient constraints. In particular, using a new strong duality principle, we prove the equivalence of the problem under consideration with a double obstacle problem and with a Lagrange multiplier problem.

**WE 16:00 PM1 001**

**Domenico Scopelliti** domenico.scopelliti@unibs.it

University of Brescia, Brescia, Italy

*Quasi-variational problems with non-self map on Banach space*

This talk focuses on the study of generalized quasi-variational inequality problems with a non-self constraint map. For such problems, the concept of the projected solution needs to be introduced. The main result deals with the existence of such solutions on real Banach spaces. Then, we introduce the concept of the projected solution for a multistage stochastic generalized quasi-variational inequality, and the existence of such a solution is provided. These theoretical results are applied in studying an electricity market with renewable power sources.

**WE 16:20 PM1 001**

**Fabio Raciti** `fabio.raciti@unict.it`

Department of Mathematics and Computer Science, University of Catania  
Mauro, Passacantando, Department of Computer Science, University of Pisa

*A multiclass network international migration model under shared regulations*

In this note we extend a previously proposed model of international human migration by introducing the possibility that some of the destination countries agree to establish a common upper bound on the migratory flows they are willing to accept jointly. In this framework, we propose a new equilibrium definition and prove its equivalence to a suitably defined variational inequality. Some numerical examples show that the flow distribution under joint regulations can differ from those corresponding to a situation where each government autonomously establishes migration bounds

**WE 16:40 PM1 001**

**Georgia Fargetta** `georgia.fargetta@phd.unict.it`

Department of Mathematics and Computer Science, University of Catania

Laura, Scrimali, Department of Mathematics and Computer Science, University of Catania

*Time-Dependent Generalized Nash Equilibria in Social Media Platforms*

In this paper, we develop a dynamic network model of the competition of digital contents on social media platforms, assuming that there is a known and fixed upper bound on the total amount of views. In particular, we consider a two-layer network consisting of creators and viewers. Each creator seeks to maximize the profit by determining views and likes. The problem is formulated as a time-dependent generalized Nash equilibrium for which we provide the associated evolutionary variational inequality, using the variational equilibrium concept. We also discuss a possible differential game formulation. Finally, using a discrete-time approximation of the continuous time adjustment process, we present a numerical example.

## Applications; Contributed Session

WE 15:40 PM1 002

Vladimír Holý vladimir.holy@vse.cz

Prague University of Economics and Business  
Tomanová, Petra, Prague University of Economics and Business

*High-Frequency Analysis of Price Clustering and Instantaneous Volatility*

In finance, an increased occurrence of specific prices is known as price clustering. This phenomenon is widely observed and well-documented for various financial instruments and markets. In the literature, however, it is rarely incorporated into price models. We focus on a particular type of price clustering – an increased occurrence of specific multiples of the tick size. For example, stocks on the NYSE and NASDAQ exchanges are traded with precision to one cent but multiples of five cents and ten cents occur much more often in prices. Such behavior is explained by several types of agents trading only in specific multiples of the tick size resulting in an increased occurrence of these multiples in prices.

We propose a discrete dynamic model relating price clustering to the distribution of prices and study the high-frequency behavior of price clustering. We model prices using a mixture of several double Poisson distributions with specific supports corresponding to agents trading in different multiples of the tick size. This mixture distribution has a location parameter, a dispersion parameter, and parameters determining portions of trader types. In our model, we introduce time variation to all these parameters. We assume the location parameter to be equal to the last observed price resulting in zero expected returns. Furthermore, we assume the dispersion parameter to depend on the last trade duration and to follow dynamics of generalized autoregressive score (GAS) models, in a similar fashion as generalized autoregressive conditional heteroskedasticity (GARCH) models. Finally, we assume the trader portion parameters to be driven by the volatility process and other variables such as the price, the last trade duration, and the volume. The resulting observation-driven model is estimated by the maximum likelihood method.

In an empirical study of the 30 Dow Jones Industrial Average (DJIA) stocks, we find that higher instantaneous volatility leads to weaker price clustering at the ultra-high frequency. This is in sharp contrast with our results at low frequencies which show that daily realized volatility has a positive impact on price clustering. The degree of aggregation therefore plays a pivotal role in the relation between price clustering and volatility. While high daily realized volatility correlates with high price clustering, high instantaneous volatility has the opposite effect. We conclude that volatility on lower frequency affects dominantly low-frequency traders through the resolution hypothesis, which states that the source of price

Applications; Contributed Session

clustering is the uncertainty. In contrast, volatility on higher frequency affects only high-frequency traders who do not tend to price clustering. Our approach can be used to improve various price models in high-frequency trading and risk management.



**WE 16:00 PM1 002**

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*A Two-Dimensional Bin Packing Problem with Precedence Constraints in the Sheet Metal Industry*

We consider an optimization problem of practical relevance arising in Salvagnini Italia, a multinational corporation in the sheet metal industry that produces computer numerical control (CNC) machines designed to cut and bend the sheet metal. We focus on cutting machines and we face the problem of determining efficient cutting layouts, that is, given a set of rectangular items to be cut, we want to place them in the available material sheets with the objective

of minimizing the waste. This problem falls into the well-known area of Two-Dimensional Bin Packing Problems (2DBPP) and, given its possible application

in multiple fields, several variants have been proposed during the last decades in the Operations Research literature. Nevertheless, the problem under study presents a set of attributes that, to the best of our knowledge, has never been considered yet. More precisely, we take into account the following practical aspects, coming from the specific cutting technology: two items can either share a side (common cut) or need to be placed at a given minimum distance, and the same may be imposed between an item and the sheets border; 90 degrees rotation is allowed and each item may have mandatory or forbidden placement areas; a hard (resp. soft) precedence may be assigned to each item, meaning that a production order has to be determined for material sheets and items with higher precedence need to (resp. should, the waste being the same) be produced before the others; optional items are also considered.

We devise a Mixed Integer Linear Programming (MILP) model able to integrate the different attributes. Moreover, in order to pursue a secondary objective

of proposing an as compact as possible cutting layout, we present a post-process optimization based on a Strip Packing MILP formulation. The proposed models have been solved on preliminary instances of practical relevance by means of Cplex. Results indicate that the packing model well

integrates the new practical features and that, in combination with the post-process optimization, it returns solutions that fully match the company's needs.

Keywords. 2D-Bin Packing, Sheet Metal Industry, Precedence Constraints, Mixed Integer Linear Programming. References.

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**Applications; Contributed Session**

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**WE 16:20 PM1 002****Sara Ceschia** sara.ceschia@uniud.it

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*Educational Timetabling: Problems, Benchmarks, and State-of-the-Art Results*

We propose a survey of the research contributions on the field of Educational Timetabling with a specific focus on "standard" formulations and the corresponding benchmark instances. We identify six of such formulations and we discuss their features, pointing out their relevance and usability. Other available formulations and datasets are also reviewed and briefly discussed. Subsequently, we report the main state-of-the-art results on the selected benchmarks, in terms of solution quality (upper and lower bounds), search techniques, running times, statistical distributions, and other side settings. Finally, we consider the issue of reliability of the results claimed in the literature, stressing the importance of the presence of instance and solution checkers, so as to provide against possible errors and misunderstandings. To this aim, we developed a web application, named OptHub (<https://opthub.uniud.it>), that allows users to check and upload both new instances and solutions.

## Machine Learning; Contributed Session

WE 15:40 PM1 003

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*Simultaneous Feature Selection and Outlier Detection: New MILP Formulation and an Experimental Study*

Let  $p^1 = (a^1, r_1), p^2 = (a^2, r_2), \dots, p^k = (a^k, r_k)$  be points of  $\mathbb{R}^{d+1}$  satisfying  $r_i = \omega a^i + \zeta + \varepsilon_i$  for every  $i = 1, 2, \dots, k$ , where  $\omega \in \mathbb{R}^d$  is a features vector,  $\zeta \in \mathbb{R}$  and  $\varepsilon_1, \varepsilon_2, \dots, \varepsilon_k$  are random errors. The simultaneous feature selection and outlier detection (SFSOD) problem (1) is

$$\min_{(w, z, s) \in \mathbb{R}^d \times \mathbb{R} \times \{0, 1\}^k} \left\{ \sum_{i=1}^k (1 - s_i) \ell(r_i - a^i w_i - z) : \|w\|_0 \leq d_0 \text{ and } \|s\|_0 \leq k_0 \right\}.$$

Above,  $\ell(\cdot)$  is a generic loss function, the 0-norm  $\|\cdot\|_0$  counts the nonzero entries of its argument and  $d_0$  and  $k_0$  are given integral budget values. The SFSOD with  $\ell(x) = x^2$  has been recently treated in several works from a mixed-integer optimization perspective and it is particularly relevant for linear regression problems having high-dimensionality and exhibiting high data corruption: an optimal solution  $(\hat{w}, \hat{z}, \hat{s})$  to (1) with  $\ell(x) = x^2$  corresponds to a hyperplane  $\hat{\mathcal{H}} = \{(x, y) \in \mathbb{R}^{d+1} : y = \hat{w}x + \hat{z}\}$  such that: 1) at most  $k_0$  points  $p^i$  with  $s_i = 1$  are discarded from the dataset as outliers; 2)  $\hat{\mathcal{H}}$  optimizes the least-square criterion with respect to the non-outlier points; 3) the feature vector  $\hat{w}$  is sparse, involving at most  $d_0$  features. In this work we consider the least absolute deviation (LAD) setting, corresponding to  $\ell(x) = |x|$  and making the objective of (1) a bilinear function. We propose a linearization for the bilinear terms in the objective of (1) based on disjunctive arguments. Although the disjunctive linearization presented here is applied to the SFSOD problem, it is valid whenever bilinear terms involving binary factors are to be linearized. Our linearization involves big- $M$  values, thus we experimentally study the impact of their magnitude on the qualitative and computational performance of MIP models for the SFSOD. Moreover, we show that the linear relaxation of the proposed disjunctive-based linearization is always as good as linear relaxations of MILP models for the SFSOD already present in the literature and that it can be strictly stronger when the involved big- $M$  values are tight enough. Finally, we computationally show that the LAD setting is competitive in terms of both performance and predictive power with respect to the least-square criterion.

Machine Learning; Contributed Session

**WE 16:00 PM1 003**

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*Multivariate Discriminant Analysis of Distributional Data*

In this work we consider data where individual units are described by distributions. Distributional data may result from the aggregation of large amounts of open/collected/generated data, or may be directly available in a structured or unstructured form, describing the variability of some features. In recent years, different approaches have been investigated and methods proposed for the analysis of such data. We present parametric probabilistic models for numerical distributional variables building upon previous models for interval-valued variables. The proposed models are based on the representation of each distribution by a location measure and inter-quantile ranges, for given quantiles. Multivariate Normal distributions are assumed for the whole set of indicators, considering alternative structures of the variance-covariance matrix. For all cases, maximum likelihood estimators of the corresponding parameters are derived. This framework is applied to the problem of identifying internet traffic redirection (attacks), both in a two-class (regular vs irregular traffic) and a five-class (regular, and four distinct relays) formulations. Results show that the proposed approach has an excellent classification performance in the problem at hand. Furthermore, the restricted covariance configurations allow for parsimonious classification rules.

**WE 16:20 PM1 003****Alberto Ceselli** `alberto.ceselli@unimi.it`Università degli Studi di Milano, Dipartimento di Informatica  
Elia, Togni, Università degli Studi di Milano, Dipartimento di Informatica*Mathematical Programming and Machine Learning for a Task Allocation Game*

We consider a combinatorial game proposed in the literature, motivated by the arising paradigm of crowdworking. It consists in assigning tasks to worker agents whose behaviour details are unknown. The game proceeds in rounds. At the end of each of them, the player is given a feedback on the effect of the choices which have been made, including an overall score and a reputation value obtained by each worker agent. The game is meant to be solved by pure player intuition. We analyze instead the effect of using quantitative models. We evaluate the effectiveness of regression models, which are trained round by round, in predicting worker agents performance. We also experiment on suggesting users choice by optimization models, in which regressors are re-encoded as parts of a mathematical program, and merged in a generalized assignment formulation. We present a computational evaluation on a dataset collected from a real online gaming system.

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*Spherical and Polyhedral separation approaches for Multiple Instance Learning*

We extend the spherical and polyhedral separation approaches to the Multiple Instance Learning (MIL) paradigm. MIL constitutes a kind of weak supervised classification, where, differently from the traditional supervised learning scenario, each example to be classified, is not represented by a fixed-length vector of features but by a bag of feature vectors called instances. In the training phase the classification labels are only provided for each entire bag whereas the labels of the instances inside them are unknown. The final task is to learn a model that predicts the labels of the new incoming bags together with the labels of the instances inside them.

We address the MIL problem in the case of two types of instances and two types of bags (positive and negative) through spherical and polyhedral approaches. The idea is to generate a spherical or a polyhedral separation surface such that, for each positive bag, at least one of its instances is inside the sphere or the polyhedron and all the instances of each negative bag are outside.

In particular, we propose to iteratively separate the bags by means of successive maximum-margin spheres (whose number is automatically determined) or maximum-margin polyhedral surfaces, obtained for both the cases by solving successive linear programs. Moreover only for the polyhedral case we come out with a nonlinear nonconvex nonsmooth optimization model of DC (Difference of Convex) type that we solve by adapting the DCA algorithm.

The results of our implementations on a number of benchmark classification datasets are presented.

## OPTSM, Optimization in Public Transport and Shared Mobility; Invited Session

WE 15:40 PM1 Auditorium A

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*Extracting series-parallel subnetworks in rail infrastructures - benefits and limits*

Managing the railway traffic in real-time after a perturbing event occurs is a difficult task by itself: the best possible train routing and/or scheduling decisions have to be quickly made to minimise delay propagation. This problem is known as real-time Railway Traffic Management Problem (rt-RTMP). The topology of the underlying railway infrastructures plays an important role when solving the rt-RTMP. Indeed, several state-of-the-art optimisation methods are able to produce good quality solutions in reasonable time, in particular if the underlying infrastructure is rather simple, e.g., a single line with passing loops. Conversely, they may struggle to do so when the infrastructure yields a very complex topology. As an example, if the network involves many parallel tracks and switches to pass from one to another, the number of routes to consider when evaluating rerouting may explode, bringing with it the problem instance size. Indeed, the effort to manage the traffic sharpens if the infrastructure is described microscopically. In this study, we evaluate the possibility of sacrificing some portions of the railway infrastructure to mitigate the complexity of its topology when solving the rt-RTMP. Specifically, we consider extracting subnetworks from the infrastructure that can be modelled as series-parallel graphs. We motivate the choice of this particular topology with two main reasons. First, several NP-complete graph theory problems, such as finding of the minimum vertex cover and the maximum matching, are solvable in polynomial time on series-parallel graphs. Second, extracting series-parallel subnetworks can be done in linear time with respect to the size of the original network. Our objective is to assess the benefits and limits of solving the rt-RTMP on a series-parallel subnetwork instead of solving it on the entire infrastructure. Specifically, we want to empirically verify whether simplifying the topology of the network yields a good trade-off between the computational time decrease, feasibility issues

**OPTSM, Optimization in Public Transport and Shared Mobility;  
Invited Session**



and solution quality.

**WE 16:00 PM1 Auditorium A****Jacob Trepats Borecka** `jacob.trepats@ivt.baug.ethz.ch`

ETH Zurich

Leutwiler, Florin, ETH Zurich; Corman, Francesco, ETH Zurich

*Computational Evaluation of Logic-based Benders Cuts for Railway Scheduling*

Responsive and effective railway operations can be based on a flexible timetable concept with daily adjustments, based on the varying needs of the network such that it satisfies a set of business objectives. This motivates the industrial need to develop solution algorithms to solve large-scale scheduling problems fast and efficiently in terms of solving speed and solution quality. Therefore we implement, on an existing logic-based Benders decomposition framework, different automatic decomposition architectures, including geographic-based, time-based and train-based. In particular, we explore a process based on dynamic aggregation of atomic subproblems into larger subproblems during the solution process, for each architecture. We evaluate how these specific choices balance to a different extent the computation effort to solve decomposed subproblems, versus coordinating them towards a global solution.

**WE 16:20 PM1 Auditorium A****Benedetta Pratelli** benedetta.pratelli@maior.it

M.A.I.O.R. SRL

Carosi, Samuela, M.A.I.O.R. SRL; Geraci, Francesco, M.A.I.O.R. SRL; Tresoldi, Emanuele, M.A.I.O.R. SRL

*A sequential approach for large scale electric vehicle scheduling problems*

In the last few years, to reduce air and noise pollution due to a growing mobility demand and to a greater traffic congestion, the large majority of local transportation companies are migrating their fleet from diesel-powered to electric buses (EV). The introduction of this type of vehicles means considering the specific characteristics the new technology is bringing along, such as managing the constraints that it requires to operate. One of the critical aspects to carefully consider is the re-design of the algorithms employed by decision support tools to provide efficient solutions for Time-Tabling, Vehicle Scheduling (VS) and Crew Scheduling planning phases. In particular, the VS phase is the most affected since the new requirements and constraints associated with EVs can modify the structure of the underlying mathematical problem. In this work we present a math-heuristic procedure for the solution of the Electric Vehicle Scheduling problem (EVS) requiring minimal modifications in the creation of vehicle blocks with respects to standard diesel-powered vehicles. Our approach acts on already constructed vehicle blocks and transform them in electric-complying vehicle blocks respecting all energy constraints and charging requirements. The core of the procedure is a flow-based Mixed Integer Linear Programming (MILP) model with additional constraints. The model is solved with a generic MILP solver (COIN-OR CBC); additional steps are taken whether potential infeasibility is detected. The approach has been tested on large-scale real-world instances, with several hundreds of electric vehicle blocks. The procedure showed to be time-comparable with similar VS instances using diesel-powered vehicles, and was always able to find feasible solutions.

**WE 16:40 PM1 Auditorium A****Valentina Cacchiani** `valentina.cacchiani@unibo.it`

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*Integrated timetabling and electric vehicle scheduling in public transport*

Timetabling and vehicle scheduling are often solved in sequence due to their complexity. In this work, instead, we tackle the two problems in an integrated way for a bus company operating in a transport network, and consider a mixed-fleet of vehicles that include electric buses. The problem was introduced for the MINOA Research Challenge. In this problem, timetabling aims at determining the best service frequency: in particular, for each line and direction, the frequency is measured at a main station of the line as the headway between two consecutive trips of the line. The goal is to select a subset of trips out of a large set in order to minimize the headway deviation from a given ideal headway. Vehicle scheduling calls for finding the sequence of trips (vehicle-block) to be assigned to each vehicle with the goal of minimizing the company costs, while ensuring that each trip selected in the timetabling is executed by one vehicle. Several additional constraints, such as service regularity, deadhead trips, available parking slots are taken into account. In addition, constraints related to charging requirements are included to handle electric buses. We propose a heuristic algorithm based on an Integer Linear Programming (ILP) model with arc-variables representing which consecutive trips are selected for the timetabling problem, and exponentially many variables corresponding to vehicle-blocks for the vehicle scheduling problem. Column generation is applied to solve the continuous relaxation of the model, and variable fixing is employed to obtain feasible solutions. Computational results are reported on instances of the MINOA Research Challenge.

## **Industrial & Startup Session**

**WE 15:40 PM1 Auditorium B**

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*Verizon Connect Italy - Industrial presentation*

**\*\* NO ABSTRACT PROVIDED \*\***

**Industrial & Startup Session**

**WE 16:00 PM1 Auditorium B**

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Intuendi

*Intuendi - Industrial presentation*

\*\* NO ABSTRACT PROVIDED \*\*

**Industrial & Startup Session**

**WE 16:20 PM1 Auditorium B**

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Deix

*Deix - Industrial presentation*

**\*\* NO ABSTRACT PROVIDED \*\***

**Industrial & Startup Session**

**WE 16:40 PM1 Auditorium B**

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OPTIMEasy

*OPTIMEasy - Industrial presentation*

\*\* NO ABSTRACT PROVIDED \*\*

**Industrial & Startup Session**



## Applications of OR; Contributed Session

WE 17:30 PM2 001

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Marina, University of Ni, Faculty of Economics, Serbia

*Urban Poverty and Material Deprivation: A Spatial Efficiency Assessment*

Urban poverty and inequality are one of the leading challenges facing modern society, with the main goal in most agendas being the need to eradicate urban poverty in all its forms and dimensions. Urban areas are, on the one hand, the bearers of economic growth and development and the cultural uplift of the population, while on the other hand, urban regions face complex and growing challenges related to population inequality. Reaching inclusive growth at the country level is based on achieving inclusive growth in urban areas, primarily bearing in mind that the majority of the world's population lives in urban areas. The traditional practice of measuring the well-being of the population based on monitoring mainly economic performance has provided an inadequate presentation of the quality of socio-economic growth and development. Modern concepts of measuring well-being include both economic and social performance, with special attention to indicators related to material deprivation, poverty and social inclusion. However, the level of poverty and material deprivation of a population is traditionally defined on the basis of data on income or wealth. Yet, modern research indicates that poverty is a multidimensional concept and that the concept of inclusive growth is becoming dominant in today's conditions. Achieving inclusive growth involves a complex process faced with numerous challenges. Achieving social inclusion, nurturing a sense of belonging, eradicating poverty and reducing social vulnerability stand out as important components of inclusive growth and development. Nevertheless, socioeconomic deprivation of the population in developing countries is usually quantified and monitored through census data, without taking into account the multidimensionality of this problem. Namely, the census data generally provide information on a particular aspect of socioeconomic deprivation, with the main focus on the percentage of the population at risk of poverty or social exclusion. Although the percentage of the population at risk of poverty or social exclusion is an important indicator of living conditions, its disadvantage is that it alone does not cover all dimensions of vulnerability, and in order to quantify the vulnerability of the population, it is necessary to create a multidimensional, comprehensive measure that encompasses various as-

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pects of poverty, social exclusion and material deprivation. With that in mind, the main goal of this paper is to contribute to the development of a methodological approach that can be applied to assess urban poverty and material deprivation using data of urban areas of the Republic of Serbia. The model developed in the paper includes primary, unprocessed data collected by the Statistical Office of the Republic of Serbia in the Survey on Income and Living Conditions (SILC), as a part of EU Statistics on Income and Living Conditions (EU-SILC) covering the period from 2015 to 2020 and the analysis, i.e. grouping individual data according to the spatial area where they were collected. The assessment of urban poverty and material deprivation will be performed by creating a composite index using the Benefit of Doubt approach. The Benefit of Doubt approach is the variant of the Data Envelopment Analysis approach which is modified in the way that it contains only outputs, and can provide information on the reasons for the inefficiency of certain urban areas. Given that policymakers have limited budgets when making strategic decisions aimed at eradicating poverty and material deprivation, the results of the analysis can provide guidance on the needs of the most vulnerable regions, and prioritise the urban areas according to the identified shortcomings.

**WE 17:50 PM2 001**

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Ariel University

*Postponing Complementary Services*

Studies on service systems and queueing theory classically assume that a customer who obtains service must be present in the system during the whole time the service is provided. However, as time passed, many service systems realized that part of the service can be performed while the customer is absent. The customer can use this time efficiently outside the system. Adopting this potentially favorable approach, we study a Markovian service system in which the service can be split into two phases: an opening service (OS), which can be provided only when the customer is present, and a complementary service (CS), which can be carried out in the absence of the customer. To improve the systems overall performance, after providing the OS, the server can postpone executing the CS to time intervals in which the system is empty of customers. The prepared OSs are stored in a designated storage facility. Once the system becomes empty, the server executes the CS for the stored OSs, one at a time. We consider two unbounded dimensions system involving a multivariate probability generating function and derive closed-form expressions for the systems steady-state probabilities and its various performance measures. An economic analysis compares the described model with a corresponding limited OS capacity model.

**WE 18:10 PM2 001****Joep Freixas** josep.freixas@upc.edu

Universitat Politècnica de Catalunya

*On the search of an optimal tie-breaking system for sport competitions with a large number of participants*

We propose a simple method of undoing tiebreaks in sport competitions with a large number of competitors and relatively small number of rounds of competition. Such methods are common in many games including Chess, Go, Bridge or Scrabble, among others.

Strength of schedule is the idea behind the methods based on the games already played: that the player that played the harder competition to achieve the same number of points should be ranked higher.

Tie-breaking methods decide in strict order the prizes to be received. One of the most commonly used methods is the well-known Buchholz method, based on the arithmetic mean of the scores obtained by the opponents. The alternative method that we propose in this paper, which is quite close (in statistical terms) to the median of the scores obtained by the opponents, is also a weighted average of the opponents' scores, whose weights are based on the binomial distribution. The main objective of the article is to compare the proposed method with that of Buchholz, highlighting the many advantages over it.

Unfortunately, even today Buchholz's method and its variants are routinely used as the first and second tiebreaker criteria. It is the used as a first and second criteria in the rapid and blitz chess world championships that took place in December 2021. We believe that Buchholz's method should be replaced by the one proposed here as soon as possible.

**WE 17:30 PM2 002**

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Clément Altman, Guy Desaulniers

*The fragility-constrained vehicle routing problem with time windows*

We study a new variant of the well-studied Vehicle Routing Problem with Time Windows (VRPTW), called the fragility-constrained VRPTW, which assumes that 1) the capacity of a vehicle is organized in multiple identical stacks; 2) all items picked up at a customer are either fragile or not; 3) no non-fragile items can be put on top of a fragile item (the fragility constraint); and 4) no en-route load rearrangement is possible. We first characterize the feasibility of a route with respect to this fragility constraint. Then, to solve this new problem, we develop an exact branch-price-and-cut (BPC) algorithm that includes a labeling algorithm exploiting this feasibility characterization to efficiently generate feasible routes. This algorithm is benchmarked against another BPC algorithm that deals with the fragility constraint in the column generation master problem through infeasible path cuts. Our computational results show that the former BPC algorithm clearly outperforms the latter in terms of computational time and that the fragility constraint has a greater impact on the optimal solution cost (compared to that of the VRPTW) when vehicle capacity decreases, stack height increases and for a more balanced mix of customers with fragile and non-fragile items.

**WE 17:50 PM2 002**

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OPTIMEasy - University of Genoa Spin off  
Ambrosino, Daniela, University of Genoa; Siri, Silvia, University of Genoa

*Last mile and first mile trucks optimization*

With the growth of international trade, the importance of an efficient management of intermodal freight transport is not negligible; moreover, the improvement of intermodal transport is considered one strategy for reducing negative externalities of transportation activities. For these reasons, each activity connected with the intermodal transport must be carefully analysed and optimized. In this work, we focus on the last and first mile trucks optimization, two activities usually managed by Multimodal Transport Operators (MTOs) in door-to-door services. The first mile consists in bringing an empty container to a customer that has to load some goods into the container to be transferred to the final destination. Generally, the full container is transferred from the customer depot to an intermodal terminal, from which it will continue its trip by rail. The last mile consists in the last part of a trip, i.e. a full container picked up at an intermodal terminal, loaded on a truck, is delivered to a customer; the customer unloads goods from the container and the empty container is moved back to an intermodal depot. In this work, an optimization approach is proposed to organize the first mile and the last mile trips of an intermodal terminal, in such a way to reduce as much as possible the trips of empty containers. The combination of two trips is possible if and only if some time constraints and some restrictions related to the type of containers (size, height, etc), type of goods and type of vehicle are respected. Some preliminary results based on random instances are presented. In particular, a comparison of solutions with and without the trip combination, in terms of kilometres travelled and service time, is reported.

**WE 18:10 PM2 002**

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grated Logistics, Université Laval, Canada

*Reducing the supply-chain nervousity thanks to flexible planning*

This study is motivated by a major fast-moving consumer goods company. It considers a 3-echelon supply chain made of one plant, one distribution center and several shops. A flexible planning (FLEX) approach is proposed to reduce the supply chain nervousity (e.g., bullwhip effect, peaks of production, peaks of inventories, shortages). FLEX tries to take the best out of both the well-known PULL and PUSH approaches. Indeed, PULL is characterized by low shortages but high production variations, whereas PUSH is characterized by low production variations but high shortages. FLEX relies on assigning penalties only if the daily production and the daily inventories are out of predetermined ideal intervals. More precisely, the following objective functions are minimized in a lexicographic fashion: the shortage at the shop level, the out-of-range production, the out-of-range inventories (in the distribution center and the shops). As the demand is non-deterministic, a simulation optimization algorithm is designed. The experiments performed on 20 instances demonstrate the benefit of FLEX when compared to both PULL and PUSH.

## NOML, Nonlinear Optimization and Machine Learning; Invited Session

WE 17:30 PM2 003

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RWTH Aachen University, Chair for Mathematics of Information Processing

*Implicit bias of gradient descent for learning linear neural networks*

Deep neural networks are usually trained by minimizing a non-convex loss functional via (stochastic) gradient descent methods. A puzzling empirical observation is that learning neural networks with a number of parameters exceeding the number of training examples often leads to zero loss, i.e., the network exactly interpolates the data. Nevertheless, it generalizes very well to unseen data, which is in stark contrast to intuition from classical statistics which would predict a scenario of overfitting. A current working hypothesis is that the chosen optimization algorithm has a significant influence on the selection of the learned network. In fact, in this overparameterized context there are many global minimizers so that the optimization method induces an implicit bias on the computed solution. It seems that gradient descent methods and their stochastic variants favor networks of low complexity (in a suitable sense to be understood), and, hence, appear to be very well suited for large classes of real data. Initial attempts in understanding the implicit bias phenomenon considers the simplified setting of linear networks, i.e., (deep) factorizations of matrices. This has revealed a surprising relation to the field of low rank matrix recovery (a variant of compressive sensing) in the sense that gradient descent favors low rank matrices in certain situations. Moreover, restricting further to diagonal matrices, or equivalently factorizing the entries of a vector to be recovered, shows connection to compressive sensing and  $\ell_1$ -minimization.

After giving a general introduction to these topics, the talk will concentrate on results by the speaker on the convergence of gradient flows and gradient descent for learning linear neural networks and on the implicit bias towards low rank and sparse solutions.



**WE 17:50 PM2 003**

**Tommaso Aldinucci** `tommaso.aldinucci@unifi.it`

Dipartimento di Ingegneria dell'Informazione, Università degli Studi di Firenze  
Enrico Civitelli, Leonardo Di Gangi, Alessandro Sestini (DINFO / Univ Firenze)

*Contextual Decision Trees*

Focusing on Random Forests, we propose a multi-armed contextual bandit recommendation framework for feature-based selection of a single shallow tree of the learned ensemble. The trained system, which works on top of the Random Forest, dynamically identifies a base predictor that is responsible for providing the final output. In this way, we obtain local interpretations by observing the rules of the recommended tree. The carried out experiments reveal that our dynamic method is superior to an independent fitted CART decision tree and comparable to the whole black-box Random Forest in terms of predictive performances.

**WE 18:10 PM2 003**

**Behzad Pirouz** behzad.pirouz@dimes.unical.it

Dimes, Universita della Calabria  
Gaudioso, Manlio, Dimes Universita della Calabria

*A Multi-Objective Programming Problem for Sparse Optimization  
with Application in SVM Feature Selection*

We propose a novel Multi-Objective Optimization (MO) model for sparse optimization based on the polyhedral  $k$ -norm. We put particular emphasis on the application of sparse optimization in Feature Selection for Support Vector Machine (SVM) classification. In our MO model, the first objective is the classic SVM classification error, while the second one is the number of significant features, that is, the number of nonzero components of the normal vector to the separating hyperplane. The model we consider is the continuous relaxation of an MINLP model. The objective is to calculate the Pareto optimal solutions, leaving it to the decision-maker to evaluate the tradeoff and the best compromise between the two objectives. We present some numerical results obtained using MO algorithms for our model. They are compared with those of several existing models based on the  $l_1$  and  $l_2$  norm in single and multi-objective format.

## Optimization on Graphs; Contributed Session

WE 17:30 PM2 Auditorium A

Carmine Cerrone [carmine.cerrone@unige.it](mailto:carmine.cerrone@unige.it)

University of Genoa  
Anna, Sciomachen, University of Genoa; Daniela, Ambrosino, University of Genoa

*A multi period VRP for evaluating distribution strategies*

In this work, a Rich Vehicle Routing Problem (RVRP) is faced for solving city logistic problems. In particular, we deal with the problem of a logistic company that has to define the best distribution strategy for obtaining an efficient usage of vehicles and for reducing transportation costs while serving customers with different priority demands during a given planning horizon [1]. Each customer's demand is partitioned into three sets in accordance with different priorities. It is possible to split the customer demand. In this case, the split delivery consists in postponing the customer's demand according to its priority. This problem can be defined as a multi-period vehicle routing problem with a heterogeneous fleet of vehicles, with customers requirements and company restrictions to satisfy, in which the fleet composition has to be daily defined. Actually, the company has a fleet of owned vehicles and the possibility to select, day by day, a certain number of vehicles from the fleet of a third-party company. Routing costs must be minimized together with the number of used vehicles. Only small instances can be solved up to optimality (i.e., instances with 20 customers). Thus, a heuristic approach based on a local search combined with a heuristic split of the input instance is proposed to solve this problem. A complete experimental campaign is presented for validating the proposed approach. Tests have been used for evaluating the quality of the obtained solutions. Moreover, the benefits that can be obtained by postponing deliveries are evaluated. Results are discussed, and some conclusions are highlighted. [1] Ambrosino, D., Cerrone, C. A Rich Vehicle Routing Problem for a City Logistics Problem, (2022) Mathematics, 10 (2), art. no. 191.

## Applications of OR; Contributed Session

WE 17:50 PM2 Auditorium A

Maria Truvolo 5388109@studenti.unige.it

Università di Genova  
Anna Sciomachen, Università di Genova

*Selection of pickup-delivery points in urban areas to reduce emission costs*

The problem of defining pickup-delivery points plays a crucial role in contemporary business development. Finding the optimal position to locate different assets of a company guarantees the reduction of the costs and emissions due to the logistical advantages that arise from the transport, storage and delivery of the goods. It also allows the expansion of the areas covered by the provided services by removing redundancies and narrowing the logistic gap between producers and consumers.[1] This work faces a variant of the classic multi-facility location problem represented by a graph, in which the set of nodes is partitioned into a set  $P$  of pickup-delivery points and a set  $C$  of customers. Customers must go to a node  $p \in P$  to pick up the required items. The number and the subset of the selected nodes of  $P$  are chosen with the goal of minimizing the total emission cost [2,3]. In this perspective, both travelling distance and means of transport (i.e., walking, bike, car, electrical vehicle, etc.) are considered. The fixed cost associated with the nodes in  $P$  is given. A customer  $C$  is assigned to a given node  $P$  if it can reach  $P$  at its minimum sustainable cost while not exceeding a predefined maximum distance between them. We present the model of the problem and develop a heuristic algorithm to produce effective solutions. The heuristic algorithm is based on a clusterization of the nodes. In order to perform extensively computational tests on realistic scenarios, we design an algorithm able to extract topological data from QGIS databases. The computational results are analyzed to certify the effectiveness of the produced approach in terms of quality of the solution and computational times.

[1] E. Ben Alaïa, I. H. Dridi, H. Bouchriha, and P. Borne, Insertion of new depot locations for the optimization of multi-vehicles multi-depots pickup and Delivery Problems using Genetic Algorithm, Proc. 2015 Int. Conf. Ind. Eng. Syst. Manag. IEEE IESM 2015, pp. 695701, Jan. 2016.  
[2] D. Ambrosino, A. Sciomachen, and M. G. Scutellà, A heuristic based on multi-exchange techniques for a regional fleet assignment location-routing problem, Comput. Oper. Res., vol. 36, no. 2, pp. 442460, Feb. 2009.  
[3] E. Nathanail, M. Gogas, and G. Adamos, Smart Interconnections of Interurban and Urban Freight Transport towards Achieving Sustainable City Logistics, Transp. Res. Procedia, vol. 14, pp. 983992, 2016.

Applications of OR; Contributed Session

## Optimization on Graphs; Contributed Session

WE 18:10 PM2 Auditorium A

Cristina Ondei [cristina.ondei@unimi.it](mailto:cristina.ondei@unimi.it)

Dipartimento di Informatica, Università degli Studi di Milano  
Ceselli, Alberto, Dipartimento di Informatica Università degli Studi  
di Milano; Righini, Giovanni, Dipartimento di Informatica Univer-  
sità degli Studi di Milano; Tresoldi, Emanuele, M.A.I.O.R.

*Exact algorithms for the electric travelling salesman problem*

Electric vehicles play an increasingly important role in transportation, making the design of adequate algorithms necessary. In the Electric TSP, a vehicle with a limited battery needs to visit a given set of clients. A set of recharge stations is also given, so that the vehicle can stop and recharge when necessary during the route. While clients must be visited only once, recharge stations can be visited multiple times. We consider a specific variant of this problem where multiple technologies (characterized by different costs and times per unit of recharge) are available at the single station. To solve it we consider two different exact techniques. The first approach is a branch-and-price algorithm, where every variable in the master problem represents a path (i.e. a sequence of clients) between two stations. The second method consists in a branch-and-cut algorithm. We experiment both algorithms on a set of instances from the literature, having different size, battery and time limits. This computational evaluation allows us to highlight the relative strengths and weaknesses of the two approaches.

## Industrial & Startup Session

WE 17:30 PM2 Auditorium B

Duccio Grandi [duccio.grandi@maior.it](mailto:duccio.grandi@maior.it)

M.A.I.O.R.

*M.A.I.O.R. and elite-level sporting events*

Presentazione per la giornata aziendale  
M.A.I.O.R. and elite-level sporting events

MAIOR, Management Artificial Intelligence Operations Research, is an Italian software house with a core business in planning, scheduling, managing public transport. We provided our software and our expertise in 3 different worldwide sporting events: Olympic Winter Games in Turin 2006, Olympic Games in Beijing 2008, FIFA World Cup in Qatar 2022. Three important similar events, with 16 years between them, in different countries with different cultures, different economic resources, different human workforce, different laws. And the same goal of providing a world-class public transport service for spectators. Public transport for events can't be planned as a standard mass transit service because every single day is different from the others due to single events occurring at specific hours in different places and involving various amounts of spectators. In events lasting 20 days, 20 different service days must be planned and managed. In Turin 2006, main goal was to transport spectators and athletes from Turin and Olympic Village to the mountains where the majority of events took place. Bus drivers came from the whole Italy with their own buses. Turin transport committee rented buses with driver from many big and small Transit Operators all over Italy. So transport planning dealt with many different labor rules and bus typologies in order to provide an optimized scheduling. With a final need of generalizations, simplifications and models to computerize the risk of a chaos. In Beijing 2008, main goal was to transport spectators all over an enormous city already congested. Workforce wasn't an issue: simple labor rules and as many drivers as you need. Buses were the most important constraint in order to optimize transit scheduling. Finally a lesson on algorithms and heuristics. In Doha Qatar 2022, main goal is to transport spectators between hotels, stadiums, metro stations and city points of interest. All of that in a city that is constantly growing and building new roads almost daily. Workforce isn't an issue, again simple labor rules and many drivers. But after 14 years since Beijing 2008, public transport expectations have changed completely. Increased dimensions: now thousands of buses and drivers are planned. Information network: data is shared between various systems, all of them must be in sync: driver apps, passenger apps, bus on-board systems, real-time control rooms, human resource offices. However, from an Operations Research standpoint the most interesting problem is the

**Industrial & Startup Session**

usage of a huge number of electric vehicles. Brand new and state of the art electric vehicles but with a range that is still not sufficient to cover all assigned trips of the day. MAIOR presents lessons learned from these 3 events that are distant geographically and culturally spanning 16 years.

**WE 17:50 PM2 Auditorium B**

**Matteo Pozzi** [matteo.pozzi@optit.net](mailto:matteo.pozzi@optit.net)

OPTIT

*OPTIT - Industrial presentation*

\*\* NO ABSTRACT PROVIDED \*\*



**WE 18:10 PM2 Auditorium B**

**Stefano Cappugi** s.cappugi@firlab.com

Firlab

*FirLab - Industrial presentation*

**\*\* NO ABSTRACT PROVIDED \*\***

**Industrial & Startup Session**

## Stochastic Optimization; Contributed Session

TH 10:00 AM1 001

Stefano Smriglio stefano.smriglio@univaq.it

DISIM - Università degli Studi dell'Aquila  
Mattia, Sara, IASI - CNR; Rossi, Fabrizio, DISIM - Università degli Studi dell'Aquila

*Robust optimization models in call centers workforce management*

Workforce management (WFM) is a complex process and represents a prominent issue in call centers optimization. Its general goal is to find a satisfactory trade-off between the Level of Service (LoS) provided to customers and personnel costs. LoS is mostly based on waiting times and quality of the response, while personnel costs constitute one major expense for call center companies. WFM is traditionally split into a sequence of almost separate steps: forecasting call volumes (forecasting); determining the staffing levels, defined as the number of agents required at each time period to guarantee the desired LoS (staffing); translating them into agents work shifts (shift scheduling); assigning agents to such shifts (rostering) and, finally, monitoring out-of-adherence situations at operational level and reacting accordingly. This process offers several significant challenges for stochastic modelling and has been deeply investigated by the scientific literature. In particular, such a decomposition is well-known to be highly suboptimal for several practical reasons. For instance, the staffing levels are hard to cover with shifts, leading to considerable overstaffing. Moreover, work shifts include rest breaks which may impact significantly on the LoS.

We present two robust optimization models where agents flexibility is exploited so as to handle such drawbacks. In one case, we propose a two-stage robust model aimed at integrating staffing with shift scheduling with the goal of preserving LoS from unpredicted demand fluctuations. As for workbreak scheduling, we introduce an element which is relevant in practice but hardly studied scientifically: the agents satisfaction. Again, We illustrate a two-stage robust optimization model for shift scheduling, where agents are free to decide when to have breaks within the regulatory restrictions. Practical cases are discussed, showing the trade off between industrial costs and agents autonomy.

**TH 10:20 AM1 001**

**Claudia Archetti** archetti@essec.edu

ESSEC Business School

Li, Yuanyuan, ESSEC Business School; Ljubic, Ivana, ESSEC Business School

*Reinforcement Learning Approaches for the Orienteering Problem with Stochastic and Dynamic Release Dates*

E-commerce markets are booming at remarkable rates. Due to an unprecedented series of lockdowns, billions of people stay at home to prevent the spread of the virus. It is reported that the e-commerce revenue saw a 10% increase in Europe in 2020 due to the pandemic. At the same time, the expectations of customers in terms of service quality are also increasing. When it comes to the specific challenges to improve customers' satisfactions on delivery, one of the crucial features is related to the starting point of the last-mile delivery leg. An important feature of last-mile distribution is that its operations start as soon as parcels are delivered to the final logistic center, typically a city distribution center (CDC). Given the short delivery times requested by the customers, delivery operations typically need to start before all parcels expected to arrive that day are available at the CDC. This raises a question: whether to wait for more or all parcels to be delivered at the CDC or to start the delivery as soon as there is any available parcel and vehicle? In this paper, we focus on the sequential decision making problem related to when to deliver parcels and which parcels to deliver under the assumption that the time at which parcels become available at the CDC (called release dates) is stochastic and dynamic. We introduce a new problem called the Orienteering Problem with Stochastic and Dynamic Release Dates (DOP-rd) where a single and uncapacitated vehicle is serving customer requests with no time window, and the service has to finish within a deadline. The release dates are considered to be uncertain, stochastically and dynamically updated during the sequential decision making process. The objective is to maximize the number of requests served within the deadline. We model the problem as a Markov decision process and present two approximation approaches for its solutions. Both are based on scenario generations representing realizations of RDs and make use of a batch approach to approximate the value of future information, and specifically to approximate the number of requests served in future routes, i.e., routes that leave the depot in a future time instant. The two approximation approaches we propose are: Policy Function Approximation (PFA) through a consensus function in which a ILP determines, for each scenario, the requests to serve immediately, i.e., in a route leaving the depot immediately, and those included in future routes, and a consensus function over all scenarios determines the final solution; one-step look-ahead policy with Value Function Approximation (VFA) where a two-stage stochastic model is solved in which the

**Stochastic Optimization; Contributed Session**

first stage is to determine the route leaving immediately, while the second stage concerns future routes. We perform computational tests on a set of benchmark instances. We compare the two approaches described above with myopic approaches mimicking common practice and upper bounds related to perfect information. The results show that both PFA and VFA largely outperform myopic approaches and provide reasonable gaps with respect to the solution with perfect information.

**TH 09:00 AM1 001**

**Javier Faulin** javier.faulin@unavarra.es

Public University of Navarre  
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*Multi-Stage Stochastic Optimization for a Biorefinery Supply Chain in Spain*

Nowadays, biofuels are evolving as renewable and sustainable energy sources, especially on developed countries, due to the neutral CO<sub>2</sub> emissions within their complete cycle. Regarding this topic, a biorefinery is considered to be set in Northern Spain. The problem considers uncertainty in biomass prices and availability, therefore, a stochastic optimization approach is needed to reduce the risks of the project. The optimization is represented as a three-stage scenario tree, composed of strategic and tactical nodes. The former refers to location of the biorefinery, while the latter refers to the rent of different warehouses. Additionally, operational nodes are rooted to the strategic and tactical nodes forming two-stage operational scenario trees. In these operational nodes, decisions related to the biomass acquisition are made. Meaningful insights are obtained from the application of stochastic optimization at all levels: strategic (the facility location problem), tactical (warehouses strategy) and operational (biomass purchases), highlighting a superior performance than the deterministic equivalent model.

**Stochastic Optimization; Contributed Session**

**TH 09:20 AM1 001**

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*Stochastic Dual Dynamic Programming and Lagrangian decomposition for seasonal storage valuation in SMS++*

The increase in the share of renewable energy sources in the power system, especially intermittent ones like solar and wind, brings several challenges. As both energy production and demand vary throughout the year (in winter, for example, there is a reduction in the supply of solar energy while the demand for energy for heating increases), energy storage becomes a relevant factor to take advantage of excess energy produced in certain seasons of the year and respond to increased energy demand in others. An important system for seasonal storage is that formed by cascading hydroelectric reservoirs. The management of such systems is a challenging task which hinges on a good assessment of the future value of stored energy (water) in these systems. In order to assess the value of water, and thus be able to properly manage these reservoir systems, a large-scale multi-stage stochastic problem spanning a year must be solved, where each stage is a weekly unit-commitment problems. Since the unit-commitment problems are non-convex in nature, they make the seasonal storage valuation problem unsuitable for what would otherwise be the most natural approach to solve it, i.e., Stochastic Dual Dynamic Programming. In this work we exploit the natural convexification capabilities of Lagrangian relaxation to devise a Stochastic Dual Dynamic Programming approach to the seasonal storage valuation problem where the Lagrangian Dual of the single-stage subproblems is solved (using a Bundle-type approach), which corresponds to solving the convexified relaxation of the original problem. This is known to be at least as tight as, and typically strictly tighter than, the standard way to convexify a stochastic MINLP amenable to the Stochastic Dual Dynamic Programming approach, i.e., the continuous relaxation. We report on extensive experiments which show that these huge-scale stochastic problems can indeed be solved on HPC architectures. This is made possible by the use of the SMS++ software framework (<https://smspp.gitlab.io/>) for large-scale problems with multiple nested forms of structure, and in particular by its native parallel capabilities that allow to exploit two different forms of parallelization (between scenarios in the SDDP approach and within subproblems in the Lagrangian one) at the same time.

**Stochastic Optimization; Contributed Session**

**TH 09:40 AM1 001**

**Maxime Grangereau** maxime.grangereau@edf.fr

EDF Lab Paris Saclay,  
Laurent, El Ghaoui, University of California at Berkeley; Fangda,  
Gu, University of California at Berkeley (USA); Riadh, Zorgati, EDF  
R&D

*Robust Optimization for Smart Charging of Electrical Vehicles*

We present a robust optimization approach accounting for various uncertainties affecting Electrical Vehicles (EV) charging stations operations, such as electricity prices, vehicle arrival and departure times, and state of charge at arrival. We develop the robust counterparts for two smart charging models. The first model, based on aggregated demand, optimizes the charging profile over a time span when the aspect of the allocation of vehicles to the different charging outlets is ignored. When considering the problem of minimizing the charging price using a linear pricing model, charging occurs only at times with lower electricity prices and with high EV availability, whereas if we consider a quadratic cost functional, consumption is smoothed over the time horizon and can be obtained by the classical water-filling approach. We consider in this first model three sources of uncertainty: electricity prices, initial states of charge of vehicles when they arrive at the charging station and arrival/departure times of vehicles. We propose several robust counterparts of the optimal charging model with linear price accounting for these three sources of uncertainties.

The robust counterpart of the model accounting for price uncertainty is cast as a Second-Order Cone problem, for which numerical results show that its solution achieves a balance between the deterministic linear pricing model, where charging at low prices moments, and the water-filling solution, which dispatches consumption uniformly over time. While the robust counterpart of the model accounting for uncertainties in the initial states of charge of vehicles may lead to overly conservative results, an affinely adjustable robust counterpart can be cast as a linear programming problem and strikes a good balance between conservativeness, computation time and performance. We use scenario uncertainty to account for the random arrival/departure times. Naïve use of this approach may lead to overly conservative results as one needs to provision for every possible scenario. An approach called interval uncertainty, which assumes independence of the uncertainty impacting different vehicles allows to reduce the number of scenarios to consider. An affinely adjustable robust counterpart model allows to reach good performance and can be cast as a linear programming problem of moderate size if one considers interval uncertainty and a finite number of scenarios. The second model, involving the allocation of EVs to the different charging station's sockets, trades-off profit versus a measure of customer satisfaction. We develop a scenario-based robust counterpart of this model where each arrival and departure

**Stochastic Optimization; Contributed Session**

times corresponds to a scenario, assuming that the initial state of charge of each EV is fully known. We also suggest another formulation of this problem, based on the cardinality function, which may be more convenient when dealing with uncertainties. In this model, physical limits on charging and load constraints are convex while vehicle and socket assignments constraints, re-formulated by using the cardinality (total number of non-zero components), require some vector to be of cardinality one, which lead to nonconvex constraints. Assuming a linear objective, our problem can be expressed as a linear programming problem with cardinality constraints. We review the use of some efficient heuristics to deal with cardinality constraints, such as L1-norm approximations or an entropy function approach.



## Discrete Optimization; Contributed Session

TH 10:00 AM1 002

Lorenzo Moreschini [lorenzo.moreschini@unibs.it](mailto:lorenzo.moreschini@unibs.it)

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Mansini, Renata, Università degli Studi di Brescia; Zanotti, Roberto,  
Università degli Studi di Brescia

### *A New Kernel Search approach for the Knapsack Problem with Forfeits*

In scientific literature, knapsack problems are among the most widely used problems to test meta- and math- heuristics. In recent years, several knapsack variants have been introduced by adding specific features to the problem. In this work, we focus on the Knapsack Problem with Forfeits (see [1] and [2]), a recently introduced generalization of the Knapsack Problem in which pairs of items are mutually exclusive and cannot be selected simultaneously, unless a forfeit is paid in the objective function. We propose a matheuristic algorithm based on the Kernel Search (KS) framework to solve the problem. KS is a well-known general-purpose framework for the solution of Mixed Integer Linear Programming (MILP) problems (interested readers are referred to [3] and to the recent work [4]). Initially proposed more than ten years ago, the method is based on the identification of a subset of promising variables (the kernel set) and the partition of the remaining variables into buckets. More precisely, KS builds and solves a sequence of small MILP subproblems, each one taking into account the kernel set plus the additional variables belonging to a bucket. To keep the framework as streamlined as possible, the solution of subproblems is usually done through a commercial MILP solver, like Gurobi or Cplex.

We propose a new KS variant that exploits parallelism. In particular, rather than solving subproblems sequentially, we tackle several subproblems at the same time, and share relevant information (new best lower bound, promising variables, etc.) among subproblems while the solution process is underway. Using the Knapsack Problem with Forfeits as test problem, we address several challenges that arise when trying to develop a parallel algorithm that uses a solver with built-in parallelism. Computational results, obtained on benchmark instances from the literature, seem to be promising. We have been able to evaluate several aspects of the new solution approach, with a particular focus on the trade-off in terms of efficiency and effectiveness between our custom parallel strategy and the solver's built-in one.

[1] Raffaele Cerulli, Ciriaco D'Ambrosio, Andrea Raiconi, Gaetano Vitale, 2020. The Knapsack Problem with Forfeits, *Combinatorial Optimization: 6th International Symposium, ISCO 2020, Montreal, QC, Canada, May 4-6, Pages 263-272*. [2] Giovanni Capobianco, Ciriaco D'Am-

Discrete Optimization; Contributed Session

brosio, Luigi Pavone, Andrea Raiconi, Gaetano Vitale, Fabio Sebastiano, 2022. A hybrid metaheuristic for the Knapsack Problem with Forfeits, *Soft Computing*, Volume 26, Pages 749-762. [3] Enrico Angelelli, Renata Mansini, M. Grazia Speranza, 2010. Kernel search: A general heuristic for the multi-dimensional knapsack problem, *Computers & Operations Research*, Volume 37, Issue 11, Pages 2017-2026. [4] Leonardo Lamanna, Renata Mansini, Roberto Zanotti, 2022. A two-phase kernel search variant for the multidimensional multiple-choice knapsack problem. *European Journal of Operational Research*, Volume 297, Issue 1, Pages 53-65.

**TH 10:20 AM1 002**

**Alessandro Agnetis** `agnetis@diism.unisi.it`

Università di Siena  
Pranzo, Marco, Università di Siena

*New results for sequencing two classes of jobs on a two-machine flow shop with a no-idle constraint*

We consider a scheduling problem with two classes of jobs having distinct features and impact on the objective function. A set of  $n$  jobs has to be performed on a two-machine flow shop. Jobs are partitioned into two classes, denoted as A and B. The jobs of class A (called A-jobs) must be processed by  $M_1$  only, while the jobs of class B (called B-jobs) must be processed by  $M_1$  and then by  $M_2$  (the processing time on  $M_2$  being larger than that on  $M_1$ ). The problem is to sequence the jobs so that the total completion time of the A-jobs is minimum, subject to the constraint that both machines must be always busy until the end of the schedule (no-idle constraint). The decision maker has therefore to balance two conflicting needs, namely to schedule the A-jobs early in the sequence (so that their contribution to the objective function is minimized) but at the same time to schedule B-jobs so that the second machine is kept busy. The motivation for this problem comes from the testing department of an electronic firm, here corresponding to machine  $M_1$ . The A-jobs correspond to orders which, after processing on  $M_1$ , are directly sold to the market, and the firm is therefore interested in minimizing the average time-to-market of these jobs. An external manufacturer also outsources testing services to the firm, and will use the tested components to produce its own electronic devices. These testing jobs correspond to B-jobs, and the manufacturer's facility corresponds to machine  $M_2$  of the flow shop. For this NP-hard problem we present a set of results, namely: (i) We show that the special case in which all B-jobs have the same length can be solved in polynomial time. (ii) We introduce a new ILP formulation of a relaxed version of the problem, which exploits some properties of the optimal solution. The formulation avoids the use of big M constants. The solution to this relaxed problem is used both by an exact algorithm, based on lazy constraint generation, and by a heuristic approach which recovers a feasible solution. (iii) We report on extensive computational results on small-size ( $n = 20$ ) and medium-size ( $n = 50$ ) instances. In particular, a large sample of instances has been generated for various values of the ratio  $\mu > 1$  between total processing time on  $M_2$  and total processing time on  $M_1$ . Computation time of the exact approach strongly depends on the value of  $\mu$ . It turns out that the most critical instances are those for which  $\mu$  is relatively small, i.e.,  $\mu = 1.1, 1.6$ , which are also the instances for which the no-idle constraint on  $M_2$  is more binding. For these instances, when  $n = 50$  the exact approach reaches a gap between 3 and 4% after 1 hour of computation, while the recovery heuristic (which requires few seconds)

displays slightly larger gaps. For larger values of  $\mu$ , the problem is solved to optimality within few seconds, even when  $n = 50$ .

**TH 09:00 AM1 002****Jocelin Cailloux** jo-celin.cailloux@unige.ch

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*Tabu search for industrial job clustering and scheduling problem*

We address a clustering and scheduling problem on a single-machine production line. In this problem proposed by a micro-machining company, the goal is to partition a set of jobs (some of them being urgent) into a minimum number of clusters such that the cyclic scheduling of the clusters is robust (using min-max criterion) with respects to the setup times. Each cluster must satisfy two constraints: only jobs with small setup times among them are allowed in the cluster and the setup and processing times in the cluster cannot exceed a shift duration of 8 hours. We divide our problem in three subproblems solved sequentially to minimize three objective functions in a lexicographic order: (A) the number of clusters containing an urgent job; (B) the total number of clusters; (C) the worst-case scenario for the scheduling. For each subproblem, graph-coloring models and methods are designed, and traveling-salesman approaches are furthermore introduced for (C). A strict computing-time (30 minutes) is imposed by industrial needs. We present a metaheuristic relying on various tabu-search procedures compared with a linear model (solved with CPLEX) and a constructive heuristic representing a current-practice rule. Extensive computational experiments were performed to assess the performance of the proposed metaheuristic.

**TH 09:20 AM1 002****Simona Mancini** `simona.mancini@aau.at`University of Klagenfurt  
Gansterer, Margaretha, University of Klagenfurt*Combined fleet sizing, facility location, and vehicle scheduling for electric public transport*

In this work we analyze the integrated problem of locating and sizing charging infrastructures, sizing a fleet of traditional and electric buses to cover a set of scheduled trips, and determine the sequence of trips to be executed by each vehicle, including stops for recharging when needed. The resulting integrated decision problem which, to the best of our knowledge, has never been addressed in the literature, can be described as follows. A set of trips to be performed is given as input. For each trip, the starting location, the arrival location, the starting time, the duration, and the energy required to cover it with an electric vehicle are known. The set of available buses is composed of three different typologies: traditional diesel vehicles (TV), standard electric vehicles (EV), electric vehicles equipped with ultra-fast recharging technology (UV). The last category includes new models equipped with a pantograph on the top, which allows to fully recharge the battery in less than 10 minutes if connected to a compatible charging device. Such vehicles exploit the latest available technology and therefore their purchasing cost as well as the cost for the compatible charging infrastructures is very high. However, the recharging time, 12 times faster than standard electric vehicles, make them very useful when dealing with tight scheduling plans. Some prototypes of these vehicles are already in use in the city of Milan since 2021, and many other municipalities are planning to integrate them in their fleet. We assume that TV are available for free (since the public transport companies already own them), while a purchasing cost must be paid for each selected EV or UV. The cost of UVs is much higher than that of EVs. A set of potential locations for charging stations are assumed to be known. Each of them is characterized by a maximum number of charging slots for standard and for ultra-fast recharging technologies together with a maximum total number of slots. EVs are compatible only with EV chargers while UVs only with UV ones. An installation cost, lower for EV chargers than for UV chargers, must be paid for each charger installed. These costs also include embedded costs for electricity, therefore the only costs paid for trips covered by EVs or UVs are those related to vehicles purchases and for installation. No additional traveling costs are considered. Differently, for each trip covered by TV a fixed travel cost is paid in addition to variable travel costs. This incurs for each vehicle traveling from (i) the depot to starting location of the first trip and (ii) to reach the depot from the arrival location of the last trip. Additionally, the percentage of battery to recharge, i.e. the duration of the recharging stop, is a decision variable itself. The goal of the problem

is to decide how many EVs and UVs to purchase, how many chargers of each type to install in which recharging station, and to provide a feasible schedule for each vehicle. The latter has to cover eventual stops for recharging, in order to minimize the overall costs. To solve the problem, we propose an innovative integer programming formulation, in which we model multiple visits to recharging stations without dummy clones and we present an exact method based on Combinatorial Benders Cuts, in which the master problem is modeled as a temporal bin packing problem with side constraints.

**TH 09:40 AM1 002**

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*Exact and heuristic approaches for a parallel machine scheduling problem with maintenance activities*

The majority of contributions in machine scheduling literature assumes that machines are always available for processing jobs over the working time horizon. However, this assumption is not always realistic. Indeed, machines can require a maintenance activity periodically to prevent malfunctions in many manufacturing situations. A maintenance activity can include several operations including inspection, changing tools, installing equipment or some physical resources that allow effective work. During these operations, machines are not available for processing jobs. In this context, a maintenance operation is an activity that a priori can avoid potential faults resulting in malfunctions and also prevents critical non-availability of the system. However, there is a cost arising from each maintenance operation and the sum of these costs can cover a big percentage of the total operating cost. On this basis, including maintenance activities in the working schedule is essential to overcome delays in production and to reduce system failure and costs. In this context, scheduling problems with maintenance activities received great attention in literature where they are classified into fixed and coordinated problems. In the first class of problems, jobs have to be scheduled coherently with planned maintenance activities, whose starting and completion times are known in advance. Instead, in the second class of problems, both jobs and maintenance activities with related starting times have to be scheduled. In this work, we study a coordinated parallel machine scheduling problem with maintenance activities arising from a real problem of a manufacturing company implementing the Industry 4.0 paradigm for internal logistics. We propose an original integer linear programming (ILP) formulation to optimally solve the addressed problem and a heuristic based on a decomposition of the problem in two phases. The results show the effectiveness of the proposed approaches and the impact of the maintenance time on the production process completion time.



## NOML, Nonlinear Optimization and Machine Learning; Invited Session

TH 10:00 AM1 003

Matteo Lapucci [matteo.lapucci@unifi.it](mailto:matteo.lapucci@unifi.it)

Università degli Studi di Firenze  
Kanzow, Christian, Universität Würzburg; Sciandrone, Marco, Sapienza  
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### *Inexact Penalty Decomposition in General Settings*

The Penalty Decomposition (PD) approach is an algorithmic framework proposed to tackle optimization problems with peculiar constraints structure, such as cardinality constrained problems [1] or low rank approximation problems [2]. First, the problems are equivalently reformulated by the variable splitting technique, which introduces a new vector of variables to decouple the complicated constraint and the rest of the problem elements. This reformulation is then solved by a sequential penalty method, where the approximate solution to penalty subproblems is found by using a two-block alternate minimization (AM) scheme. Recently, an inexact version of the approach has been proposed [3] for the case of sparsity constrained problems with no additional constraints; in this case, one of the two steps of AM is carried out by a single descent step along the gradients direction. In this talk, we will review various settings where the PD approach could be successfully employed and we will discuss the theoretical convergence properties of the inexact scheme in general cases. The framework is also seen in relation to a recently proposed augmented Lagrangian method [4].

[1] Z. Lu and Y. Zhang. Sparse approximation via penalty decomposition methods. *SIAM Journal on Optimization*, 23(4):2448-2478, 2013. [2] Y. Zhang and Z. Lu. Penalty decomposition methods for rank minimization. *Advances in neural information processing systems*, 24, 2011. [3] M. Lapucci, T. Levato, and M. Sciandrone. Convergent inexact penalty decomposition methods for cardinality-constrained problems. *Journal of Optimization Theory and Applications*, 188(2):473-496, 2021. [4] X. Jia, C. Kanzow, P. Mehlitz, and G. Wachsmuth. An augmented lagrangian method for optimization problems with structured geometric constraints. arXiv preprint [arXiv:2105.08317](https://arxiv.org/abs/2105.08317), 2021.

**TH 09:00 AM1 003**

**Antonio M. Sudoso** sudoso@diag.uniroma1.it

Sapienza University of Rome  
Piccialli, Veronica, Sapienza University of Rome

*Global Optimization for Cardinality-constrained Minimum Sum-of-Squares Clustering via Semidefinite Programming*

The minimum sum-of-squares clustering problem (MSSC), or  $k$ -means type clustering, aims to partition  $n$  data points into  $k$  clusters so that the total sum of squared Euclidean distances between the data points and the cluster centers is minimized. The MSSC problem is traditionally considered an unsupervised learning task. In recent years, using background knowledge to improve the cluster quality and promote interpretability of the clustering process has become a hot topic at the intersection of mathematical optimization and machine learning research. Taking advantage of background information in data clustering leads to the so-called semi-supervised or constrained clustering. In this talk, we present a branch-and-cut algorithm for MSSC where the background knowledge is incorporated in the form of strict cardinality constraints. For the lower bound procedure, we derive a new semidefinite programming relaxation and we use a cutting-plane procedure for strengthening the bound. For the upper bound, instead, by using integer programming tools, we propose an adaptation of the  $k$ -means algorithm to the constrained case. Numerical results show that our method outperforms state-of-the-art algorithms, significantly increasing the size of the instances either solved to global optimality or with an optimality gap of less than 1%.

**TH 09:20 AM1 003****Federica Porta** federica.porta@unimore.it

Università di Modena e Reggio Emilia  
Franchini, Giorgia, Università di Modena e Reggio Emilia; Ruggiero,  
Valeria, Università di Ferrara; Trombini, Ilaria, Università di Fer-  
rara

*Proximal stochastic gradient methods with variable learning rate and  
dynamical variance reduction*

Proximal first order stochastic optimization methods are effective tools for the minimization of problems arising in machine learning applications. Since they only require the computation of the gradient corresponding to either a single or a small number of training examples, their overall cost per iteration is low and they can be exploited with very large datasets. However, two drawbacks can be identified when using proximal first order stochastic optimization algorithms: a strong dependency of the practical performance on the choice of the learning rate and, even for very regular objective functions, a poor convergence rate due to the large variance introduced by random sampling. We develop a proximal first order stochastic method which mitigates these two aspects. We indeed combine a proper technique to dynamically reduce the variance of the stochastic gradients along the iterative process with a descent condition in expectation for the objective function, aimed to automatically fix the value for the learning rate parameter at each iteration and to give a local estimate of the inverse of the local Lipschitz constant of the objective function gradient. For general objective functionals, the stationarity of the limit points of the sequence generated by the proposed scheme can be proved, almost surely. For convex objective functionals, both the almost sure convergence of the whole sequence of the iterates to a minimum point and an  $O(1/k)$  convergence rate for the objective function values have been shown. This contribution has been submitted for the invited session Nonlinear Optimization and Machine Learning.

**TH 09:40 AM1 003**

**Manlio Gaudio** manlio.gaudio@unical.it

DIMES, Università della Calabria and ICAR-CNR  
Miglionico, Giovanna, DIMES- Università della Calabria

*On the stepsize choice in subgradient methods.*

The subgradient method is the classic tool for dealing with minimization of convex nonsmooth functions. It is an easily implementable non-monotone algorithm. The displacement from the current approximation of a solution is exclusively based on the knowledge of one subgradient at such a point and on fixing an appropriate value of the stepsize along the anti-subgradient. Starting from an analysis of the two-point approach of Barzilai and Borwein for smooth functions, we focus on designing some stepsize rules able to retain memory of the previous step in the subgradient method framework. We present the results of our numerical experiments on several benchmark test problems.

## Optimization on Graphs; Contributed Session

TH 10:00 AM1 Auditorium A

**Davide Donato Russo** [d.russo7@studenti.unimol.it](mailto:d.russo7@studenti.unimol.it)

Università degli Stude del Molise  
Cerrone, Carmine, Università di Genova; Perea Rojas-Marcos, Federico, Universidad de Sevilla

*Path planning for autonomous vehicles in smart warehouses*

Autonomous vehicles are becoming a reality in controlled scenarios thanks to the fast growth of technologies. They are largely used, for example, in autonomous warehouses or automated city transport systems. In this work, we present the Concurrent Shortest Path Problem. It is a variant of the Shortest Path Problem in which, given a discretized time horizon, is possible to handle multiple shortest paths, while avoiding collisions between vehicles. The aim of the problem is to minimize the total path length while avoiding collisions on nodes. We present two formulations for the problem. The first, consider a multilayer temporal graph, and the second is inspired by the bin packing problem. A deep comparison of these two formulations is performed, to analyze which one works better under which conditions. Finally, several tests were performed to assess the effectiveness of the proposed approaches.

**TH 10:20 AM1 Auditorium A****Victor Hugo Vidigal Corrêa** victor.vidigal@ufv.br

Federal University of Viçosa

Dong, Hang, Nagoya University; Iori, Manuel, University of Modena and Reggio Emilia; Gustavo dos Santos, André, Federal University of Viçosa; Yagiura, Mutsunori, Nagoya University; Zucchi, Giorgio, University of Modena and Reggio Emilia

*An Iterated Local Search Algorithm for a Multi-period Orienteering Problem Arising in Car Patrolling*

In this work, we address a real-life multi-period orienteering problem arising in a large Italian company that needs to patrol a vast area in order to provide security services. The area is divided into clusters, and each cluster is assigned to a patrol. A cluster comprises a set of customers, each requiring different services on a weekly basis. Some services are mandatory, while others are optional. It might be impossible to perform all optional services, and each of them is assigned a score when performed. The problem is to determine a set of routes, one for each patrol and each day, that maximizes the total collected score, while meeting a number of operational constraints, including hard time windows, maximum riding time, and minimum time between two consecutive visits for the same service at the same customer.

To solve the problem, we propose a mixed integer linear programming (MILP) model and an iterated local search (ILS) algorithm. The ILS invokes at each iteration an inner variable neighborhood descent (VND) procedure. While the ILS uses large neighborhood structures to shake the solution, the VND uses a set of more specialized neighborhood structures in order to lead the solution to an improved locally optimal solution.

The performance of a commercial solver on the MILP model and of the ILS heuristic was assessed by testing them on a large set of real-life instances, from several provinces in Italy, provided by the company. The MILP model was solved by using Gurobi 9.5 and was able to find optimal solutions for small-size instances in a two-hour time limit. For larger-size instances, the ILS heuristic yielded better solutions than Gurobi. The solutions produced by the ILS were also better than those practically in use at the company for all instances that were addressed.

**TH 09:00 AM1 Auditorium A****Diego Maria Pinto** `diegomaria.pinto@iasi.cnr.it`

IASI-CNR

Marco, Boresta, IASI-CNR; Annalivia, Croella, DIAG-SAPIENZA ; Claudio, Gentile, IASI-CNR ; Laura, Palagi, DIAG-SAPIENZA ; Giuseppe, Stecca, IASI-CNR ; Paolo, Ventura, IASI-CNR

*Optimal Network Design for Waste Management in Regional Districts: the PIPER Project*

Waste management (WM) optimization is one of the key tasks to realize circular economy and achieve sustainability in large metropolitan areas. In this regard, location models are one of the main quantitative tools for spatial planning of service networks and, in combination with other methods such as data analytics and simulation, they can be effectively used in order to support network reengineering processes. Considering the WM setting, these models are able to support the reality of decision making whenever they also take into account the underlying network changes such as demand evolution, cost patterns modifications, transport and facility technology progresses.

This work proposes a network design model for a large metropolitan area, as a part of regional research project named PIPER - Intelligent Platform for the Optimization of Recycling Operations (grant n. A0375-2020-36611). The project aims at exploiting advanced applied research in the fields of optimization and artificial intelligence, and to apply them to the problems related to the sustainability of recycling processes, in terms of environmental, social, end economic targets.

The reengineering of the waste management network allows the optimization of specific objectives, such as network crossing times, costs and waitings, while satisfying a variety of constraints both of recycling performance and of financial balance. Costs evaluation will take into account both facilities construction and maintenance costs and the transportation costs through the network. In the reengineered network a key role is played by the so called transshipment locations, facilities used to lower the time spent by collection vehicles travelling the network instead of collecting waste bins. The models take into consideration the regional allocation of waste storage, treatment and selection plants, the distribution and concentration of urban agglomerations and industrial districts. Regarding the type of facilities, we distinguish waste sorting plants, waste-to-energy plants, composting plants, incineration plants and landfills. These models can indeed suggest the location of a new facility based on the demand, the variability and the type of urban and industrial waste produced in the area.

Thus, applying the principles of self-sufficiency and proximity to disposal, we proceeded to the definition of mathematical models useful for recommending the type of strategic and operational interventions required

to improve a regional waste management network.

Some of the environmental indicators and data used are the same monitored by the regional agency for environment protection ARPA, by the Italian agency ISPRA and by AMA Spa, the main logistic player in the region in question and one of the the biggest WM companies in Europe.



**TH 09:20 AM1 Auditorium A****Cristina Requejo** crequejo@ua.ptUniversity of Aveiro  
Pereira, António, University of Aveiro*A preliminary approach to the short-length time-slotted routing topologies problem*

The data transmission process is of the utmost importance nowadays and consists of transferring data between digital devices. The process enables devices or components within devices to communicate between them and occurs via point-to-point data streams or channels. These channels may previously have been in the form of copper wires but are now much more likely to be part of a wireless network.

The way data is transmitted by these channels is regulated through protocols such as the Time Slotted Channel Hopping (TSCH). This is one of the medium access control modes that is defined in IEEE 802.15.4e standard, a protocol designed for the Industrial Internet of Things (IIoT) applications such as smart city, smart home, and smart factory. Data transmission in TSCH networks is performed according to a tight time schedule. The higher the time schedule length, the higher the energy consumption of the network nodes and the end-to-end transmission delay. The amount of data transferred within a given time period is the data transfer rate, which dictates whether or not a network supports tasks that require complex, data-intensive applications. A higher data throughput improves user experience and increases reliability. Thus is important the use of short-length time-slotted routing topologies.

In this work, we consider the problem of finding tree routing topologies that minimize the time-slotted length. We are given a network and a set of data packets that need to be sent to the root node. In order to reduce interferences, each node is active at most one time at each time-slotted (half-duplex) and once a packet is sent, it never stops and goes directly to the root node. The objective function, to be minimized, is the time-slotted length. We characterize the problem, propose a mixed integer linear programming formulation, and evaluate the influence of the characteristics of the problem on the solution. A computational experience is carried out to assess the solutions obtained and the proposed solution strategies.

**TH 09:40 AM1 Auditorium A****David Rey** david.rey@skema.edu

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*MaaS network pricing with non-cooperative transportation service providers*

We address a pricing problem in the context of Mobility-as-a-Service (MaaS). The past decade has witnessed a significant increase in the diversity of urban mobility services. Ranging from conventional mass transportation, to shared mobility and on-demand transit services, these mobility solutions coexist and compete with each other in transportation networks. MaaS is an emerging business model that aims to integrate multimodal transportation solutions and provide seamless mobility solutions to users. This motivates the study of path-based pricing mechanisms where users are charged based on their path choice in a multimodal transportation network. Yet, most studies on MaaS have thus focused on characterizing travelers demand for this new service scheme rather than on providing optimized pricing mechanisms.

In this study, we consider a multimodal transportation network where nodes of the network represent trip origins, destinations, or transfer hubs across transportation services. Two nodes may be connected by one or more links representative of different transportation modes. We consider a set of trips representative of origin and destination pairs in the network with known travel demand. Each trip can be accomplished by traveling onto a path in the network connecting the origin and the destination of this trip. We model paths' attractiveness using generalized cost functions that combine path travel time and path cost. We consider that reserve mobility alternatives outside of the MaaS network are available and we use linear elastic travel demand functions to capture the proportion of demand served by a path.

Links of the network are assumed to be controlled by multiple profit-maximizing transportation service providers (TSPs). TSPs can adjust link fares to increase revenue subject to link capacity constraints. We take the perspective of a network regulator which aims to maximize ridership in the MaaS network by providing path-based subsidies to users while anticipating the strategies of non-cooperative TSPs and their effect on path generalized costs. This sets the basis for a Stackelberg game model wherein the leader player represents the network regulator and multiple follower players represent the TSPs. This game-theoretical framework is

known as a single leader multi-follower game (SLMFG).

We conduct a theoretical analysis of this SLMFG by identifying necessary and sufficient conditions for the existence of solutions to the parameterized generalized Nash equilibrium problems (GNEP) that is played amongst TSPs. Notably, we show that this GNEP is jointly convex and use this property to develop an exact numerical approach to solve the SLMFG. Numerical results reveal the impact of TSP competition in this MaaS network pricing problem and shed novel insights into the design of optimal path-based subsidy policies. We also investigate how subsidies can be designed to promote equity in the MaaS network.

## Continuous and Multiobjective optimization; Contributed Session

TH 10:00 AM1 Auditorium B

Maria Chiara Nasso `mc.nasso@dimes.unical.it`

University of Calabria  
Sergeyev, Yaroslav D., University of Calabria; Lera, Daniela, University of Cagliari

*Lipschitz global optimization using space-filling curves*

A wide variety of applications in engineering, machine learning, electronics, optimal control are interested in Lipschitz global optimization problems (see [1, 3]). In this work, we consider a multidimensional Lipschitz global optimization problem where the objective function is a black-box function which is supposed to be multiextremal and hard to evaluate. It is known that this optimization problem can be reduced to an equivalent univariate Hölder one through space-filling curves, (see [2, 4]). In this talk, two different approximations of Peano-Hilbert curve are employed. The first one is broadly used in global optimization whereas the second one, the non-univalent approximation, is less known. Each method is tested on 900 randomly generated test functions taken from the literature. Numerical experiments confirm advantages of the presented algorithms with respect to their direct competitors.

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**TH 10:20 AM1 Auditorium B****Sara Mattia** sara.mattia@iasi.cnr.it

IASI-CNR

*Optimistic vs Pessimistic Policy in Bilevel Programming*

Bilevel programming problems models situations where two stakeholders hierarchically ordered, known as leader and follower, are involved in a decision process. This leads to a mathematical model with a nested structure. Depending on the cooperation between the leader and the follower, there exists two versions of the same bilevel problem: an optimistic version, where the leader and the follower cooperate, and a pessimistic version, where there is no cooperation. These two policies correspond, in general, to different solutions of the problem. We consider mixed integer linear bilevel programming problems and describe necessary and sufficient conditions ensuring that the policy can be neglected, as the optimistic and the pessimistic problem produce the same solution. We also analyze a simple situation where, contrary to what one may expect, this is not the case.

**TH 09:00 AM1 Auditorium B****Andrea Cristofari** andrea.cristofari@uniroma2.it

Univ di Roma Tor Vergata

*A decomposition method for lasso problems with zero-sum constraint*

In this talk, an algorithm is presented to solve lasso problems with a constraint imposing that the sum of all variables is zero. Models of this type are commonly required for the analysis of compositional data in high-dimensional spaces. The proposed method uses a tailored active-set technique to estimate the zero variables in the optimal solution and a 2-coordinate descent scheme to update the variables. At each iteration, the algorithm chooses between two different strategies by a simple test based on the progress in the objective function. In particular, the first strategy requires to compute the whole gradient of the smooth term of the objective function and is more accurate in the active-set estimate, while the second strategy only needs to compute partial derivatives and is computationally more efficient. Global convergence of the algorithm to optimal solutions is proved. Finally, numerical results are presented on synthetic and real datasets, showing the effectiveness of the proposed method.

**TH 09:20 AM1 Auditorium B****Terézia Fulová** terezia.fulova@gmail.com

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*A conic optimization approach for solving Procrustes problems with quadratic constraints*

A Procrustes problem (PP) is a matrix approximation problem that searches for a transformation matrix of the given dataset to fit another dataset. Since their first appearance in psychometrics, PPs have arisen in many applications such as factor analysis, multivariate analysis, computer vision, multidimensional scaling, or global positioning systems. However, there are still subclasses of PPs lacking an effective solving algorithm. In this contribution, we introduce a rank-constrained semidefinite reformulation of the PP with quadratic constraints representing a specific transformation matrix. To solve rank constrained semidefinite problems, we apply a semidefinite relaxation and a modified rank reduction algorithm based on solving semidefinite programs. Unlike other methods, our approach can be applied to a wider class of PPs, including PPs with different types of transformation matrices, weighted PPs, PPs with partially specified targets, or PPs with additional affine constraints. We demonstrate our approach's performance while solving orthogonal Procrustes problems.

**TH 09:40 AM1 Auditorium B****Rosario Messina** `rosario.messana@unimi.it`

Università degli Studi di Milano

*Enhancing online combinatorial optimization with linear profits using mathematical programming*

We consider the following class of online optimization problems: the decision maker chooses a vector in  $\{0, 1\}^d$  and then observes a linear profit whose parameters are unknown until the decision maker's choice is made. The goal is to maximize the cumulative profit up to  $T$  iterations with respect to the best cumulative profit in hindsight.

The problem and some of its variants have been addressed in several works, including Freund & Shapire 1997, Koolen et al. 2010, and Pasteris et al. 2019. It is in fact suitable to model combinatorial optimization problems such as online facility location, online 0-1 knapsack and many others. A common strategy to address it is to relax the integrality constraints on the decision variables and to interpret the profit as the expected value of the same profit with binary variables. This step is key to enable the use of analytical methods like e.g. online convex optimization algorithms, and to obtain good regret bounds, i.e. sub-linear with respect to  $T$ . In fact, previous attempts introduce frameworks that alternate an online optimization step for the update of the relaxed variables with a randomized decision step for the choice of the binary-valued decision vector based on probabilistic interpretation of the updated relaxed variables. These frameworks lack in the capability of being together efficient and open to the insertion of arbitrary constraints on the decision vector.

We investigate both theoretically and experimentally the introduction of methods involving mixed integer programming resolution to address sub-problems of the problem described above. We are indeed motivated by the idea of estimating the applicability and flexibility in similar online settings. The aim of our work is to provide methods that improve on the generality of the existent approaches and that ensure good empirical efficiency.



## Variational Inequalities and equilibrium problems; Contributed Session

TH 11:30 AM2 001

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dad de Sevilla; Mármol, Amparo, Universidad de Sevilla

*Environmental damage reduction: when countries face conflicting objectives*

Numerous international environmental agreements of countries have been aimed at limiting their polluting emissions. However, this is an arduous goal to achieve since it involves two often conflicting objectives for their governments: maximizing their monetary benefits and minimizing the perception of environmental damage, both of which depend on the level of pollution emitted by the set of all countries. Taking these two objectives into account, the situation is analyzed as a two-criteria game where each country has a tolerance threshold with respect to global emissions. The approach considered makes it possible to deal with a key issue in the analysis: the fact that it is not possible to compare in monetary terms the results obtained when countries act strategically in pursuit of their objectives. We show that depending on the relationships between the thresholds for each country, different sets of equilibria arise. A significant consequence of this research is that all of these equilibria provide strategies with a positive effect on emission reductions and can play an important role in reversing climate change.

**TH 11:50 AM2 001**

**Valerio Dose** `valerio.dose@uniroma1.it`

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*Active Network and Price of Anarchy in Multi-Commodity Routing Games with Variable Demands*

Equilibria in nonatomic routing games describe how traffic distributes on a network used by a large number of agents which are interested in minimizing their own delay. The mathematical model where such equilibria arise, is composed of a directed graph representing the network, and cost functions associated to each edge of the graph, which represent the delay experienced on an edge, as a positive nondecreasing function of the amount of traffic traveling on that same edge. In this framework, equilibria can be described as optimal solutions to a minimization problem. Nevertheless, they are usually not optimal with respect to a different, and more meaningful, objective function, which is the total delay experienced by all users of the network. For this reason, the Price of Anarchy has been considered in the literature, as an index of the inefficiency of equilibria. It is defined as the ratio of the total delay in an equilibrium and the optimal total delay.

The traditional way of studying the Price of Anarchy has been determining upper bounds for it, which are tight in the worst case scenario. Recently, the Price of Anarchy has also been considered as a function of the traffic demand. In a previous publication, the authors analyze networks with a single commodity, which means that all users want to travel between the same origin and destination in the graph. In this situation, it is shown that with affine cost functions, the Price of Anarchy as a function of the demand, achieves local maxima only at points where it is not differentiable, and between two such points it can achieve at most one smooth local minimum. This confirms a behavior observed in previous empirical works on the subject. An important concept to be considered in this analysis is the one of active network, which is, for each level of demand, the set of edges which are used in equilibrium. If the active network is not constant in a neighborhood of some demand, we call such a demand a breakpoint. It is exactly at breakpoints that the Price of Anarchy can be non differentiable and achieve a local maximum.

In the work we are presenting, we apply the same approach to networks with multiple commodities. In these type of networks, the users can be of different types, each of them traveling between different pairs of vertices of the graph. We consider the Price of Anarchy not only as a function of every possible vector of demands across all the commodities, but also as functions of a single real parameter where the vector of demands is given by a fixed demand function of the parameter. In both situations we

**Variational Inequalities and equilibrium problems; Contributed Session**

can define the active network and breakpoints analogously to the single commodity case. We show that, with affine cost functions, if the demand function keeps the vector of demands on a line through the origin, then the behavior of the Price of Anarchy is the same as in the single commodity case. However, this is not true if the vector of demands moves on a line which does not go through the origin. In networks with continuously differentiable cost functions and strictly positive derivatives, we prove a result concerning the left and right derivative of the Price of Anarchy at breakpoints when the demands vary on a line through the origin. Finally, we also study how the active network varies in the whole spectrum of demands, focusing on the case of parallel networks where all types of users travel between the same two vertices, but each type uses a different set of paths.

**TH 12:10 AM2 001****Marcello Sanguineti** marcello.sanguineti@unige.it

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Olga, Matthiopoulou, Vodafone Greece; Benoit, Bardy, University of Montpellier; Antonio, Camurri, University of Genova; Giorgio, Gnecco, IMT Lucca; Denis, Mottet, University of Montpellier

*Detection of the Origin of Movement: Graph-Theoretical Model and Data Processing*

The agreement among participants in a survey is used to define a ground truth for the origin of full-body human movement, as it is perceived by observers. This may differ from the physical origin of movement, as it is defined by experts. Then, a computational model based on the theory of cooperative games is exploited to find automatically the perceived origin of movement. In more details, a transferable-utility game is built over a skeletal representation of the human body, based on a characteristic function related to how movement features change on adjacent vertices of the graph (joints), which are the players of the game. Then, the Shapley values of the joints are evaluated and used to extract a higher-level feature, which provides an estimate of the joint from which movement either originates or propagates. The method developed in [1,2] is refined (as in [3]) by considering a pre-processing of the available motion capture dataset, dealing with issues such as missing data, outlier detection, and noise reduction. This research received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 824160 EU (Project EnTimeMent) and from the Università Italo-Francese (project GALILEO 2021 no. G21\_89). G. Gnecco and M. Sanguineti are members of Gruppo Nazionale per l'Analisi Matematica, la Probabilità e le loro Applicazioni (GNAMPANational Group for Mathematical Analysis, Probability and their Applications) of the Istituto Nazionale di Alta Matematica (INdAMNational Institute of Higher Mathematics).

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**TH 12:30 AM2 001**

**Ricardo Almeida** ricardo.almeida@ua.pt

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*Optimization conditions for functionals dealing with variable order fractional derivatives and with dependence on an arbitrary function*

In this work we combine two ideas: fractional derivatives of variable order and fractional derivatives depending on another function. With such operators, we develop a variational problem theory by presenting necessary conditions of optimization for different kind of problems. An integration by parts formula is also proven, fundamental for the developing of our theory.

## Discrete Optimization; Contributed Session

TH 11:30 AM2 002

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*On the solution of optimal timing problems for single machine rescheduling problems with new jobs arrival*

This study on the idle times insertion is motivated by a rescheduling problem on a single machine with unpredicted new jobs arrival. In the problem, a regular scheduling function is minimized and there is a constraint on the absolute time deviation of jobs w.r.t. the original optimal schedule. This second constraint is an alternative for modelling a second objective of the rescheduling problem, which is the minimization of the disruption induced by per-turbing the initial schedule of old jobs. When the perturbation is computed as the absolute deviation from the original completion time, then it is given by a non-regular function. At a first glance, the minimization of a regular objective function leads to active schedules with no idle times. However, the second objective, even if it is considered as an  $\varepsilon$ constraint, may generate idle times in an optimal solution. When solving any of the related problems, there is the need of identifying whether a solution may or may not include idle times to develop the right model and a suitable solving procedure. This work presents such an analysis on the above-mentioned rescheduling problem, with different classical scheduling objective functions. Several underlying arguments around the insertion of idle times are presented, such as causes, special cases and examples. The analysis is then extended to cover all typical objective functions used in scheduling. As a result, for each objective function, it is presented a list of properties, that include if the problem belongs to the exceptions of those not containing idle times, properties on the ordering of the jobs - which is related to the insertion of idle times - if there exist special cases with different properties and, whenever known, the complexity of the problem.

**TH 11:50 AM2 002**

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*A Heuristic Algorithm for the Capacitated Demand-Driven Metro Timetabling Problem*

Metro lines are normally operated with regular timetables, where trains have a constant headway between all stations. Such timetables are typically designed based on aggregate demand forecasts for time periods spanning a number of hours, e.g., morning peak.

Given the recent technological advances in passenger billing and tracking (e.g., smart transit cards), it is now possible to predict passenger demand at a refined temporal level. This possibility prompted research into non-periodic timetabling strategies that directly adapt services to a time-dependent demand profile. However, operating on a refined temporal level necessitates dealing with detailed vehicle scheduling decisions to ensure the feasibility of the resulting timetable. Moreover, a detailed modeling of passengers boarding is required so as to optimize service measures. For these reasons, non-periodic models are far more complex than periodic ones. In this vein, a problem entitled the demand-driven timetabling problem (DDTP) has been proposed by [1]. The DDTP explicitly matches the train timetable to a given passenger demand, so as to minimize the total passenger waiting times. Specifically, the trains are scheduled, without predetermined frequencies, using short-turning operations. These imply that trains are not required to serve the line from terminal to terminal, but instead, may reverse their direction before reaching a terminal of the line.

Trains are assumed to be uncapacitated in the DDTP. In this paper, we explore the capacitated demand-driven timetabling problem (CDDTP). Indeed, the integration of capacities in the DDTP introduces a number of complexities related to modeling and evaluating passenger waiting times. In the CDDTP, capacities are modeled through the instantaneous capacity utilization of the individual trains, assuming a non-centralized boarding policy, i.e., that the boarding decisions of the passengers may not be controlled. This implies that when vehicle capacity is not sufficient to board all waiting passengers, which passengers end up boarding is determined through a fixed boarding policy.

To efficiently solve the CDDTP, we develop an effective Iterated Local Search metaheuristic for the problem. The development of the proposed heuristic involved several algorithmic contributions. We devised a polynomial evaluation procedure for assessing the total passenger waiting time generated by a given timetable, and an effective lower-bound which is evaluated in linear time. The local search phase of the ILS is implemented

through a variable neighborhood search (VNS), for which we developed three tailored neighborhoods. Finally, we present a modified evaluation procedure designed for efficiently evaluating a subset of the timetables that are produced during the local search phase.

Through extensive computational experiments, we evaluate the effectiveness of the developed heuristic and benchmark the achieved solutions against the results of an exact algorithm for the DTPR. Additionally, we demonstrate the operational advantages of the CDDTP by comparing it with periodic timetables.

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**TH 12:10 AM2 002****Domenico Serra** dserra@unisa.it

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*New Approaches for the kidney exchange problem*

In this talk, we address the well-known kidney exchange problem (KEP), that arises in the context of transplant programs allowing two or more incompatible patient-donor pairs to swap kidneys. Often when the patient needs a kidney transplant, a possible donor is identified among the family members, but there may be problems related to incompatibility of blood groups or problems related to other pathologies. What is typically done is to swap donors between patients. This problem can be modelled through a directed graph, in which the nodes represent the incompatible patient and relative donor pairs, while there is a directed arc from node  $i$  towards node  $j$  if the  $i$ -th donor can donate to the  $j$ -th patient. The probability of success of the transplant is associated with each arc. The problem consists in identifying oriented cycles that do not intersect, with the aim of covering as many nodes as possible, maximizing the probability of success. Identifying cycles guarantees that, if the  $i$ -th donor donates a kidney to the  $j$ -th patient, the  $i$ -th patient receive a kidney, too. Any donor donates a kidney if and only if its related patient receives a compatible one. Prohibiting intersections ensures that a donor can only donate once and a patient receives a kidney from only one donor. This problem has been extensively treated in the literature through both exact and heuristic approaches. We want to provide new models and algorithms based on the arc-deleting approach. The idea behind the arc-deleting approach is to remove arcs from a graph with the aim of identifying a specific sub-structures like oriented cycles. To test the proposed approaches, we used several instances to see how promising they are.

**TH 12:30 AM2 002**

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*On Vertex Enumeration and Hypergraph Dualization: relevance in combinatorial optimization and a new decomposition approach*

Any convex polyhedron can be described through two different equivalent formulations: as the intersection of closed halfspaces or as the Minkowski sum of the convex hull of a finite set of points, plus a conical combination of vectors [1]. By asking whether there is a way to pass from one representation to the other, the Vertex Enumeration and the Facet Enumeration problems arise. In 1992, Lovasz [2] underlined the similarity between these two problems and the Hypergraph Dualization problem. Consider the set-covering polyhedron  $P(A, 1) := \{x \in \mathbb{R}^n, x \geq 0 \text{ with only integral vertices and } A \text{ as ideal matrix [3]. These vertices are in bijection with the minimal transversals of the hypergraph } H \text{ associated to the matrix } A. \text{ Indeed, the columns and the rows of } A \text{ correspond to the vertices and the characteristic vectors of the hyperedges of } H, \text{ respectively. Thus, the problem of enumerating the vertices of } P \text{ is equivalent to the problem of computing the minimal transversals of } H. \text{ Then, an efficient procedure to solve the Hypergraph Dualization problem would lead to an efficient procedure to also solve this special restriction of the Vertex Enumeration (and vice versa), but may not hold for the general case. Anyway, given the celebrated result by Fredman and Khachiyan in 1996 [4], the vertices of } P \text{ can be enumerated in quasi-polynomial time, which makes the Vertex Enumeration problem unlikely to be NP-hard. In this talk, first we remark the relevance of such problems in operations research and combinatorial optimization, and we provide a brief overview about the main approaches to solve the Vertex (Facet) Enumeration problem. Then, we present another possible decomposition for the Hypergraph Duality problem, which the Hypergraph Dualization problem can be reduced to [5]. This decomposition offers a strong bound which, however, in the worst case, has the same time complexity as [4]. Anyway, these results encourage the study and the development of other approaches, also to investigate the exact complexity of the problems, which is still an open question.}$

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## **NOML, Nonlinear Optimization and Machine Learning; Invited Session**

**TH 11:30 AM2 003**

**Cecilia Salvatore** [cecilia.salvatore@uniroma2.it](mailto:cecilia.salvatore@uniroma2.it)

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### *Model Extraction based on Counterfactual Explanations*

Automated decision-making classification systems based on Machine Learning algorithms are often used in many real-life scenarios such as healthcare, credit, or criminal justice. There is thus increasing interest in making Machine Learning systems trustworthy: interpretability, robustness, and fairness are often essential requirements for the deployment of these systems. In particular, according to the European Union's General Data Protection Regulation (GDPR), automated decision-making systems should guarantee the "right to explanations", meaning that those affected by the decision may require an explanation. Counterfactual Explanations are becoming a de-facto standard for a post-hoc explanation. Given an instance of a classification problem, belonging to a class, its counterfactual explanation corresponds to small perturbations of that instance that allow changing the classification outcome. The objective of this work is to try and exploit the information revealed by a small set of examples with their counterfactual explanations to build a surrogate model of the classification system. The idea is to define an optimization problem that provides in output a Forest of Optimal Trees as close as possible to the original classification model, given the information derived from the counterfactual points. This tool can be used either to attack the original model or to improve it, depending on the application context. Preliminary results show the viability of this approach.

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Università degli Studi di Firenze; Bagattini, Francesco, Flair Tech;  
Galvan, Giulio, Flair Tech

*A Robust Initialization of Residual Blocks for Effective ResNet Training without Batch Normalization*

Batch Normalization is an essential component of all state-of-the-art neural networks architectures. However, since it introduces many practical issues, much recent research has been devoted to designing normalization-free architectures. In this paper, we show that weights initialization is key to train ResNet-like normalization-free networks. In particular, we propose a slight modification to the summation operation of a block output to the skip-connection branch, so that the whole network is correctly initialized. We show that this modified architecture achieves competitive results on CIFAR-10 without further regularization nor algorithmic modifications.

**TH 12:10 AM2 003****Sara Venturini** sara.venturini@math.unipd.itUniversity of Padua  
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Sasso Science Institute; Cristofari, Andrea, University of Padua*Semi-supervised learning in multilayer hypergraphs*

A variety of complex systems has been successfully described as networks whose interacting pairs of nodes are connected by links. However, in real-world applications, we need to describe interactions in more detailed and varied ways. Many real systems display collective actions of groups of nodes and simplicial complexes or hypergraphs are the natural candidates to describe these group interactions. Moreover, often we can measure different types of relationships between the same nodes, and multilayer networks provide the mathematical formalism to describe these multi-channel interactions. Evidence show that each of these tools can improve modelling capacities with respect to standard graphs. However, relatively few studies simultaneously consider multilayer and higher-order structures in complex networks so far. This is also due to the fact that such a sophisticated structure comes at the cost of an additional complexity and a harder treatability. In this work we take a first step in the study of semi-supervised learning over multilayer hypergraphs, trying to deal with this additional complexity.

**TH 12:30 AM2 003**

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RWTH Aachen

Rauhut, Holger, RWTH Aachen; Schmidt, Mark, UBC

*Robustness and Generalization in Training Deep Neural Networks*

Deep Learning (DL) models are nowadays the key to achieve state-of-the-art performances in a wide range of real problems. Despite their extensive use, the understanding of DL is limited and the theoretical guarantees are few. Moreover, performances of DL models are very sensible to various training algorithmic choices, for instance and above all, the learning rate. The robust selection of the learning rate is indeed a very central topic in DL and it is still one of the main concern of optimization researchers working in this area. In this project, we will study non-monotone Stochastic Gradient Descent (SGD) algorithms to improve the robustness of the training method w.r.t. the learning rate. Despite these methods are a very natural choice for highly nonlinear models, this is the first time in which they are applied on the top of a SGD-like algorithm. A new theory has been developed to adapt the convergence rates of deterministic nonmonotone methods to the stochastic setting. Numerical results are showing that the intrinsic properties of nonmonotone methods are extremely well suited when dealing with large-scale highly-nonlinear stochastic problems.

## PRPI, Path and routing problems in industry; Invited Session

TH 11:30 AM2 Auditorium A

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*Shortest path with acceleration constraints: Complexity and approximation algorithms*

We introduce a variant of the Shortest Path Problem (SPP), in which we impose additional constraints on the acceleration and speed over the arcs, and call it Bounded Acceleration SPP (BASP). This variant is inspired by an industrial application: a vehicle needs to travel from its current position to a target one in minimum-time, following pre-defined geometric paths connecting positions within a facility, while satisfying some speed and acceleration constraints, depending on the vehicle position along the currently traveled path. The motivation for studying this problem is related to the fact that the shortest path is not always the fastest one. BASP is the combination of two different problems. The first is the combinatorial one of detecting the best path from a source to a destination node over an oriented graph with constant costs associated to its arcs (i.e., the SPP). The second is the continuous one of minimum-time speed planning over a fixed path, under speed and acceleration constraints. We characterize the complexity of BASP, proving its NP-hardness. Indeed, in BASP we still have the combinatorial search for a best path as in SP. However, differently from SP, the cost of an arc (more precisely, the time to traverse it) is not a constant value, but depends on the travel speed along the arc itself. This, in turn, depends on the speed and acceleration constraints not only over the same arc, but also over those preceding and following it, along the selected path. We also show that, under additional hypotheses on problem data, the problem admits a pseudo-polynomial time-complexity algorithm. Moreover, we present an approximation algorithm with polynomial time-complexity with respect to the data of the original problem, and the inverse of the approximation factor  $\epsilon$ . The idea is to discretize the squared speeds, in order to obtain a finite set of possible squared speeds at each node of the graph. In this way, imposing that the initial and final squared speeds along each arc belong to the discretized set of squared speeds, the set of possible speed profiles over each arc becomes finite. Hence, we can define an extended graph that enables us to solve this discretized version of the problem by means of Dijkstra's algorithm.

**PRPI, Path and routing problems in industry; Invited Session**



**TH 11:50 AM2 Auditorium A****Francesco Gallesi** francesco.gallesi@unimore.itDISMI University of Modena and Reggio Emilia  
Côté, Jean-François, CIRRELT and Laval University; Alves de Queiroz,  
Thiago, IMTec Federal University of Catalão; Iori, Manuel, DISMI  
University of Modena and Reggio Emilia*A Branch-and-Regret Algorithm for the Same-Day Delivery Problem*

In the last years, the number of e-commerce sellers has increased, and many companies changed their focus to direct-to-customer deliveries to improve their business. Online purchases have been a more and more common practice to request services or goods at home. This trend has increased because of the Covid-19 pandemic, which made people reluctant to leave their homes. Online purchases have become a crucial logistic activity and managing the problem in an efficient way is not an easy task. Historically, this type of problem has been addressed in the field of stochastic dynamic vehicle routing problems. In the problem we face, the requests arrive dynamically during the day and must be served within a strict time window. The aim is to use a fleet of vehicles to maximize the number of served requests and minimize the traveled distance. This problem is known in the literature as the Same-Day Delivery problem (SDDP). We first solve the SDDP by means of a simple but efficient reoptimization heuristic that locks past decisions, adds newly revealed requests, and then optimizes the routing plan with an adaptive large neighborhood search (ALNS). We then propose a scenario-based planning approach (SBPA) that considers fictive requests sampled by a probability distribution. In each scenario, a routing plan is optimized with the ALNS, and a consensus function chooses which plan to adopt. Finally, we propose a branch-and-regret (BR) algorithm that extends the SBPA by evaluating different possible alternatives for each request. We consider as alternatives a vehicle departing now, a vehicle departing in the future, and the assignment of a request to third-party logistic operator. We create different routing plans by branching on these alternatives and invoking the ALNS. The plan to implement is chosen again with the help of a consensus function. The algorithms are also adapted to solve the problem variant where vehicles are allowed to perform preemptive returns to the depot. Extensive computational experiments on a large variety of instances prove the outstanding performance of the BR, also in comparison with recent literature, in terms of served requests, traveled distance, and computing time.

**TH 12:10 AM2 Auditorium A****Tobia Marcucci** tobiam@mit.edu

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*Shortest paths in graphs of convex sets, and their applications in control and robotics*

Given a graph, the Shortest-Path Problem (SPP) requires finding a sequence of edges with minimum cumulative length that connects a source to a target vertex. We consider a generalization of this classical problem in which each vertex in the graph is paired with: i) a convex set, and ii) a point in the convex set that represents the spatial location of the vertex. As opposed to the classical SPP, where edge lengths are constants, we let the length of an edge be a convex function of the location of its endpoint vertices. The problem we obtain is then mixed discrete-continuous, as it requires to simultaneously identify a discrete path in the graph and optimize the continuous location of the vertices visited by the path. We name this family of optimization problems "SPPs in graphs of convex sets," and we show how this framework encompasses a wide variety of decision problems in control, robotics, networks, and logistics.

The versatility of the framework we propose is reflected in the problem complexity: contrarily to the classical SPP, the SPP in graphs of convex sets is easily seen to be NP-hard. Our main contribution is formulating this problem as a Mixed-Integer Convex Program (MICP) whose convex relaxation is very tight, but also lightweight; making it possible to efficiently find globally-optimal paths in large graphs and in high-dimensional spaces.

The first application we consider is optimal control of hybrid systems (i.e., dynamical systems that exhibit both continuous and discrete behaviors). This topic has been intensively studied in the last two decades, and has already had a strong impact in the automotive industry, in power systems, and in robotics. We show that optimal control problems for hybrid systems are naturally formulated as SPPs in graphs of convex sets, and therefore can be tackled using the optimization framework we propose. In our computational experience, this leads to MICPs that are orders of magnitude faster to solve than state-of-the-art formulations of these control problems.

The second application we discuss is robot motion planning in environments with obstacles. Using existing algorithms, we efficiently decompose the robot environment into a collection of collision-free convex regions. Then we design a continuous trajectory within the union of these "safe" regions using Bezier curves and our SPP framework. In stark contrast with existing mixed-integer motion planners, in the great majority of the practical applications, the convex relaxation of our MICPs is extremely tight, if not exact. The solution of a single convex program, possibly followed

by a simple rounding step, is then typically sufficient to detect a globally-optimal collision-free trajectory. From a practical perspective, planning problems that were previously tackled with mixed-integer semidefinite programming can now be reliably solved via a single second-order-cone program. We demonstrate our planning algorithm on a variety of robotic systems, including quadrotors flying in cluttered environments and robot arms in high-dimensional manipulation tasks.

**TH 12:30 AM2 Auditorium A****Irene Saccani** irene.saccani@unipr.it

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studi di Parma

*Multi-agent Path Finding on Strongly Connected Digraphs*

We consider a set of agents moving along the edges of a directed graph. Each agent is not allowed to move in a node occupied by another agent. The Multi-Agent Path Finding (MAPF) consists in finding a sequence of moves that brings the agents to assigned target positions, avoiding collisions. It is known that finding a solution with the minimum number of moves is NP-hard. Indeed, the various optimal solvers considered in literature have a computational time that grows exponentially with the number of agents. The literature also presents suboptimal solvers with lower computational time. Anyway, they are not complete, that is, they are not always able to find a feasible solution. Complete, suboptimal algorithms that run in polynomial time exist for undirected graphs and for biconnected directed graphs. In this paper, we will show a new way of combining these algorithms to find a feasible solution for strongly connected directed graphs in polynomial time. The proposed method always finds a feasible solution, if it exists. Essentially, our approach generalizes the method presented in [3] to digraphs. Namely, we decompose the graph into biconnected components, and use some methods presented in [1] to reconfigure the agents in each biconnected component. We present a method, based on [2], that checks the problem feasibility in linear time with respect to the number of nodes. Also, we present an algorithm (diSC) that finds a solution for all admissible problems with at least two holes, generalizing the method in [3]. We ran the algorithm on a set of random graphs. The results show that the solution length and the computational time grow polynomially with respect to the number of nodes and the number of agents.

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## Applications: Sustainability, Health Care; Contributed Session

TH 11:30 AM2 Auditorium B

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*CHP Systems Optimization in Presence of Time Binding Constraints*

As decarbonization becomes a global priority, there is a need to increase the efficiency of energy production. Combined Heat and Power (CHP) is an energy efficient technology that generates electricity and captures the heat that would be wasted otherwise in order to provide thermal energy, often used to feed district heating networks. Unit Commitment (UC) is a key problem in this context. The goal in UC is to determine a schedule for the machines that maximize the operative margin, satisfying a forecasted heat demand coming from a district heating network as well as functional and regulatory constraints deriving from system composition and placement. This gives rise to Unit Commitment (UC) problems. In this work, we formulate and solve Mixed Integer Linear Problems for the short-term optimization of real world CHP systems. We present some key features that make the problem hard to be solved in practice with particular attention to time binding constraints, e.g., limitations on the number of turn-ons over a period, minimum time on/off permanence, ramp-up and ramp-down constraints, heat storage, regulatory limitations defined over the legislative year. As for the latter, we study how Primary Energy Saving (PES) limitations introduced by the European Parliament Directives can be modeled in a MILP formulation and which are the critical aspects to consider. We then present a time-based decomposition metaheuristic for the optimization of mid-term (i.e., one year budgeting) UC problems, with computational results obtained over real world problem optimizations. A relevant factor for the accuracy of the energy production plan is the ability to forecast the heat demand of the network. Thus, we developed a forecasting module that, given the historical heat demand and other relevant data, automatically builds accurate prediction models. Specifically, each predictive model is trained and tuned using the most appropriate machine learning technique among a pool of state-of-the-art algorithms. The methodology proposed is implemented within a Decision Support System currently in use by plant managers of several CHP systems connected to district heating networks dislocated in Italy. We give an overview of the DSS interfaces and relative use cases. Further, we will introduce current development directions, such as the support for the integration with the power markets sessions, and enhancement to deal with plants where machines are operated in series and operating temperatures

Applications: Sustainability, Health Care; Contributed Session

become important decision variables along with the amount of energy produced.

**TH 11:50 AM2 Auditorium B****Tine Meersman** `tine.meersman@ugent.be`Ghent University  
Maenhout, Broos, Ghent University*Multi-objective optimisation for constructing cyclic appointment schedules for elective and urgent patients*

In this paper, we study the construction of a cyclic appointment schedule in an outpatient department. In particular, we determine the capacity distribution between elective and urgent patients and the scheduling of the time slots reserved for these patients such that the operational waiting times of elective and urgent patients are minimised. The proposed solution methodology devises a Pareto set of cyclic appointment schedules based on these waiting times with different capacity allocations for urgent patients. An approximation of the Pareto set of non-dominated schedules is obtained using a multi-objective archived simulated annealing heuristic. To accurately validate the cyclic appointment schedules, we incorporate operational decision-making via scheduling individual patients. To this end, we simulate operational variability, i.e., patient arrivals, no-show behaviour, punctuality and scan durations, based on real-life input data. The patients are assigned one-by-one using an online scheduling rule. Computational experiments are conducted with a real-life case study. We compare different appointment scheduling rules and discuss the impact of the capacity distribution between elective and urgent patients and the timing of urgent slots in the cyclic appointment schedules. The results show that the distribution of capacity between patient types, the timing of urgent slots and appointment rules all have significant impacts on patient waiting times. Appointment waiting times improve when urgent slots are spread equally over and throughout the days considered and when the BaileyWelch rule is used to schedule patients. Trade-offs between elective and urgent waiting times resulting from different capacity distributions or slot timing are exemplified via a Pareto front. The proposed method outperforms relevant single-pass methodologies, and we demonstrate that its performance is strengthened thanks to the integrated optimisation of strategic, tactical and operational decisions.

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*Optimization for surgery department management: an application to a hospital in Naples*

Surgery department with its operating rooms represents the financial backbone of modern hospitals accounting the main part of a hospital cost and revenue. Therefore, maximizing its efficiency is of vital importance since it can have important implications on cost saving and patient satisfaction. In this context, Operations Research methodologies can play a relevant role supporting hospital executives in operating room management and surgery scheduling issues. In particular, great relevance has been given in literature to the Surgery Scheduling Problem. In its general form, it consists in determining a day, an operating room and a starting time of a set of surgeries. In this work, we address the Surgery Scheduling Problem faced by a local hospital of Naples. The aim of the hospital is to determine a surgery schedule capable of handling unforeseeable events (e.g., the arrival of an emergency) while maximizing the number of performed surgeries, according to some medical guidelines. This problem has been modelled by an original integer linear programming formulation that has been tested and validated on several instances derived from real data provided by the hospital. Finally, the proposed formulation can be used to simulate different surgery operating scenarios. The results of this simulation can be used to provide useful managerial insights for an efficient schedule of the hospital surgeries.



**TH 12:30 AM2 Auditorium B****Gabriele Zangara** gabriele.zangara@unical.itDepartment of Mechanical, Energy and Management Engineering,  
University of CalabriaRosita, Guido, Department of Mechanical, Energy and Management  
Engineering, University of Calabria; Giuseppina, Ambrogio, Depart-  
ment of Mechanical, Energy and Management Engineering, Univer-  
sity of Calabria; Domenico, Conforti, Department of Mechanical,  
Energy and Management Engineering, University of Calabria*A flexible job shop scheduling model for Sustainable Manufacturing*

The research work was carried out with particular attention to the use of energy in production processes and the costs deriving from its consumption. The discussion was verticalized within a case study in the manufacturing sector, developing and implementing an optimization model to support the planning and scheduling of processing activities of heat exchangers with the aim of minimizing costs due to energy consumption. The formulated model was in fact tested on real data collected considering the products made at multinational corporate operating in the manufacturing industry. Following the formulation and testing of the customized optimization model, the results obtained showed that the cost due to the energy required for production is about 10% lower than the current production.

## Keynote

**TH 14:30 PM0 Auditorium A**

**Dick Den Hertog** [d.denhertog@uva.nl](mailto:d.denhertog@uva.nl)

Faculty of Economics and Business, University of Amsterdam

### *Analytics for a Better World*

In this talk I will describe two Analytics applications that contribute to one or more of the 17 Sustainable Development Goals (SDGs) of the United Nations. The first application is an optimization model to optimize the food supply chain for the World Food Programme. This application received the INFORMS Franz Edelman award in 2021. The second application is an optimization model to optimize health care facility locations in Timor-Leste and stroke center locations in Vietnam. This project is carried out in collaboration with the World Bank. If time permits I will shortly describe current and future activities of the recently initiated Analytics for a Better World Institute ([analyticsbw.org](http://analyticsbw.org)).

**Keynote**

## Stochastics, Equilibria, Applications; Contributed Session

TH 15:40 PM1 001

Emel Savku esavku@gmail.com

University of Oslo, Department of Mathematics

*A constrained nonzero-sum game application: Bancassurance*

We develop an approach for two player constraint zero-sum and nonzero-sum stochastic differential games, which are modeled by Markov regime-switching jump-diffusion processes. We provide the relations between a usual stochastic optimal control setting and a Lagrangian method. In this context, we prove corresponding theorems for two different type of constraints, which lead us to find real valued and stochastic Lagrange multipliers, respectively. Then, we illustrate our results for an example of cooperation between a bank and an insurance company, which is a popular, well-known business agreement type, called Bancassurance. We found out a Nash equilibrium for this game and solved the adjoint equations explicitly for each state. It is well known that the timing and the amount of dividend payments are strategic decisions for companies. The announcement of a dividend payment may reduce or increase the stock prices of a company. From the side of the bank, it is clear that creating a cash flow with high returns would be the main goal. Hence, in our formulation, we provide an insight to both of the bank and the insurance company about their best moves in a bancassurance commitment under specified technical conditions.

[1] E. Savku, A stochastic control approach for constrained stochastic differential games with jump and regimes. Submitted 2022.

**TH 16:00 PM1 001**

**Milan Hladík** `hladik@kam.mff.cuni.cz`

Charles University, Faculty of Mathematics and Physics, Department of Applied Mathematics

*Complexity Issues in Interval Linear Programming*

Interval linear programming studies linear programming problems with interval coefficients. Herein, the intervals represent a range of possible values the coefficients may attain, independently of each other. They usually originate from a certain uncertainty of obtaining the data, but they can also be used in a type of a sensitivity analysis. The goal of interval linear programming is to provide tools for analysing the effects of data variations on the optimal value, optimal solutions and other characteristics. This paper is a contribution to computational complexity theory. Some problems in interval linear programming are known to be polynomially solvable, but some were proved to be NP-hard. We help to improve this classification by stating several novel complexity results. In particular, we show NP-hardness of the following problems: checking whether a particular value is attained as an optimal value; testing connectedness and convexity of the optimal solution set; and checking whether a given solution is robustly optimal for each realization of the interval values.

**TH 16:20 PM1 001****Nikola Obrenovi** nikola.obrenovic@biosense.rs

University of Novi Sad, BioSense Institute

Selin, Ataç, École Polytechnique Fédérale de Lausanne, Transport and Mobility Laboratory; Stefano, Bortolomiol, École Polytechnique Fédérale de Lausanne, Transport and Mobility Laboratory; Sanja, Brdar, University of Novi Sad, BioSense Institute; Oskar, Marko, University of Novi Sad, BioSense Institute; Vladimir, Crnojevi, University of Novi Sad, BioSense Institute

*The Crop Plant Scheduling Problem*

With the increase in world population, the efficient production of food becomes an ever more important goal. One of the particular tasks associated with this goal is to find an optimal crop planting time, considering the allowed planting time windows and the following objectives: 1) weekly harvest must not surplus the available storage capacity and produce waste, and 2) the labor force should be utilized in the efficient manner. To tackle this problem, we define the crop plant scheduling problem (CPSP), in the form of mixed integer linear problem, and solve it with a commercial mathematical programming solver. To estimate the harvest time, we also predict the time needed for accumulation of the sufficient amount of growing degree units (GDUs), using an ARIMA model. In this paper, we present the developed GDU forecasting and CPSP models, and the obtained results for the two selected problem instances.

**TH 16:40 PM1 001**

**Rosario Scatamacchia** `rosario.scatamacchia@polito.it`

Dipartimento di Ingegneria Gestionale e della Produzione, Politecnico di Torino, Torino, Italy  
Dragotto, Gabriele, Canada Excellence Research Chair in Data Science for Real-time Decision-making, École Polytechnique de Montréal, Montréal, Canada

*ZERO Regrets Algorithm: Optimizing over Pure Nash Equilibria via Integer Programming*

In Algorithmic Game Theory (AGT), designing efficient algorithms to compute Nash equilibria poses considerable challenges. We make progress in the field and shed new light on the intersection between Algorithmic Game Theory and Integer Programming. We introduce ZERO Regrets, a general cutting plane algorithm to compute, enumerate, and select Pure Nash Equilibria (PNEs) in Integer Programming Games, a class of simultaneous and non-cooperative games. We present a theoretical foundation for our algorithmic reasoning and provide a polyhedral characterization of the convex hull of the Pure Nash Equilibria. We introduce the concept of equilibrium inequality and devise an equilibrium separation oracle to separate non-equilibrium strategies from PNEs. We test ZERO Regrets on problems in the literature such as, among others, the Knapsack Game, an Integer Programming Game where each player solves a knapsack problem, and paradigmatic classes of games in AGT such as the Network Formation Game, where players build a network over a graph via a cost-sharing mechanism. Our algorithm successfully solves relevant instances of the considered games and shows promising applications for equilibria selection.

## Discrete Optimization; Contributed Session

TH 15:40 PM1 002

Yasmine Alaouchiche yasmine.alaouchiche@utt.fr

University of Technology of Troyes  
Ouazene, Yassine, University of Technology of Troyes; Yalaoui, Farouk,  
University of Technology of Troyes.

*Throughput evaluation of large series-parallel production lines: a fast and efficient approach*

Introduction Efficient performance of manufacturing systems is of crucial importance. Throughput evaluation of serial production lines has been largely treated in the literature. In contrast, parallel manufacturing systems are important but complex structures and the literature dedicated to their study is more scarce. Existing studies either use aggregation techniques to transform each parallel station into an equivalent one and then implement serial line evaluation tools, or directly evaluate the series-parallel system through decomposition methods. Nevertheless, most available methods either study limited and sometimes unrealistic systems (small, unbuffered, or reliable), or require important computational time. Therefore, we propose a fast and accurate throughput evaluation method for large series-parallel production lines with unreliable non-identical machines.

Problem description and solution method The manufacturing system studied is a series-parallel production line with  $S$  parallel machine workstations separated by and  $S - 1$  intermediate buffers of finite capacities. Each workstation  $S_i$  may have  $K_i$  unreliable and non-identical parallel machines following the exponential reliability model. To study the series-parallel system, each parallel workstation is aggregated into an equivalent station using aggregation techniques of parallel machines from the literature ([1], [5], and [3]). After aggregating each parallel workstation into an equivalent station, the throughput of the flow system is evaluated based on the Equivalent Machine Method [4] where buffer states are analyzed using a birth death Markov process. State space cardinality is drastically reduced through the consideration of only full and empty buffer states rather than all buffer states. Then, each station  $S_i$  is replaced by an equivalent one taking into account the probabilities of blockage and starvation. The throughput of the system is defined as the bottleneck between the effective production rates of all the stations.

Numerical experiments and results The proposed method is formulated as a non-linear program which is implemented on a mathematical solver for conducting numerical experiments. A benchmark introduced in [2] is used to compare the performance of the approach with the evaluation method proposed in [2] against an implemented simulation model on FlexSim. Numerical results of throughput estimation for both balanced and asyn-

chronous configurations with up to 50 parallel workstations, demonstrate the great accuracy and efficiency of the proposed method compared to the evaluation method in [2]. Indeed, the proposed algorithm performs very well with total average errors of 4.91% and 2.64%, whereas [2] evaluation method registers total average errors of 7.87% and 5.41%, for the balanced configurations and the asynchronous configurations respectively. In addition, the computational time for all cases is reduced drastically. Indeed, it ranges between 3.51s up to 15.30s, whereas in [2] evaluation method computational time ranges between 8.2s up to 1.67h.

**Conclusion** The proposed approach offers the possibility to evaluate with good accuracy the performance of large complex series-parallel production lines in few seconds. We believe that this evaluation tool could be the key to solving efficiently design problems in real manufacturing systems. Future research includes using the proposed method as an evaluation tool to solve design problems such as the buffer and/or server allocation problem in complex production systems.

[1] B. Ancelin and A. Semery. Calcul de la productivité d'une ligne intégrée de fabrication : Calif, un logiciel industriel basé sur une nouvelle heuristique. *Automatique-productique informatique industrielle*, 21(3) :209238, 1987. [2] A. Diamantidis, J.-H. Lee, C. T. Papadopoulos, J. Li, and C. Heavey. Performance evaluation of flow lines with non-identical and unreliable parallel machines and finite buffers. *International Journal of Production Research*, 58(13) :38813904, 2020. [3] J. Li. Modeling and analysis of manufacturing systems with parallel lines. *IEEE transactions on automatic control*, 49(10) :18241832, 2004. [4] Y. Ouazene, H. Chehade, A. Yalaoui, and F. Yalaoui. Equivalent machine method for approximate evaluation of buffered unreliable production lines. In *2013 IEEE Symposium on Computational Intelligence in Production and Logistics Systems (CIPLS)*, pages 3339. IEEE, 2013. [5] A. Patchong and D. Willaeyts. Modeling and analysis of an unreliable flow line composed of parallel-machine stages. *Iie Transactions*, 33(7) :559568, 2001.



**TH 16:00 PM1 002****Carmine Sorgente** csorgente@unisa.it

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*Cluster Deletion Problem*

Clustering deals with partitioning a given set of items into homogeneous subsets on the basis of their relations. If such items are regarded as the nodes of a graph, the output of the clustering task is a disjoint union of cliques and is also referred to as cluster graph. This talk addresses the Cluster Deletion problem, which aims to identify the minimum set of edges whose removal from the original graph produces a cluster graph. It is known that minimizing the total number of edges between the clusters is equivalent to maximizing the total number of edges within the clusters. The problem belongs to a family of cluster graph modification problems, it finds application in DNA clone classification and is known to be NP-hard on generic graphs. We address the Cluster Deletion problem by designing an Integer Linear Programming formulation and a heuristic approach based on edge contraction operations which iteratively merge promising nodes in order to obtain good quality clique partitions. We finally compare the performances of the proposed approaches on both real and randomly generated instances.

**TH 16:20 PM1 002****Mauro Gaggero** mauro.gaggero@cnr.it

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University of Genoa, Genoa

*A MILP Formulation and a Metaheuristic Approach for the Scheduling of Drone Landings and Payload Changes on an Automatic Platform*

We present a mixed-integer linear programming formulation and a metaheuristic approach based on direct search to schedule landings and payload changes of a set of unmanned aerial vehicles that cooperate to achieve given mission objectives. In more detail, such vehicles require landing on an automatic platform able to rapidly substitute batteries and switch the payload they are currently carrying with another one, if required by the mission at hand. Preliminary numerical results are presented to show the effectiveness of the metaheuristic algorithm as a compromise between accuracy of suboptimal solutions and computational effort.

**TH 16:40 PM1 002****Alessio Sortino** `alessio.sortino@unifi.it`

DINFO, University of Florence  
Cappanera, Paola, DINFO University of Florence; Di Gangi, Leonardo,  
DINFO University of Florence; Lapucci, Matteo, DINFO University of Florence; Pellegrini, Giulia, DINFO University of Florence; Schoen, Fabio, DINFO University of Florence

*Scheduling Airport Personnel by Exact Optimization Models*

Defining shifts and assigning jobs to personnel in large companies is a common problem, yet not trivial to handle. Effective and efficient approaches have been proposed through the years by operations research experts. In this work, the rostering problem is considered as an activity-based scheduling in the specific case of the ground staff in a large Italian airport. This case study, compared to the classical scheduling problem, shows significant additional complexities, such as highly specialized personnel and great granularity of jobs to be carried out. Within this work, exact mathematical optimization models are proposed to tackle this problem. In particular, an integer linear programming model is defined, starting from a set of possible shifts calibrated on the basis of demand. In addition, computationally effective valid inequalities defined on groups of overlapped jobs and clique-based are introduced in order to reduce the computational burden of the ILP solver. Experimental results show how the proposed model is effective and able to produce the desired planning, with good optimality guarantees and the employment of reasonable computational resources.

## OML, Optimization for machine learning; Invited Session

TH 15:40 PM1 003

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*Distributed extension of the Douglas-Rachford method with applications.*

In this talk, we describe how the graph-based extension of the Douglas-Rachford method introduced at our companion's talk provides new fully distributed decentralized schemes for solving non-smooth convex optimization and monotone inclusion problems composed of many terms.

The proposed method is based on a two layers architecture, consisting of what we call base and state graphs. We discuss the role of the two layers in detail, showing that while the state graph fixes the communication structure of the method, the choice of the base graph leads to essentially different schemes with different convergence properties. In particular, we observe both from explicit convergence rates and numerical experiments that choosing a base graph with higher algebraic connectivity seems to improve the convergence speed of the method. However, the main drawback of having higher connectivity is the higher amount of information that flows through the communication graph, which we formalize in the notion of communication cost. Here, the design of a distributed scheme with low communication cost intertwines with purely graph-theoretical challenges. In fact, the proposed definition of communication cost depends on the sparsity of a class of faithful orthogonal representations of the base graph in the sense of Lovász, which can be hard to bound. As a first example, we show that a distributed protocol with minimal communication cost can be designed without effort when the base graph is a tree. Then, we focus on the case of the so-called chordal or monotone transitive base graphs, where a distributed optimization protocol with low communication cost can be designed via QR decomposition of the incidence matrix.

In the experiments, we first apply the devised method to a congested optimal transport problem showing that: (i) the algebraic connectivity of the base graph does indeed affect the convergence performance of the method, (ii) before convergence, each node provides different estimates of the solution which inherit the properties of the corresponding operator. We conclude with an application to distributed Support Vector Machines showing that the proposed method is highly competitive with state-of-art methods such as P-EXTRA and a distributed Primal-Dual Hybrid

OML, Optimization for machine learning; Invited Session

Gradient method while requiring significantly lower storage capabilities.

**TH 16:00 PM1 003**

**Jonathan Chirinos Rodriguez** jonathanchirinosrodriguez@gmail.com

Università degli studi di Genova  
Bredies, Kristian, University of Graz; Naldi, Emanuele, TU Braunschweig

*Learning Resolvent Operators*

In the past years, Machine Learning techniques have become a breakthrough in various fields of Applied Mathematics, such as Convex/Non-convex optimization, Inverse problems, PDEs or Optimal transport. In particular, when solving variational inverse problems, there has been a huge attempt to use Neural Networks in a wide variety of situations: by learning the parameters of a regularizer, by learning the regularizer itself, or even the data-discrepancy term. In parallel, and motivated by the Forward-Backward-Splitting algorithm, Plug-and-play algorithms have been introduced. Many authors have understood that, actually, the step involving the proximal operator of the regularizer acts as a data-denoising step and, therefore, such proximal operator may be replaced by a learned denoiser. To do so, different techniques and approaches have been observed and applied. In this talk, we focus on exploiting the properties that the proximal operator of any convex function may have. Such properties may be derived by simply studying properties of the space of nonexpansive operators. Given this observation, we consider Supervised Learning techniques to construct nonexpansive operators with theoretical guarantees. Moreover, we propose a constructive method to do so by considering Triangulation Techniques. We guarantee partial convergence results of our method to the minimizer of the empirical risk and, finally, propose applications where our method could be applied and compete with state of the art regularizers.

**TH 16:20 PM1 003**

**Emanuele Naldi** e.naldi@tu-braunschweig.de

TU Braunschweig  
Kristian, Bredies, UniGraz and Enis Chenchene, UniGraz

*Graph extension of the Douglas-Rachford method with minimal lifting*

In this talk, we propose several generalizations of the Douglas-Rachford method to solve monotone inclusion problems involving  $N$  maximal monotone operators. In particular, our objective is to show that, starting from an ordered undirected connected graph, it is possible to construct a generalization of the Douglas-Rachford algorithm with a communication structure that respects the connections of such a graph. The resulting schemes we present are unconditionally stable frugal resolvent splitting methods with minimal lifting in the sense of Ryu. Indeed, every scheme is required to store only  $N - 1$  variables at a time. We describe our methods in the (degenerate) Preconditioned Proximal Point framework and, in this way, we are able to prove convergence of every derived algorithm in a unifying way. Specifically, we show that the proposed methods are instances of the proximal point algorithm. We start our talk by introducing the general convergence analysis of degenerate Preconditioned Proximal Point algorithms. We then derive the convergence analysis for the graph generalization of Douglas-Rachford as an application. To do so, starting from the ordered undirected connected graph, we construct a maximal monotone operator in a large product space (of dimension  $2N - 1$ ) and a degenerate preconditioner in such a way that the correspondent reduced Preconditioned Proximal Point algorithm will involve only  $N - 1$  variables and will have the communication structure dictated by the graph. The graph generalization of Douglas-Rachford we introduce has its own interest since it gives rise to several generalizations of the well-known Douglas-Rachford method. In fact, we show that we can achieve at least one distinct generalization for every ordered undirected connected graph. In addition, our companion talk focus on the applications that such extensions can have in distributed optimization.

## Optimization on Graphs; Contributed Session

TH 15:40 PM1 Auditorium A

**Roberto Zanotti** roberto.zanotti@unibs.it

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Mansini, Renata, University of Brescia - Department of Information Engineering

*A matheuristic approach for a Vehicle Routing Problem with Parcel Lockers and Green Customers*

Due to the COVID 19 pandemic, the volume of online purchases has increased dramatically in the last couple of years. As a consequence, the impact of last-mile logistics on city centers and main roads has further increased, both in terms of traffic jams and increased pollution. Several solutions are being evaluated, such as the use of alternative delivery means, like electric vehicles and drones, or the introduction of incentives for less impactful delivery practices, including very flexible delivery times or wide time windows [1]. Among the solutions identified to reduce this negative impact of last-mile deliveries, parcel lockers are receiving considerable attention. Instead of delivering parcels directly to customers' homes, a last-mile delivery company can leave them in secure parcel lockers where customers can pick them up later. The company needs to decide the number and location of the locker stations to minimize its delivery costs. This delivery solution can be extremely beneficial for the company, given the expected reduction in traveled distances, and this has been the most analyzed side of the problem in the literature. However, an often-neglected impact of the introduction of lockers is the environmental one, since the distances traveled by customers to pick up parcels are usually not considered. In this work, we focus on a location and routing problem that jointly considers as objective function the minimization of the overall emissions due to both the delivery company and the customers that need to collect their parcels. A key aspect of the problem is the introduction of different customer profiles, that define the distance that a customer is willing to travel with or without using zero-emission transportation means. We adapt a mathematical formulation from the literature and propose several ways to improve it. Then, we introduce a hybrid matheuristic algorithm based on the Kernel Search framework [2] and local search heuristics to solve it. The solution algorithm is tested on a comprehensive set of instances that considers different customer profiles and behaviors. The computational results are promising and show the effectiveness of the devised framework. Additionally, interesting insights can be derived from the experimental analysis, especially regarding the fact that the role of customers is one of the main drivers for controlling the environmental impact.

**Optimization on Graphs; Contributed Session**



- [1] Daniele Manerba, Renata Mansini, Roberto Zanotti, 2018. Attended Home Delivery: reducing last-mile environmental impact by changing customer habits, IFAC-PapersOnLine, Volume 51, Issue 5, Pages 55-60. [2] Enrico Angelelli, Renata Mansini, M. Grazia Speranza, Kernel search: A general heuristic for the multi-dimensional knapsack problem, Computers & Operations Research, Volume 37, Issue 11, 2010, Pages 2017-2026.

**TH 16:00 PM1 Auditorium A****Orlando Marco Belcore** mdigangi@unime.itDepartment of Engineering, University of Messina  
Di Gang Massimo Antonio; Polimeni, Department of Engineering,  
University of Messina*C-Weibit discrete choice model: a path based approach*

In traffic assignment a key role is played by the path choice that simulate the path chosen by users in relation to the perceived costs. Various models are proposed in literature in order to accomplish this task (e.g., those obtained from generalized extreme value model). One of the main problems encountered is the overlap among paths between the same origin-destination pair. In order to overcome this problem, the research was directed towards models like C-logit, Path-Size Logit or Probit that are able to take into account this aspects. In this paper the use of a C-Weibit model is proposed, by introducing a commonality factor that modify the utility function when the paths overlap. From the benefits of this model, is to highlight that the probability can be calculated in a closed form. The C-Weibit was used within a stochastic user equilibrium assignment procedure. The results and some comparisons are reported, in these tests C-Weibit had better performances than other models.

**TH 16:20 PM1 Auditorium A****David Di Lorenzo** david.dilorenzo@verizonconnect.com

Verizon Connect Research, Florence, Italy  
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Leonardo, Taccari, Verizon Connect Research, Florence, Italy; Marco,  
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Verizon Connect Research, Florence, Italy; Alessandro, Lori, Veri-  
zon Connect Research, Florence, Italy

*Ten years of Routist: vehicle routing lessons learned from practice*

The Vehicle Routing Problem (VRP) has been intensively studied for more than five decades, and many variants have been introduced over the years, spanning from simple specializations such as the Capacitated Vehicle Routing Problem (CVRP) or Vehicle Routing Problem with Time Windows (VRPTW) to more exotic ones. VRP dramatic implications on operational costs explain the significant effort that has been put in researching effective and efficient solution methods, both from academia and businesses worldwide. Most companies have adopted third party software solutions, others, e.g. delivery fleets, keep developing internal tools to keep operational costs as low as possible and increase margins. In Verizon Connect we have been working for ten years on Routist, a VRP Software-as-a-Service product, and we have learnt many lessons from our customers along the way. Most of all, we discovered that useful optimization algorithms need to fit customer needs and problems. Thus, they require optimization techniques that are not often addressed in the scientific literature. In this work we retrace the path that led us to where we are today, highlighting some of those challenges after all, it is the journey that matters.

**TH 16:40 PM1 Auditorium A****Carla De Francesco** carla@math.unipd.it

Università di Padova, Dipartimento di Matematica "Tullio Levi-Civita"

Luigi, De Giovanni, Università di Padova, Dipartimento di Matematica "Tullio Levi-Civita"

*Integer Linear Programming Formulations for the Fleet Quickest Routing Problem on Grids*

In an automated transportation system, a fleet of vehicles moves on a grid, each from its starting point on one side, to its destination on the opposite side. For the sake of efficiency, the only allowed routes are nonstop shortest paths. Among these, one route for each vehicle has to be properly chosen, avoiding that two vehicles cross the same node or move on the same edge at the same time. Therefore, an assignment of origin-to-destination nonstop collision-free shortest path routes is required. The Fleet Quickest Routing Problem on Grids aims at finding the minimum number of grid lanes allowing for such an assignment. We present two Integer Linear Programming models that exploit some combinatorial properties of conflicting shortest paths: the first one has binary variables and refines a multicommodity flow formulation; the second one exploits a compact representation of shortest paths with a reduced number of integer variables. We compare the two formulations through test on random and on purpose generated instances, showing the better performance of the compact formulation, and we discuss their potential towards more efficient methods.

## Sustainability; Contributed session

TH 15:40 PM1 Auditorium B

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Bruglieri, Maurizio, Dipartimento di Design, Politecnico di Milano;  
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Keskin, Merve, Sheffield University Management School;  
Mancini, Simona, Alpen-Adria-Universität Klagenfurt e Dipartimento per lo Sviluppo Sostenibile e la Transizione Energetica, Università del Piemonte Orientale

### *The Effect of Low Emission Zones on the Routing of Electric and Fossil-Fuel Vehicles*

Due to the recent concerns about the environment and climate change, some countries around the world are implementing policies and rules for promoting the use of Alternative Fuel Vehicles (AFVs), especially in road transport which is responsible for a significant percentage of the total GreenHouse Gas emissions of the transportation sector. Among AFVs, Electric Vehicles (EVs) can significantly contribute to reducing both noise and environmental pollution. Some countries have established restrictions on the utilization of fossil-fuel powered Traditional Vehicles (TVs) in urban areas such as Low Emission Zones (LEZs) where TVs are either banned from entering or required to pay a toll to enter for the first time. Instead, EVs can travel without any restriction. The aim of our work is supporting the transportation companies toward an ecological transition, providing them with optimization-based approaches suitable to assist them in the process of replacing/integrating their traditional fleet. In fact, we address the problem of efficiently routing a mixed fleet comprising both TVs and EVs based at a common depot, for serving a set of customers at minimum total operating cost. We refer to it as the Mixed Fleet Vehicle Routing Problem with LEZ (MFVRP-LEZ). The operating costs include the cost of electricity recharged to EVs both at the depot and en-route, the fuel cost of TVs, and the tolls paid by TVs for entering the LEZ. Each vehicle starts its tour from the depot, serves a subset of customers, and returns to the depot before the end of its shift. Moreover, we assume that each customer must be served within a specified time window and an EV can recharge (also partially) en-route. We mathematically formulate MFVRP-LEZ as an arc-based Mixed Integer Linear Program (MILP) by allowing multiple visits to a station without cloning it and by identifying a-priori the set of non-dominated stations between each pair of customers. We solve small-sized instances using CPLEX. For solving large-sized instances, we design an Adaptive Large Neighborhood Search (ALNS) that extends the set of moves, already proposed in the related literature, with

Sustainability; Contributed session

problem-specific new mechanisms. The experimental campaign is carried out on a set of benchmark instances of varying sizes derived from those already presented in the related literature by adding LEZs and arcs avoiding LEZs. Numerical results validate the effectiveness of ALNS and provide managerial insights.

**TH 16:00 PM1 Auditorium B****Matteo Pozzi** [matteo.pozzi@optit.net](mailto:matteo.pozzi@optit.net)

OPTIT

Bischi, Aldo, University of Pisa; Gordini, Angelo, OPTIT

*Integrated planning of multi-energy systems (PlaMES): a comprehensive modelling framework and decision support tool*

The European Unions commitment towards a carbon-neutral economy can only be accomplished by a synergistic implementation of measures where Renewable Energy Sources expansion, integration of different energy systems and Transmission/Distribution infrastructure development are calibrated to meet future (2050) energy needs. The high complexity of the task comes from problem dimension, where future national demand and supply must be managed taking into account the interconnection between electricity, gas, heat and mobility sectors, with an hourly granularity to take into account multi-energy coupling dynamics. The Horizon 2020 project PlaMES, currently in its last year, aims to determine the optimal target system, including the investment trade-off between different technologies, infrastructure configurations and emissions reductions that minimize overall system costs. Introducing the overall business challenge, further explored in its detailed modelling and resolution strategies by the academic partners of the project during the session. Particular focus will be devoted to the decision support tool, that must handle extremely large quantities of data to provide significant scenario management capability to perspective decision makers, be them Transmission System Operators designing optimal infrastructure plans or Country Planners identifying what technology mix guarantees effective future energy systems that meet the challenges of decarbonisation.

**TH 16:20 PM1 Auditorium B****Antonio Punzo** antonio.punzo5@unibo.itDEI, University of Bologna  
Monaci, Michele, University of Bologna; Vigo, Daniele, University  
of Bologna*Transmission expansion planning for future European energy grid*

PlaMES is an Horizon 2020 project aimed at developing an integrated planning tool for multi-energy systems on a European scale, taking into account both the expansion of generation and storage technologies and the related infrastructure in an integrated manner, so as to deliver to the European Unions COP21 commitments. The PlaMES architecture consists of six tools. In this talk we will introduce the module designed for solving the Transmission Expansion Planning (TEP), which aims at identifying cost-efficient expansion and congestion management measures to ensure the system security and reliability of future electrical transmission grids. Our modelling approach considers different expansion and reinforcement measures and yields to an integer linear programming formulation, which is solved by using an exact enumerative algorithm in which a Benders decomposition scheme is used to compute a dual bound. The method is enhanced by means of a metaheuristic algorithm, and is computationally tested on realistic instances of large size.



**TH 16:40 PM1 Auditorium B****Silvia Anna Cordieri** `silviaanna.cordieri2@unibo.it`DEI, University of Bologna  
Monaci, Michele, University of Bologna; Paronuzzi, Paolo, University of Bologna; Vigo, Daniele, University of Bologna*A decomposition approach for the Central Energy System planning*

The Central Energy System (CES) planning is a problem including both unit commitment problem and generation expansion planning, and it is formulated as a linear program. The system consists of a set of nodes, each one with a set of available energy production technologies, a set of time steps, and a transmission network topology. For each node and time step a demand is given, and the objective is to minimize the sum of operational and installation costs, while satisfying the demand and respecting the maximum limit on CO<sub>2</sub> emissions. Given the scale at which the problem is treated, a heuristic algorithm exploiting the block-structure presented by the mathematical formulation of the problem has been designed. In particular, the procedure works in two distinct phases. In the first phase, the considered time-horizon is divided in a number of subperiods, each one defining a subproblem presenting the same characteristic of the original problem. Then, these subproblems are solved (possibly in parallel) and their solution are used to define the values of all the design variables (i.e., the amount of capacity for each technology installed at each node and the possible expansion of the network). After the design variables has been fixed, in the second phase of the algorithm, the same subproblems are solved again (possibly in parallel), this way operational variables are also defined and a feasible solution is found.

**Assemblea AIRO - AIRO Council meeting**

**TH 17:30 PM2 Auditorium A**

**Assemblea AIRO**

*AIRO council meeting*

**\*\* NO ABSTRACT PROVIDED \*\***

**Assemblea AIRO - AIRO Council meeting**

## Applications of OR; Contributed Session

FR 10:00 AM1 001

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*Capacitated Disassembly Lot-Sizing Problem with Disposal Decisions for Multiple Product Types with Parts Commonality*

This paper addresses capacitated disassembly lot sizing problem for multiproduct structure with parts commonality. Disposal decisions are considered to manage the accumulation of unnecessary items obtained after disassembly operations during the planning horizon. A new mixed-integer programming (MIP) model is given to formulate the problem. Exact method by using CPLEX solver can be applied to obtain optimal solutions for the small-sized problem. A fix-and-optimize heuristic is proposed for larger sizes of the problem, it solves successively a series of sub-problems. In each sub-problem, a subset of variables are fixed while the remaining are optimized using an exact method. Computational tests are performed on a number of randomly generated instances and the results demonstrate the performance of the proposed model and methods.

**FR 10:20 AM1 001**

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versiteit Amsterdam; Ulmer, Marlin, Chair of Management Science  
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*Anticipatory Time Window Assignment for Next-Day Service Routing*

In many home delivery services, customers must be present when the Logistics Service Provider (LSP) arrives and operates. This type of service is known as Attended Home Delivery (AHD) services. Examples of AHD are the delivery of large, valuable, or perishable items, technician services for installment, repair, maintenance, or meter reading, and several healthcare applications. In most AHD applications, customers are not entitled to select the time at which the service takes place, but a service time window is assigned to the customer by the LSP. From an operational viewpoint, whenever a new customer requests service, the LSP must decide whether the request should be accepted or rejected and, if accepted, on which day and within which time window to serve the customer. If a time window is offered, then all accepted requests must be served within the corresponding offered time windows. Yet, to guarantee efficient operations, the LSP should assign the time windows to the customers to serve as many customers as possible while maintaining flexibility for future unknown requests.

The dynamic assignment of time windows to customers poses several optimization challenges, such as how many drivers should be scheduled per day? On which day (if any) should a new customer be served? Which time window should be offered to a customer on that day? In this talk, we address this last question. In particular, throughout a capture phase (today), customers request service within a fulfillment phase (tomorrow). Each customer is either assigned a time window from a predefined set (9-10 a.m., 10-11 a.m., 11-12 a.m., ...) or the customer is postponed to another day (outside of the scope of this work). A time window can only be assigned if a vehicle routing plan that serves the new customer and the previous customers within their respective time windows can be found. The goal is to maximize the number of customers that can be served in the fulfillment phase.

The problem we address can be formulated as a stochastic dynamic decision problem. However, finding an optimal policy is a challenging task for two main reasons. First, in every state, checking the feasibility of offering a time window to the new customer calls for solving a Vehicle Routing Problem with Time Windows (VRPTW), which is NP-hard. Second, evaluating the impact of offering a (feasible) time window at a given state requires the anticipation of future customers and future time-window

**Applications of OR; Contributed Session**

decisions, on which only limited stochastic information is known. We propose a solution method that addresses these two issues by (a) checking the feasibility of a time window with an exact solution method and (b) assessing the quality of a decision (i.e., offering a given time window) at a given state through Bellman equations of immediate reward (1 or 0) and an approximation of the expected future reward (value). In particular, the future reward is approximated by generating a set of scenarios, each corresponding to a team-orienteering problem (TOP) with multiple time windows and mandatory customers. We approximate the reward of each TOP by deriving fast upper bounds provided by the linear relaxation of a set packing formulation solved via column generation.

We test our algorithm on artificial data and real-life data from Iowa city. The results show that our method increases the number of customers served significantly compared to a rolling horizon approach without anticipation. Our algorithm can also provide solutions that, on average, serve 90% of the customers when compared to an ex-post upper on the static counterpart of the problem.

**FR 09:00 AM1 001**

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*Demand Forecasting Methods: A Case Study in the Italian Processed  
Meat Industry*

Demand forecasting is acquiring more and more importance in the fast-changing business world, where market instability and economic shocks such as Covid-19 pandemic require firms to be both efficient and flexible. This work is based on a research project aiming at the development of a demand forecasting model for a company that operates in the Italian processed meat segment. The purpose is to obtain a forecast as accurate as possible and then use it at a later stage to carry out an optimal production scheduling (see, e.g., [1], [2]). Especially in the food sector, a proper integration of forecast and production management is essential, because the perishable nature of the items does not allow for over production. In this work, we compared different Machine Learning forecasting algorithms, including Linear Regressor, Random Forest Regressor, Support Vector Regressor and Multi-layer Perceptron Regressor. We compared these methods with the ones used in the literature to define a baseline, like random walk and seasonal mean. Extensive computational tests on a two-year real-world data series prove the effectiveness of the algorithms, especially the Support Vector Regressor, in providing an accurate forecast. The resulting model is now used by the company on a daily basis.

Acknowledgements: We thank Inalca S.p.A. for financial support.

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**FR 09:20 AM1 001**

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*A new efficient heuristic for the Automatic Scene Detection Problem*

Nowadays, the automatic extraction of semantic and metadata information from video content has become essential in tackling the huge amount of audio and visual data that are produced every day. The several applications of this task range from video management and advertising insertions to automatic audio description and fast video browsing. As a result, its automation constitutes a compelling matter for video industry and consumers as well. The Automatic Scene Detection Problem (ASDP), first introduced in the literature of video processing in [1], is a combinatorial optimization problem that consists in segmenting a set of shots, each constituted by a sequence of frames ideally taken from the same viewpoint, into semantically consistent scenes, by optimizing a measure of similarity between shots. We specifically consider the ASDP variant introduced in [2], that is nontrivial for a generic number of scenes, and deciding its complexity is still an open question. We present an approximate solution algorithm [3] able to outperform the previous state-of-the-art one [2] both in terms of speed and quality of the solution. We also provide a complete characterization of the computational complexity of the two algorithms, by laying out fundamental concepts on the combinatorics of the ASDP.

[1] Daniel Rotman, Dror Porat, and Gal Ashour. Robust and efficient video scene detection using optimal sequential grouping. In Proceedings of the 2016 IEEE International Symposium on Multimedia (ISM), pages 275280, 2016. [2] Daniel Rotman, Dror Porat, Gal Ashour, and Udi Barzeley. Optimally grouped deep features using normalized cost for video scene detection. In Proceedings of the 2018 ACM on International Conference on Multimedia Retrieval, pages 187195, 2018. [3] Daniele Catanzaro, Raffaele Pesenti, and Roberto Ronco. A new fast and accurate heuristic for the automatic scene detection problem. Computers and Operations Research, 136:105495, 2021.

**Applications of OR; Contributed Session**

**FR 09:40 AM1 001**

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*A unified approach to data envelopment analysis models*

Data envelopment analysis (DEA) defines a variety of models to assess the performance of decision-making units. The models take form of mathematical programming problems that link together an efficiency measure and a given technology set in the input-output space. DEA defines two basic classes of models. The models in the first class assume proportional change of inputs and outputs and search for the benchmark by following a parametric path. The models in the second class allow individual change of each input and output component and integrate the input excesses and output shortfalls into an overall efficiency measure. We analyze properties of models in each of the two classes by means of a unified framework and offer a generalized dual (multiplier) form of models in each class.



## Applications: Health Care; Contributed Session

FR 10:00 AM1 002

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### *A Two-Stage Stochastic approach for the Integrated Multi-Period Combinatorial Auction and Nurse Routing Problem*

We study a Nurse Routing Problem (NRP) where a hospital manages patients assignments through a Multi-Period Combinatorial Auction (MPCA) that allows the outsourcing of visits. In the MPCA, external providers offers are composed of a subset of visits and the total cost required to perform them. For the patients not externally assigned, the NRP schedules daily routes for each nurse [1]. Additional consistency constraints limit the maximum number of nurses assigned to a patient in performing his/her visits [2]. The goal of the hospital is to select external bids to minimize the auction cost and the travelling costs to serve patients. In the deterministic version of the problem, both the hospital and the providers have access, at the beginning of the time horizon, to the exact information regarding patients and their required visits. However, to capture the complexity of real-life application, we introduce a degree of uncertainty in the model. Due to the multi-periodicity of the problem, each day the number of visits and their service time may vary from what previously agreed with the hospital [3]. Thus, we propose a two-stage stochastic formulation where we model the number of visits and their length as stochastic variables while the total number of patients remains deterministic. At the first stage, the hospital needs to make decisions about the bid based on the expected values of the random variables. The quality of these decisions can be evaluated at the second stage with the realization of such variables in a specific scenario. Our objective is to study how different hospital recourse policies affect the final solutions and the overall costs.

[1]A. Gobbi, D. Manerba, R. Mansini, R. Zanotti (2019). A Kernel Search for a patient satisfaction-oriented Nurse Routing Problem with Time Windows. In: IFAC-PapersOnLine 52 (13):1669-1674. Proceedings of MIM2019, 9th IFAC Conference on Manufacturing, Modelling, Management and Control. August 28-30, 2019. Berlin (Germany). [2]Y. Song, M. W. Ulmer, B. W. Thomas, and S. W. Wallace (2020). Building trust in home services - Stochastic team-orienting with consistency constraints. Transportation Science, 54(3):823-838. [3]Lars M. Hvattum, Arne Løkketangen, Gilbert Laporte, (2006) Solving a Dynamic and Stochastic Vehicle Routing Problem with a Sample Scenario Hedging Heuristic. Transportation Science 40(4):421-438.

Applications: Health Care; Contributed Session

**FR 09:00 AM1 002**

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*A branch-and-price-and-cut algorithm for operating room scheduling under human resource constraints*

Operating theater scheduling may be often severely affected by unexpected unavailability of resources. Solving the integrated planning and scheduling problem of an operating theater is an important task to ensure the efficiency of surgical operations.

We define an integrated operating room planning and scheduling problem including constraints commonly considered, for similar problems, both in practical contexts and in the literature. We focus particularly on constraints on human resources, i.e., surgeons, and nurses. The defined problem considers surgeries with different infection levels and sequence-dependent operating room cleaning times.

For this integrated planning and scheduling problem, we devise a branch-and-price-and-cut algorithm based on a problems time-indexed formulation. The proposed column generation scheme relies on a label-correcting algorithm purposely designed for solving the related strongly NP-Hard pricing problems. The pricing problems are formulated as single operating room scheduling problems with time-dependent costs and sequence-dependent cleaning times as required.

The efficiency of the label-correcting algorithm is ensured by dominance rules for labels and by two procedures for computing the upper and the lower bound of the labels. The upper-bound computation is based on the linear programming relaxation of a multidimensional 0-1 knapsack problem and the lower-bound is computed by means of a greedy heuristic procedure. For tightening the linear relaxation of the problem, we develop an effective cutting procedure inspired by Benders decomposition and based on duality theory for linear programming.

We conduct a numerical study both on instances from the literature and on newly generated instances to demonstrate the computational effectiveness of the solution method. The Benders-like cutting procedure is shown to be effective in tightening the linear programming bound of the problem and improves the linear programming relaxation of the problem even though the computation time is not negligible. The label correcting algorithm is efficient for generating columns. The column generation stops even for large-sized instances (up to 160 surgeries) with a moderately reduced number of columns added to the restricted master problem,

**Applications: Health Care; Contributed Session**

typically about thousands of columns. The devised branch-and-price-and-cut algorithm outperforms both competing methods from the literature and a commercial solver.

The approach of the Benders-like cutting procedure is sufficiently generic to be applied in the case of an arbitrary number of resources for the generation of resource-related cuts, surgeon and nurse cuts in our case, improving the linear programming relaxation of the procedure master problem.

**FR 09:20 AM1 002****Mirko Cavecchia** `mirko.cavecchia@unimore.it`

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*A Facility Location Problem to support Helicopter Emergency Medical Services*

Locating helipads in strategic positions, especially in mountain areas, is a crucial decision to reduce transport time of injured people to hospitals. The problem has been largely studied in the literature. Many researches focus on identifying the optimal set of locations to cover a given population percentage by implementing a maximal covering location problem, while other studies aim to minimize the average response time over the entire population or minimize the total rescue time. This work originates from the need of the Parma Helicopter Emergency Medical Service (PHEMS) to identify which existing helipads should be equipped with modern infrastructures for night landing and, if necessary, where to build new helipads. PHEMS provided us with the historical data referring to the rescue interventions carried out in the last years in the province of Parma. We used this large data set to build two different bi-objective optimization models: the first minimizes the cost of equipped helipads and the total rescue time; whereas the second minimizes the cost of equipped helipads and the total delay with respect to given target due-dates identified on the basis of the injured urgency levels. Both models have been solved via an epsilon-constrained method and tested on the PHEMS case. The resulting solutions are characterized by relevant improvements with respect to the existing real-world solutions, both in terms of total rescue time and total delay.

**FR 09:40 AM1 002**

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*Nurse Routing Problem with Incompatible Services and Minimum Demand: An ALNS+Kernel Search solution approach*

In recent decades, the average age of the population has grown steadily along with the number of people suffering from chronic diseases and asking for treatments. Hospital care is expensive and often unsafe, especially for older individuals and particularly during a pandemic as the SARS-CoV-2 one. Hence, hospitalization at home has become a valuable alternative for several treatment requests with lower risk to fragile patients [1], while guaranteeing a high quality of service. This new care process clearly requires the redefinition of health services organization and the optimization of scarce resources, such as the available nurses. In this work, we study a Nurse Routing Problem [2] aiming at finding a good balance between hospital costs reduction and the well-being of patients, also considering realistic operational restrictions like maximum working times for the nurses and possible incompatibilities between services jointly provided to the same patient. We first propose a MILP formulation for the problem, strengthened by some cuts. Then, we propose a simple branch-and-cut algorithm to derive ground benchmarks. Finally, to efficiently solve the problem, we develop an ALNS hybridized with a Kernel Search [3]. The algorithm performance is tested over a large set of different realistic working scenarios. Such numerical experiments show that our matheuristic manages to find good solutions in a reasonable amount of time (even for the most difficult instances) and allow us to derive some interesting managerial insights for the healthcare provider.

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**Applications: Health Care; Contributed Session**

## OML, Optimization for machine learning; Invited Session

FR 10:00 AM1 003

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*GPU-based Implementations of MM Algorithms. Application to Spectroscopy Signal Restoration*

Restoration of analytical chemistry data from degraded physical acquisitions is an important task for chemists to obtain accurate component analysis and sound interpretation. The high-dimensional nature of these signals and the large amount of data to be processed call for fast and efficient reconstruction methods. Existing works have primarily relied on optimization algorithms to solve a penalized formulation. Although very powerful, such methods can be computationally heavy, and hyperparameter tuning can be a tedious task for non-experts. Another family of approaches explored recently consists in adopting deep learning to perform the signal recovery task in a supervised fashion. Although fast, thanks to their formulations amenable to GPU implementations, these methods usually need large annotated databases and are not explainable. In this work, we propose to combine the best of both worlds, by proposing unfolded Majorization-Minimization (MM) algorithms with the aim to reach fast and accurate methods for sparse spectroscopy signal restoration. Two state-of-the-art iterative MM algorithms are unfolded onto deep network architectures. This allows both the deployment of GPU-friendly tools for accelerated implementation, as well as the introduction of a supervised learning strategy for tuning automatically the regularization parameter. The effectiveness of our approach is demonstrated on the restoration of a large dataset of realistic mass spectrometry data.

OML, Optimization for machine learning; Invited Session

**FR 10:20 AM1 003**

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*Iterative regularization in classification via hinge loss diagonal methods*

Iterative (implicit) regularization is a classic idea in regularization theory, that has recently become popular in machine learning. On the one hand, it allows to design efficient algorithms controlling at the same time numerical and statistical accuracy. On the other hand it allows to shed light on the learning curves observed while training neural networks. In this talk, we focus on iterative regularization in the context of classification. After contrasting this setting with that of inverse problems, we develop an iterative regularization approach based on using the hinge loss function. More precisely we present an inertial diagonal approach for which we show convergence as also rates of convergence. Our approach compares favorably with other alternatives, as confirmed also in numerical simulations.

**FR 09:00 AM1 003**

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Dirk, Lorenz

*Faster Randomized Block Sparse Kaczmarz by Averaging*

The standard randomized sparse Kaczmarz (RSK) method is an algorithm to compute sparse solutions of linear systems of equations and uses sequential updates, and thus, does not take advantage of parallel computations. In this work, we introduce a parallel (mini batch) version of RSK based on averaging several Kaczmarz steps. Naturally, this method allows for parallelization and we show that it can also leverage large over-relaxation. We prove linear expected convergence and show that, given that parallel computations can be exploited, the method provably provides faster convergence than the standard method. This method can also be viewed as a variant of the linearized Bregman algorithm, a randomized dual block coordinate descent update, a stochastic mirror descent update, or a relaxed version of RSK and we recover the standard RSK method when the batch size is equal to one. We also provide estimates for inconsistent systems and show that the iterates converge to an error in the order of the noise level. Finally, numerical examples illustrate the benefits of the new algorithm.



**FR 09:20 AM1 003**

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*Asynchronous parallel block-coordinate forward-backward algorithm*

We are going to present our work on the convergence properties of a randomized block-coordinate descent algorithm for the minimization of a composite convex objective function, where the block-coordinates are updated in parallel, asynchronously and randomly according to an arbitrary probability distribution. In that work, we prove that the iterates generated by the algorithm form a stochastic quasi-Fejér sequence and thus converge almost surely to a minimizer of the objective function. Moreover, we prove a general sublinear rate of convergence in expectation for the function values and a linear rate of convergence in expectation under an error bound condition of Tseng type. Under the same condition strong convergence of the iterates is provided as well as their linear convergence rate.

**FR 09:40 AM1 003**

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Center for Brains, Minds and Machines, Massachusetts Institute of  
Technology; Silvia, Villa, MaLGa, DIMA, Università degli Studi di  
Genova

*Iterative regularization for convex regularizers with activation onto  
a priori information*

Inverse problems are often reduced to solve a system of equations in a stable way with respect to noise in the data. A typical approach to enforce stability and select a meaningful solution is to introduce a regularizer, which is minimized under the constraint given by the system of equations. The regularization function is supposed to be convex, but not necessarily smooth neither strongly convex. In this paper, we propose and study two new iterative regularization methods, based on primal-dual algorithm, to solve the problem above. Our analysis, in the noise free case, provides convergence rates for the Lagrangian and the feasibility gap. In the noisy case, it provides stability bounds and practical early-stopping rules with theoretical guarantees. The main novelty is the exploitation of some a priori knowledge about the solution set, i.e. redundant information. We discuss various approaches to take advantage of the redundant information, that are at the same time consistent with our assumptions and flexible in the implementation. Finally, we illustrate our theoretical findings with numerical simulations for robust sparse recovery and image reconstruction through total variation. We confirm the efficiency of the proposed procedures, comparing the results with state-of-the-art methods.

Optimization for machine learning

## Transportation; Contributed Session

FR 10:00 AM1 Auditorium A

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Tadi, University of Rijeka, Faculty of Maritime Studies; Borina, De-  
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### *Decision support system in urban traffic management*

Traffic congestion is an unavoidable problem in large cities. Therefore, traffic management centers must respond quickly to traffic disruptions and apply the most appropriate measures to solve problems in the traffic network. The causes leading to traffic congestion are usually related to regular or extraordinary traffic events and traffic condition. Due to a regular traffic event such as a traffic collision on the main traffic corridor, illegal parking and emergency interventions, actions such as detection, closure and speed limits are mostly used. During an extraordinary traffic event such as manifestations or roadwork, applied actions include the partial or complete closure of the road, change of route, change of travel methods, etc. Solving this complex task requires not only a quick response, but also a lot of expertise given the large number of possible actions that need to be considered during the decision-making process. Therefore, simulation models or decision support tools are increasingly used. In this project, the simulations are intended to demonstrate the possibilities of using simulation tools in the decision-making and traffic management process as innovative methods within intelligent solutions for traffic management in cities. The purpose of prototyping is to test innovative scenarios and standard operating procedures that will be used to support decision making. The prototype created in this way can be further developed through validation and calibration procedures to obtain a real traffic situation in an area, based on which different solutions affecting traffic flow can then be tested. As part of the development activities of the CEKOM Connected Traffic scientific research project, an advanced information and communication system is being developed to support decision-making and urban traffic management. The improvement of traffic management within this project will also have a positive impact on the development of mobility and the increase of traffic safety in the city of Rijeka. The innovation of this platform is reflected in its approach to connectivity and Big Data analytics, as well as its real-time traffic management. In this paper, the authors focus on testing innovative scenarios and standard operating procedures for the purpose of decision support to demonstrate the effectiveness of traffic management in urban areas by applying innovative solutions (modeling and simulation). The development of the simulation model in terms of functionality and sus-

Transportation; Contributed Session

tainability covers the narrower and wider urban area of Rijeka and the application of a multi-layer modeling methodology that integrates macro and micro level traffic simulations. Reliable and accurate measurement of vehicle load on individual roads was used to create the simulation. Since the simulation will be validated with some new traffic routes, new realistically calculated traffic load data is expected as one of the outputs of the project. By applying intelligent traffic solutions and information and communication technology, it is possible to integrate large amounts of processed data through the platform, thus achieving the validation of the prototype and the generation of traffic conditions, which increases the quality of traffic management.

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

**FR 10:20 AM1 Auditorium A****Martina Fischetti** [Martina.FISCHETTI@ec.europa.eu](mailto:Martina.FISCHETTI@ec.europa.eu)

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*How the European Union uses Operations Research for transport analyses*

One of the main European Union (EU) policy priorities under the European Green Deal is to achieve climate neutrality by 2050. Transport is a key player in that task, as it is a major consumer of energy, and extensive contributor to greenhouse gas emissions. In this context, the EU mandate includes the monitoring of the performances of both public transport and road transport across the EU member states. This is key to be able to inform the relevant policy decisions on the topic. One of elements of analysis that the EU employs is the use of comprehensive data to compute performance and accessibility-to-opportunities metrics associated with different types of transport. Underneath these measures lies a number of operations research (OR) challenges. The road transport analysis, for example, is a routing problem defined on (very) large networks. Moreover, if traffic information is considered, the problem turns into a time-dependent routing problem. In this presentation we will give an overview of some of the OR transport-related challenges faced by the EU and some of possible solution methods proposed by the Joint Research Center (JRC) of the European Commission. The work presented is developed in collaboration with the Department of Mathematics of the University of Pavia.

**FR 09:00 AM1 Auditorium A****Maurizio Bruglieri** maurizio.bruglieri@polimi.itPolitecnico di Milano  
Peruzzini, Roberto, Università Politecnica delle Marche; Pisacane,  
Ornella, Università Politecnica delle Marche*Optimizing a real-time carpooling service*

According to a recent survey, in Europe, the average occupancy rate of most frequent car trips is 1.7 persons/car (including the driver). Moreover, this value has decreased over the last decades. This decreasing trend implies an increase in the number of private cars on the road and then, in the traffic congestion. In addition, more cars on the road also means an increase in the harmful emissions. A possible solution to this problem, more flexible than public transport, is given by carpooling. Carpooling (also known as ridesharing) refers to a mode of transportation in which travelers share a vehicle for a trip with others that have similar itineraries and time schedules, and split travel costs (e.g., those due the fuel consumption). Carpooling is a service that can combine the flexibility and speed of private cars or taxi services with the reduced cost of fixed-line systems. Besides saving travel costs, carpooling also allows reducing the number of circulating cars and thus in mitigating traffic congestion and reducing air pollution. By effectively using new communication technologies, such as smartphone and global positioning system (GPS), there are some attempts to enable real-time ridesharing systems, i.e., a system which supports an automatic ride-matching process among participants on very short notice or even en-route. In this work, we want to investigate the benefit of using autonomous vehicles in a real-time ridesharing service. Indeed, if on one hand, such a service has the clear advantage of not requiring any participant that acts as a driver, on the other hand, it requires that the routes of each vehicle are planned by a central system to optimize simultaneously different objectives such as the total number of passengers served and the total traveled distance. Then, this central system acts as a dispatcher of the requests and provides the users with their assignment to a vehicle that may already have passengers on board. In the assignment process, such a dispatcher has to take into account the level of service and then, to avoid situations in which passengers already on board make a long detour in order to allow the vehicle also serving other users. The resulting decision problem is a challenging Vehicle Routing Problem. To solve it, we propose a mathematical programming based approach in which, in each iteration, a lexicographic Mixed Integer Linear Programming model is solved in order to find partial solutions. Finally, in order to address real-life instances in reasonable computational time, we also develop a metaheuristic in which we combine moves taken from the literature with those ad hoc designed for the problem. Preliminary numerical results on instances derived from a carpooling service in Mel-

bourne show the effectiveness of the proposed metaheuristic compared to the mathematical programming based approach.

**FR 09:20 AM1 Auditorium A****Giusy Macrina** giusy.macrina@unical.itUniversity of Calabria  
Archetti, Claudia, ESSEC Business School in Paris; Guerriero, Francesca,  
University of Calabria*Bundles generation and pricing in crowdshipping*

In this work we investigate the crowdshipping paradigm, an innovative framework of delivering which is gaining more and more success in the last mile delivery context. The main idea of crowdshipping is to exploit the capacity of ordinary people, namely occasional drivers (ODs), who offer their own vehicles and free time for performing shipments, allowing the delivery companies to provide a more flexible, faster and cheaper delivery service. Deciding which customer requests should be served by the internal own fleet of vehicles and which, instead, should be assigned to the ODs, is a challenging issue, as well as determining the compensation that should be offered to the ODs to minimize the expected total distribution cost. Hence, we develop a bundle-based strategy to decide how many, and which parcels should be assigned to the ODs. We then focus on matching and pricing problems, with the purpose of maximizing the numbers of assigned parcels and minimizing the costs. We propose a pricing scheme to determine the compensation for the ODs. We also assume that each OD has a willingness to serve function, that is a compensation for which the OD will accept to deliver a bundle. Hence, we simulate two auction strategies: a static and a dynamic one. We carry out an exhaustive computational study to compare the pricing strategies and the two auctions, outlining several managerial insights.



**FR 09:40 AM1 Auditorium A****Amparo Mármol** amarmol@us.es

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Universidad Pablo de Olavide de Sevilla

*A pick-up rule for sharing transportation costs in itinerant events*

Fixed route problems model situations in which a company must visit several customers located in different places, traveling along a fixed route that starts and ends at the same point. When the objective of the fixed route is the transportation of material and the installation of equipment for the celebration of itinerant events, there are certain differentiated characteristics that must be taken into account when allocating the corresponding transportation costs. In this paper, we firstly propose some cost-sharing rules for the fixed route problems that represent these situations. Subsequently, we introduce a TU game representing the costs that the different coalitions should bear in these situations, the pick-up game. We prove that pick-up games are convex, thus the existence of stable allocations is assured. Moreover, one the cost-sharing rules previously proposed is highlighted in this context the pick-up rule, since we prove that it coincides with the Shapley value, the nucleolus and the tau-value of the pick-up game.

## Continuous and Multiobjective optimization; Contributed Session

FR 10:00 AM1 Auditorium B

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*Comparing digital and quantum annealing heuristics: the cardinality constrained quadratic knapsack case*

In recent years, several optimization solvers inspired by quantum annealing have been developed, either running on actual quantum hardware or simulating it on classical digital computers. They all provide heuristic solutions for so-called Ising models, which are equivalent to quadratic unconstrained binary optimization problems (QUBO). In this work we benchmark the performance of different solvers for the resolution of the cardinality constrained quadratic knapsack problem (kQKP), which extends QUBO models in a minimal way, including only one inequality and one equality constraint. The solvers we benchmark are of three types: quantum annealing on quantum hardware, quantum-inspired heuristics designed for dedicated digital hardware, probabilistic algorithms for general purpose digital hardware. We test both the use of these solvers to directly provide a primal feasible solution and their use as sub-routine within a heuristic on digital computers. We compare these heuristic solutions with those retrieved by an ad-hoc heuristic and with the dual bound provided by a Dantzig-Wolfe decomposition from literature. We perform extensive computational analyses covering the following aspects: (i) how to obtain effective formulations, mapping the kQKP to a pure QUBO, (ii) which algorithmic steps on digital hardware are useful to enhance the solutions of the solvers, and (iii) how to tune the solvers by parametric analysis. In particular, the reformulation of the problem as a QUBO faces two main choices: how to reformulate the linear constraints and how to encode slack integer variables as a set of binary ones. We explore both the option of reformulating constraints as equalities and penalizing their squared violation in the QUBO, and traditional Lagrangian relaxation with multipliers update. We also explore different encodings of the integer variables. Our results may help to understand strengths and weaknesses of quantum annealers in facing constrained quadratic combinatorial problems.

Continuous and Multiobjective optimization; Contributed Session

**FR 10:20 AM1 Auditorium B****Annarita De Maio** annarita.demaio@unical.itDepartment of Economics, Statistics and Finance Giovanni Anania,  
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Department of Economics, Statistics and Finance Giovanni Anania,  
University of Calabria (Italy)*Optimization techniques for the risk mitigation in the hazardous material truck transportation*

The transportation of hazardous material (hazmat) involves the movement of freight representing a high risk to health, safety, or environment. For this reason, this topic has gained great popularity in the last decades within the scientific community, to preserve the safety of people involved in the transportation activities, as well as to pay more attention on environmental issues. Indeed, the incidents involving hazmat vehicles may cause extensive damages to the affected communities, because of the release of dangerous substances. Due to its nature, hazmat transportation is regulated by strict laws and must be treated separately from classical transportation. From optimization perspective, the risk assessment of the service plays a central role. The problem under consideration refers to road transportation of hazmat and can be treated as a variant of the well-known Hazmat Vehicle Routing and Scheduling Problem with Time Windows (HVRPTW). It consists in defining the routes performed by a logistics operator with a given fleet of vehicles for the hazmat transportation by considering time windows constraints for the customers and the depot. The risk measurement is modelled as an arc attribute by balancing different criteria: accident probability, population density, distance from fire stations, type of road surface, traffic conditions, etc. Therefore, the time horizon of the service is divided in different time slots and a time-expanded network is built. The risk attribute can vary within the different slots. The variant of the HVRPTW is modelled as a three-objective optimization problem to be minimized. The three objective functions refer to the total risk, the total service time, and total vehicle cost. To determine a Pareto optimal solution of the problem, the  $\varepsilon$ -constraint method is applied. In the experimental phase, we consider a road network in Northern Italy, where a logistics operator has to carry cylinders of compressed oxygen in order to serve a group of customers with known demand level. Managerial insights deriving from the experimental phase are presented.

**FR 09:00 AM1 Auditorium B**

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*Econometrics analysis of multidimensional urban poverty determinants*

Urban poverty differs from rural poverty in terms of demographic, economic and infrastructural aspects in conditions of accelerated urbanization. Poverty can be, also, viewed as an absolute and relative category, respecting its subjective and objective dimensions. This is an issue that is closely related to the issue of sustainable development, sustainable economic growth and sustainable employment. As a part of the 2030 Agenda for Sustainable Development adopted in 2015 which includes 17 Sustainable Development Goals (SDGs), the United Nations General Assembly promoted the number one SGD: No Poverty, closely related to the second SGD: Zero hunger. One of the targeted indicators until 2030 is to mitigate poverty in every country by increasing a persons daily living budget above 1,25 USD. Additionally, cutting down by half the number of deprived persons in all segments of poverty defined by the national regulation by 2030 is the second most important aim of the SGD1. Having this in mind, the aim of the paper is to consider the determinants of urban poverty in the Republic of Serbia (later referred to as Serbia) in order to identify the factors of poverty reduction. Serbia is on its way to the transformation from a state-controlled to a market-oriented economy in order to enter European Union (EU). The process of profound social and economic changes is evolving and the transition caused significant effects on social welfare. Although the number of people at risk of poverty or social exclusion in Serbia is declining since 2014 from 42.6 to 29.8 per cent in 2020, it is still above the EU27 average by 7.8 percentage points to Eurostat. Moreover, the most threatened categories of poverty and social exclusion are females (30.6%) compared to men (29%), and people between 55 and 64 years old (33.6%). Therefore, the profile and dynamic aspect of urban poverty will be explored. Specifically, the determinants of urban poverty in Serbia will be examined. The research methodology will include panel data regression analysis. The input of the analysis will be data obtained by the Statistical Office of the Republic Serbia and collected for the purpose of the Survey on Income and Living Conditions SILC for the period from 2015 to 2020. The data will cover four domains at the household level: (1) basic data, (2) housing, (3) material deprivation and (4) income, and five domains at the personal level: (1) basic/demographic data, (2) education,

(3) health, (4) labour and (5) income. The paper contributes to defining the concept of urban poverty and measuring it, as well as understanding the differences in relation to rural poverty. The ultimate goal of the analysis is to provide recommendations to policymakers in order to create successful strategies for reducing urban poverty and poverty risk.

**FR 09:20 AM1 Auditorium B****Bo Peng** bo.peng@univie.ac.atUniversity of Vienna  
Bomze, Immanuel, University of Vienna*Conic formulation of QPCCs applied to truly sparse QPs*

We study (nonconvex) quadratic optimization problems with complementarity constraints, showing an exact completely positive reformulation of it under — apparently new — mild conditions involving only the constraints, not the objective. Moreover, we also give the conditions for strong conic duality between the obtained completely positive problem and its dual. Another novelty of our approach is a purely continuous model which avoids any branching or use of large constants in implementation. An application on pursuing interpretable sparse solutions of quadratic optimization problems is shown to satisfy our settings, and therefore we link quadratic problems with an exact sparsity term  $\|x\|_0$  to copositive optimization. The covered problem class includes sparse least-squares regression under linear constraints, for instance. Numerical comparisons between our method and other approximations are reported from the perspective of function value.

**FR 09:40 AM1 Auditorium B****Emanuele Pizzari** emanuele.pizzari@uniroma2.itUniversità degli Studi di Roma Tor Vergata  
Caramia, Massimiliano, Università degli Studi di Roma Tor Vergata*Bilevel Formulations for Municipal Waste Management*

We propose two bilevel models to cope with problems concerning municipal waste management. The model is a facility location and transportation problem. The upper-level decision maker is a municipality, interested in defining a proper network for managing waste. The municipality needs to locate sorting facilities, and landfills and incinerators. On the other hand, the lower-level decision maker is a company in charge of transporting waste from collection points to sorting centres, and, finally, from sorting centres to either landfills or incinerators. The municipality wants to reduce the overall emissions, as well as the impact of facilities on peoples health and land, while the company wants to reduce the transportation costs.

The first proposed formulation stems from a multi-objective version of the problem present in the literature. We developed a theorem that proves that the aforementioned model works under the hypothesis of homogeneous transportation cost per arc. Taking into account this theoretical finding, we define a second formulation that allows more network design flexibility. For both models we provide the optimistic and the pessimistic versions. We validate these formulations on a case study in the Pathum Thani province in Thailand. Moreover, we compare the results obtained by the bilevel formulation to those obtained by a multi-objective version of the problem.

Finally, we provide our thoughts on future applications in this field.

## Supply Chains and Inventory; Contributed Session

FR 11:30 AM2 001

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BASF SE

*Mathematical programming models for managing the profitability-sustainability trade-off in complex chemical value chains*

Limiting the effects of global warming and climate change is one of the main objectives that the international community has set for the next decades. Therefore, several countries approved laws legally binding them to achieve net-zero targets within the next 25-30 years. One of the major greenhouse gases emitted by human activity is carbon dioxide (CO<sub>2</sub>) which accounts for more than 75% of the global greenhouse gas emissions. Industry and transport sectors account for more than 35% of the global emissions and there is increasing pressure on industry to pledge net-zero emissions. To remain competitive in their markets while reducing their emissions, companies need to re-optimize their entire supply chain focusing not only on financial key performance indicators (KPIs), such as costs, but also on non-financial KPIs, in particular greenhouse gas emissions. In this work we propose two linear programming models to optimize a deterministic multi-objective supply chain problem aimed at minimizing CO<sub>2</sub> emissions and their related costs. We perform an extensive campaign of tests motivated by a real-world industry setting to compare the efficiency of the two model formulations and to analyze the differences with the former supply chain structure when emissions were not a primary concern.



**FR 11:50 AM2 001**

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*Generalized Model of a Production System with Fixed Supplies and Deliveries*

Let us consider a generic production system; at a look from the outside, we see that it gets raw materials from its suppliers and delivers finished products to its customers; raw materials may be either stocked in a buffer, to be worked later, or immediately taken as semifinished products and addressed to the workshop; inside the workshop semifinished products are subjected to one or more successive operations, with the scope of creating final products requested by the customers at given delivery times; every operation may require specific technical resources (rooms, work benches, machines, work islands, etc.) and human resources (operators with different skills and tasks). The problem daily faced by managers consists in scheduling all operations in order to minimize total cost by satisfying all customers and respecting constraints imposed by resources and raw materials availability. Such a problem becomes more and more complex if final products are many, some final products can be obtained by different alternative working procedures, and/or from different raw materials, by means of different operations and related resources engagement, some resources can be engaged to work different semifinished products; moreover sometimes we cannot precisely forecast supplies, and sometimes customers requests may vary after the requested products working procedures have already started (such accidents happen in particular in the food field and when the system works on commission). Here we suggest an abstract metamodel which can describe such complex systems and permits to obtain an operation schedule which optimizes their management also in dynamic conditions. We may consider the environment and the following sets: semifinished products set, process set, resources set. Semifinished products are all objects entering the system, being subjected to operations and possible pauses inside it and finally delivered; every semifinished product is uniquely defined according to its physical characteristics (materials, shape, size, weight, etc.) and may be present in the system in lots of any size in different times: every lot is characterized by number of units and arise time, related either to entering from the environment or to production by an operation. Every process is uniquely defined by the performed operation, the input and output semifinished products, the engaged resources, and the related respective times: the possible adjustment time before the operation start, the production time, the amounts of input and output products per production unit time, the amounts of engaged resources during the adjustment and/or during the production; two pro-

**Supply Chains and Inventory; Contributed Session**

cesses are different if any of the above definition characters is different; the same process may be iteratively activated in different times. The environment supplies semifinished products, either directly through suppliers in the form of raw materials or indirectly through buffers, and requests semifinished products, to be delivered either to customers in the form of finished products or to be stored in buffers. System structural parameters are stored in matrices reporting processes characters; problem data include products forecasted supplies, products requested deliveries and resource availability in time; decision variables include all processes activations start and end time, related to input and output products amount and to resources amounts. The management problem solution shall respect all constraints due to available semifinished products and available resources in time and obtain the minimum total cost. An optimal solution can be obtained by specialized packages for small problem size, while a heuristic method giving an acceptable suboptimal solution, adopting algorithms coming from the project management field is suggested for large problem size. An application in the food production and distribution field is reported.

**FR 12:10 AM2 001**

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*A model and a solution approach for optimal green investment in a two stage supply chain*

In order to contrast climate change, governments established strong chronological paths to reach emission reduction in the next years. The European Commission recently deployed the so called European Green Deal, i.e., a set of policy initiatives aimed at overarching the carbon neutrality in 2050 and achieving a reduction of 55% of net Green House Gas (GHG) within 2030. While clean technologies can help to decrease environmental impact, investment programs must be carefully planned to reach the green targets and maintain or improve industrial efficiency. This is extremely important in supply chains where industrial technologies have a complex impact on efficiency, service level, and emissions of entire production and distribution chains. Moreover, investments in green technologies to increase sustainability in supply chains has become a common practice also because the awareness of consumers on green products is continuously increasing and, therefore, people are more and more willing to buy green products in place of non-green ones. Therefore, even if there are higher costs in producing with green technologies and processes, there is also a higher mark up on the price of products which rewards the former costs. In this work, we propose a multi-period mathematical model for deciding the optimal chronological allocation of a given investment budget on production technologies and on environment protection to meet an aggregate demand in a two layered supply chain. The model has two objectives and non-linear constraints. The main decisional variables are the flow of products from suppliers to facilities, and the environment protection investment for each facility and for each planning period. The objective function measures the total cost of CO<sub>2</sub> emission produced by the plants over time plus the cost associated with the investment over time. Other than flow and capacity constraints, a non-linear constraint defines the relation between the investment made until a certain time, for each facility, and the emission for unit of flow at that time, for the same facility. Being the model very difficult to solve by means of a commercial solver, we propose lower bounds and an approximate solution approach. The proposed model and algorithms have been tested on synthetic instances properly generated to evaluate their ability in finding effective schedules of the investments in a given planning horizon.

**Supply Chains and Inventory; Contributed Session**

**FR 12:30 AM2 001****EP Mezatio** eric\_papain.mezatio@utt

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Troyes, France; I., Ferreira, Institut français du textile et de lha-  
billement(IFTH), Troyes, France

*Design forward and reverse closed-loop supply chain to improve eco-  
nomic and environmental performances*

This paper focuses on modelling and solving the problems related to fourlevel supply chain (SC) management with reverse logistics, from the supplier to the retailers and the recycling center. A new mathematical integer programming model has been developed. This model can be used as a decision support tool for all types of industries that want to improve their economic and environmental performances. In this study, we adressed specially the case of the textile industry. The results show that by recycling and reusing recycled resources, the textile industry can reduce its CO2 emissions up to 42.5%, for an additional investment of 34.19%, with a carbon price of 86 per ton of emissions. While, without recycling and for the same carbon price, industries would invest 68.73% more, for an emissions reduction of 12.74%.

## Best AIROYoung Dissertation 2022

FR 11:30 AM2 002

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Sapienza - University of Rome

### *Real-time Train Scheduling: Reactive and Proactive Algorithms for Safe and Reliable Railway Networks*

Train scheduling is a critical activity in rail traffic management, both off-line (timetabling) and on-line/in real-time (dispatching). The research aims at the design and development of advanced optimization models and methods for the real-time re-scheduling. The study covers two overlapping areas and defines two different but somewhat complementary research questions:

- (i) in case of disturbance, how can we quickly generate a new feasible plan?
- (ii) in case of disruption (or partial re-scheduling information), how can we add an additional level of safety to the system?

To answer the first question, we exploited and extended the Dynamic Discretization Discovery (DDD) paradigm, recently introduced by Boland for the continuous time service network design problem. The result is a restricted Time-Indexed formulation for train

traffic re-scheduling problem and an algorithm to solve it with running times comparable with the best alternatives presented in the literature. Furthermore, the implemented procedure does not suffer by any approximation error introduced by a standard time discretization and can be applied to the broader field of job-shop scheduling. This work has been presented at a renowned railway conference (ICROMA).

The second research issue is answered by formulating a Safe Place Assignment Problem. This new model is tested on a set of instances provided by a large Class I U.S. railroad company, demonstrating how it can be used effectively in a real-world context. The relative work has been published on a top tier Operation Research journal whose main focus lays on transport (Transportation Science).

Both research outputs are very innovative and off the beaten track. The achievements regards both the theoretical and methodological point of view and present in addition a practical relevance.

Keywords: Real-time Train Rescheduling; Dynamic Discretization Discovery; Disruption Management.

**FR 11:50 AM2 002**

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University of Bergamo

*Models and Approximations for Optimization Problems under Uncertainty with Applications to Support Vector Machine and Revenue Management*

In this thesis, we deal with decision making problems plagued by the presence of uncertainty. The first problem we analyze aims at linearly separating two sets of points that have non-disjoint convex closures. To solve this classification task, we formulate robust Support Vector Machine (SVM) models with uncertainty sets in the form of hyperrectangles or hyperellipsoids, and propose a moment-based Distributionally Robust Optimization (DRO) model enforcing limits on first-order deviations along principal directions. The efficiency of the new classifiers is evaluated on real-world databases. Numerical experiments show that considering uncertainty explicitly in the models leads to better solutions with respect to the ones provided by the corresponding deterministic program. Despite the wide applicability of DRO models, this class of problems is notoriously difficult to solve. For this reason, secondly, we propose approximation techniques that provide (lower and upper) bounds on the optimal value for DRO problems. This is done through scenario grouping and using the ambiguity sets associated with  $\phi$ -divergences and the Wasserstein distance. Numerical results on a multistage mixed-integer production problem show the efficacy of the novel bounding schemes through different choices of partition strategies, ambiguity sets, and levels of robustness. Thirdly, the last problem we investigate aims at detecting the optimal assortments a retailer shall offer to the market with the aim of maximizing expected profits, when strong preferences among products are observed. This Revenue Management (RM) problem with dominated alternatives is firstly modeled through stochastic dynamic programming, which becomes intractable for instances with a large number of resources. To deal with this curse of dimensionality we recover a compact and tractable deterministic approximation and present preliminary numeric results.

Keywords: Support Vector Machine; Robust Optimization; Distributionally Robust Optimization; Revenue Management.

**FR 12:10 AM2 002**

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*Optimizing and Reoptimizing: Tackling Static and Dynamic Combinatorial Problems*

In this thesis both static and dynamic problems of Operations Research are addressed by either designing new procedures or adapting well-known algorithmic schemes. Specifically, three variants of the well-known Shortest Path Problem (SPP) and a Scheduling Problem in 3D printing are studied.

Firstly, we dealt with the Reoptimization of Shortest Paths, in case of multiple and generic cost changes. We implemented an exact primal-dual procedure, and compared its performance with Dijkstras label setting procedure to detect the approach to prefer, according to the graph features and the type of cost perturbation.

Secondly, the k-Color Shortest Path Problem is tackled: it is a recent problem, defined on an edge-constrained graph, for which we proposed a Dynamic Programming algorithm; its performance is compared with the state of the art solution approach, namely a Branch & Bound procedure.

Finally, the Resource Constrained Clustered Shortest Path Tree Problem is presented. It is a newly defined problem for which we detail both a mathematical model and a Branch & Price procedure; moreover, the performance of this solution approach is compared with that of CPLEX solver.

Furthermore, the first part of the dissertation addresses the Path Planning in Urban Air Mobility, considering the definition of the Free-Space Maps and the computation of the trajectories. For the former purpose, three different but correlated discretization methods are described; as for the latter, a two steps resolution of the resulting shortest path problems is performed, and it is checked if the reoptimization algorithm is suitable for the second step.

The last part of the thesis is devoted to the recently studied Additive Manufacturing Machine Scheduling Problem with not-identical machines. Specifically, a Reinforcement Learning Iterated Local Search meta-heuristic featuring a Q-learning Variable Neighbourhood Search is proposed to solve this problem and its performance is compared with the one of CPLEX solver.

It is worthwhile mentioning that, for each of the proposed approaches, a thorough experimentation is performed and each Chapter is equipped with a detailed analysis of the results in order to appraise the performance of the method and to detect its limits.

Keywords: Constrained Shortest Path Problem; Combinatorial Opti-

**Best AIROYoung Dissertation 2022**

mization; Additive Manufacturing Machine Scheduling.



**FR 12:30 AM2 002**

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*Theory and Algorithms for Sparsity Constrained Optimization Problems*

The dissertation is concerned with mathematical optimization problems where a sparsity constraint appears. The sparsity of the solution is a valuable requirement in many applications of operations research. Several classes of very different approaches have been proposed in the literature for this sort of problems; when the objective function is nonconvex, in presence of difficult additional constraints or in the high-dimensional case, the problem shall be addressed as a continuous optimization task, even though it naturally has an intrinsic combinatorial nature.

Within this setting, we first review the existing knowledge and the theoretical tools concerning the considered problem; we try to provide a unified view of parallel streams of research and we propose a new general stationarity condition, based on the concept of neighborhood, which somehow allows to take into account both the continuous and the combinatorial aspects of the problem.

Then, after a brief overview of the main algorithmic approaches in the related literature, we propose suitable variants of some of these schemes that can be effectively employed in complex settings, such as the nonconvex one, the derivative-free one or the multi-objective one. For each of the proposed algorithms we provide a detailed convergence analysis showing that these methods enjoy important theoretical guarantees, in line with the state-of-the-art algorithms.

Afterwards, exploiting the newly introduced concept of stationarity, we propose a completely novel algorithmic scheme that, combining continuous local searches and discrete moves, can be proved to guarantee stronger theoretical properties than most approaches from the literature and to exhibit strong exploration capabilities in a global optimization perspective.

All the proposed algorithms have finally been experimentally tested on a benchmark of relevant problems from machine learning and decision science applications. The computational results show the actual quality of the proposed methods when practically employed.

Keywords: Nonlinear Optimization; Sparsity; Convergent Algorithms.

## MLO4EMD, Machine learning-based optimization for extreme metamaterials design; Invited Session

FR 11:30 AM2 003

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Leamy Michael, Georgia Institute of Technology

*Designing a broadband GRIN lens through a deep learning based data-driven method*

Controlling flexural waves in thin plates is a challenging task with implications for a variety of applications in acoustic problems. One of the most fascinating problems in such medium is optimizing the amount of focused wave intensity in the focal area for gradient-index (GRIN) acoustic lenses [1], for energy harvesting purposes. Recently, machine learning techniques have been utilized extensively to solve variety of problems in physical sciences and engineering. As such, we use numerically produced data to predict the shape of a discrete lens, formed from a lattice of circular scatterers in a thin aluminum plate, for given focal shapes. For each of these lenses, the inclusion diameters and their locations are varied randomly to obtain different lens shapes. In support of such concepts, twenty one thousands different lens shapes are considered, and the corresponding wave fields are computed numerically using multiple scattering formulation. Next, nineteen thousand of these recorded wavefields (each of them 200 \*200 pixels) are input into a ResNet [2] with twenty layers to train the convolutional neural network to predict the shape of the lens. In addition, the last two thousands samples are used as the test set to evaluate the performance of the network. In order to train the network, ADAM optimizer algorithm with the learning rate of 0.001 is chosen, along with the categorical crossentropy as the loss function, and batch size of thirty two. After running the algorithm for three hundred iterations (each with fifty epochs) the designed network successfully is trained with the loss of 1E-4 and the accuracy of 0.987 percent. Next, the performance of the trained network is tested with the two thousand validation test, to obtain the accuracy of 0.97 with the loss being equal to 2E-3. Finally, three different wave field responses are input to the trained network to predict the shape of the desired lens. The proposed idea herein can be extended to other media such as phononic devices, air, Bulk waves, electromagnetic waves, optical Bulk waves and photonics by changing the phase velocity of the medium.

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**MLO4EMD, Machine learning-based optimization for extreme metamaterials design; Invited Session**

**FR 11:50 AM2 003****Danilo Macciò** `danilo.maccio@cnr.it`

Institute of Marine Engineering, National Research Council of Italy  
Francesco, Rebora, Institute of Marine Engineering, National Research Council of Italy; Cristiano, Cervellera, Institute of Marine Engineering, National Research Council of Italy

*Voronoi recursive binary trees for the optimization of nonlinear functionals*

We propose an algorithm for the approximate solution of general nonlinear functional optimization problems through recursive binary Voronoi tree models. Unlike typical binary tree structures commonly employed for classification and regression problems, where splits are performed parallel to the coordinate axes, here the splits are based on Voronoi cells defined by a pair of centroids. Models of this kind are particularly suited to functional optimization, where the optimal solution function can easily be discontinuous even for very smooth cost functionals. In fact, the flexible nature of Voronoi recursive trees allows the model to adapt very well to possible discontinuities. In order to improve efficiency, accuracy and robustness, the proposed algorithm exploits randomization and the ensemble paradigm. To this purpose, an ad hoc aggregation scheme is proposed. Simulation tests involving various test problems, including the optimal control of a crane-like system, are presented, showing how the proposed algorithm can cope well with discontinuous optimal solutions and outperform trees based on the standard split scheme.

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Andrea, Bacigalupo, Università di Genova; Maria Laura, De Bellis,  
Università di Chieti-Pescara; Federico, Nutarelli, IMT School for  
Advanced Studies, Lucca*On dispersion curve coloring*

A novel automatic technique for smooth curve coloring - i.e., curve identification - in the presence of curve intersections is presented. Formally, the proposed algorithm aims at minimizing the summation of the total variations over a given interval of the first derivatives of all the labeled curves, when these are written as functions of a scalar parameter. The algorithm develops the one proposed in [1]. Specifically, it is based on a first-order finite difference approximation of the curves and a prediction/correction steps sequence. At each step, the predicted points are attributed to the subsequently observed points of the curves by solving a Euclidean bipartite matching subproblem. A comparison with a more computationally expensive dynamic programming formulation is analyzed. The proposed algorithm is applied to mechanical filters made of metamaterials, also known as metafilters [2]. Its output is shown to be in excellent agreement with the desired smoothness and periodicity properties of the metafilter dispersion curves. Possible developments, including those based on machine-learning techniques, are pointed out.

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## Transportation; Contributed Session

FR 11:30 AM2 Auditorium A

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Corvello, Vincenzo, Università della Calabria - Dipartimento di Ingegneria Meccanica, Energetica e Gestionale; Musmanno, Roberto, Università della Calabria - Dipartimento di Ingegneria Meccanica, Energetica e Gestionale; Pavone, Giuseppe, Regione Calabria - Dipartimento Turismo, Marketing Territoriale e Mobilità; Santoro, Francesco, ITACA s.r.l.

### *Graph Partitioning in Public Transport*

The talk addresses the problem of designing optimal lots in Italian transport systems by referring to bus services. In defining lots in terms of number, size, and boundaries, the decision-maker should consider both the service cost (efficiency) and the capacity to meet transport demand, with a special focus on customer satisfaction (effectiveness). Under certain assumptions, this problem can be formulated as a graph partitioning model (GPM) in which the objective function is defined in accordance with a decree-law enacted by the Italian Minister of Transport. In order to individuate high-quality solutions for the GPM, a multi-start approach based on adaptive large neighbourhood search is proposed. In addition, the results of an extensive computational study based on real data from the Calabria Region are presented.

**FR 11:50 AM2 Auditorium A****Maksim Lali** lamaksim@biosense.rs

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Nikola, Obrenovi, Institute BioSense, University of Novi Sad; Sanja, Brdar, Institute BioSense, University of Novi Sad; Ivan, Lukovi, Faculty of Organizational Sciences, University of Belgrade; Michel, Bierlaire, Transport and Mobility Laboratory (TRANSP-OR), École Polytechnique Fédérale de Lausanne

*Assisting Passengers on Rerouted Train Service Using Vehicle Sharing System*

Unexpected blockages of railway sections force trains that usually pass through them to change their route, affecting passengers whose boarding and alighting stations are skipped. In such cases, shared vehicles, whose stations are positioned around railway stations, could be used as an emergency transport option and mitigate the consequences of train rerouting. This paper provides an integer linear program for simultaneous routing of affected passengers and used shared vehicles. Our model assumes that the new train route is fixed, and provides a solution that minimizes the number of dropped passengers and total passenger travel time while keeping additional vehicles engagement as low as possible. Computational experiments are performed on realistic case studies over a part of the Swiss railway network. Behavior characteristics of the analyzed transportation system under low or high passenger demand are recognized and presented.

**FR 12:10 AM2 Auditorium A**

**Gabriella Stecco** gabriella.stecco@act-operationsresearch.com

ACT Operations Research

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*Scheduling and Routing of AGVs: solving industrial applications using Constraint Programming*

In this talk we consider the scheduling and conflict-free routing problems of multiple Automated Guided Vehicles (AGVs). The objective is to minimize the makespan. These AGVs travel on predetermined guide paths with capacity constraints and bidirectional paths. In order to compute a solution in short computing time, we propose a decomposition approach: the first problem assigns the tasks to the AGVs and the second one routes the vehicles in order to prevent conflicts and dead-locks [1, 2]. The two problems are tackled using Constraint Programming (CP) models and they are solved using the CP-SAT solver of Google OR-Tools. Moreover, in order to speed up the computation of the second problem, a heuristic based on the Quickest Path Problem with Time Windows (QPPTW) algorithm [3] is used.

This work is developed under the ongoing H2020 1-SWARM project. Tests are performed on use cases provided by an industrial partner that provides hardware and software solutions to apply autonomous navigation to mobile agents.

[1] Riazi, S., Diding, T., Falkman, P., Bengtsson, K., Lennartson, B.: Scheduling and routing of AGVs for large-scale flexible manufacturing systems. In Proc. IEEE 15th International Conference on Automation Science and Engineering (CASE), pp. 891896, Vancouver, BC, Canada, (2019). [2] Riazi, S., Bengtsson, K., Lennartson, B.: Energy Optimization of Large-Scale AGV Systems. IEEE Transactions on Automation Science and Engineering, 18, 891-896, (2021). [3] Brownlee, A.E.I., Swan, J., Senington, R., Kocsis, Z.A.: Conflict-free routing of multi-stop warehouse trucks, Optimization Letters, 14, 1459-1470, (2020).



**FR 12:30 AM2 Auditorium A****Cristiano Cervellera** `cristiano.cervellera@cnr.it`

Institute of Marine Engineering, National Research Council of Italy  
Francesco, Rebora, Institute of Marine Engineering, National Research Council of Italy; Danilo, Macciò, Institute of Marine Engineering, National Research Council of Italy

*Receding-horizon dynamic optimization of port-city traffic interactions over shared urban infrastructure*

We introduce a receding-horizon dynamic optimization approach for the real-time efficient management of conflicting traffic flows from a port terminal and urban mobility, in contexts where the port is located within a city center. This common situation typically entails a negative impact on the urban transport network, where the need to share the infrastructure causes issues both to the logistic and mobility flows. For the purpose of mitigating the negative impact, we formalize a model-predictive control scheme based on an integrated model of the port-city environment, focusing on the import and export chains in proximity of the terminal where trucks and general mobility vehicles interact. By exploiting available forecasts on mobility demand and container traffic, together with the coordinated action of perimetral and gate control, our proposed scheme aims at optimizing a desired performance index reflecting the interests of the involved stakeholders. Simulation results are presented regarding a context based on the port of Genova in north-west Italy, showcasing the ability of the proposed receding-horizon scheme to manage complex situations such as bottlenecks and transitions to mobility rush hours.

## Continuous and Multiobjective optimization; Contributed Session

FR 11:30 AM2 Auditorium B

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*Multi-Objective Covering Location Problems with advanced connectivity features and zonal requirements: Exact and Matheuristic approaches*

Real-world facility location problems often demand to tackle simultaneously zonal requirements and facility interconnection issues; these may arise from administrative, managerial and operational needs, aiming to ensure an equal distribution of services, while concurrently securing an efficient flow of goods, people or information among the located facilities. As the literature appears rather limited at addressing this challenge, in this work we bridge such a gap by exploring the integration of the Maximal Covering Location Problem with spatial-related requirements and advanced connectivity features.

We adopt a broad modeling perspective, accounting for structural and economic aspects of connectivity attributes in facility location, while allowing for the choice of one or more depots to serve and feed the networks of located facilities, and containing the maximal distance between any located facility and such depots. The resulting mathematical models find straightforward applications, among other fields, in Healthcare Management, allowing for instance to optimally design large scale vaccination campaigns or to efficiently set-up mass screening procedures, e.g. during the response to a pandemic. Under the above mentioned modeling assumptions, the objectives to be fulfilled result multiple and inherently conflicting in nature, thus reflecting the increased managerial complexity of the related problems. In order to enhance decision-making in this scenario, we introduce a novel class of Multi-objective Covering Location problems, prove their NP-hard computational complexity, and devise original Mixed Integer Linear Programming models for their mathematical formulations.

As a first contribution to the solution process we adapt the robust version of the AUGMENTed epsilon-CONstraint generation method (AUGMECONR) [1] as an efficient framework to explore the corresponding Pareto Sets. As a second contribution we exploit the mathematical properties of the introduced problems to design a Matheuristic algorithm which is integrated

Continuous and Multiobjective optimization; Contributed Session

within the AUGMECON-R scheme to allow scalability of the solution method, with particular reference to the case of multiple depots.

We conduct a comprehensive computational study on benchmark instances adapted from the extant literature on Location Problems with interconnected facilities and Clustered Shortest Path Problems. The numerical experiments provide a proof of concept of the proposed models and highlight the challenging nature of the advanced connectivity features, particularly in presence of multiple depots. Both the Exact and the Matheuristic approaches provide a rich and articulate approximation of the relevant Pareto Sets for medium sized problems, while the Matheuristic shows a highly scalable performance when tackling large sized instances and multiple depot configurations.

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**FR 11:50 AM2 Auditorium B****Aly-Joy Ulusoy** aly-joy.ulusoy15@imperial.ac.ukImperial College London  
Pecci, Filippo, Imperial College London; Stoianov, Ivan, Imperial  
College London*Multi-objective design-for-control of water networks with global bounds*

The optimal design and operation of water distribution networks (WDN) requires the consideration of conflicting operational objectives. In particular, this study investigates the problem of simultaneously optimizing the placement of new links (pipes or pressure control valves) and valve control settings, for the joint maximization of WDN resilience and the minimization of pressure-induced leakage. We investigate global methods for the solution of the resulting design-for-control problem, which belongs to the challenging class of bi-objective mixed-integer non-linear programs (MINLP) with non-convex constraints. Recently, multi-objective branch-and-bound methods have been proposed to compute outer approximations of the efficient and/or non-dominated sets of a wide range of multi-objective optimization problems, including convex MINLPs (De Santis et al., 2019), continuous NLPs with non-convex objective functions (Niebling & Eichfelder, 2019) and non-convex multi-objective MINLPs (Eichfelder et al., 2022). Following the general framework presented by (Eichfelder et al., 2022), we develop a bi-objective branch-and-bound algorithm based on tailored branching rules, discarding tests and upper and lower bounding procedures to approximate the non-dominated set of the WDN design-for-control problem with guarantees of global non-dominance. We evaluate the proposed bi-objective branch-and-bound algorithm on case study networks with different sizes and levels of connectivity and show that it outperforms previously investigated scalarization-based methods (Ulusoy et al., 2021).

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- [2] Eichfelder, G., Stein, O., & Warnow, L. (2022). A deterministic solver for multiobjective mixed-integer convex and nonconvex optimization. Optimization Online, Preprint ID, 128. [3] Niebling, J., & Eichfelder, G. (2019). A branch-and-bound-based algorithm for nonconvex multi-objective optimization. SIAM Journal on Optimization, 29(1), 794821. <https://doi.org/10.1137/18M1169680> [4] Ulusoy, A.-J., Pecci, F., & Stoianov, I. (2021). Bi-objective design-for-control of water distribution networks with global bounds. Optimization and Engineering. <https://doi.org/10.1007/s11081-021-09598-z>

**FR 12:10 AM2 Auditorium B****Andrea Brilli** brilli@diag.uniroma1.it

Sapienza University of Rome Department of Computer Control and Management Engineering A. Ruberti

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*An interior point method for nonlinear constrained derivative-free Optimization*

In this paper we consider constrained optimization problems where both the objective and constraint functions are of the black-box type. Furthermore, we assume that the nonlinear inequality constraints are non-relaxable, i.e. their values and that of the objective function cannot be computed outside of the feasible region. This situation happens frequently in practice especially in the black-box setting where function values are typically computed by means of complex simulation programs which may fail to execute if the considered point is outside of the feasible region. For such problems, we propose a new derivative-free optimization method which is based on the use of a merit function that handles inequality constraints by means of a log-barrier approach and equality constraints by means of a quadratic penalty approach. We prove convergence of the proposed method to KKT stationary points of the problem under quite mild assumptions. Furthermore, we also carry out a preliminary numerical experience on standard test problems and comparison with a state-of-the-art solver which shows efficiency of the proposed method.

## Keynote

FR 14:30 PM0 Auditorium A

Maria Paola Scaparra [m.p.scaparra@kent.ac.uk](mailto:m.p.scaparra@kent.ac.uk)

Kent Business School, University of Kent (U.K.)

*Leveraging OR to build more sustainable, resilient, and equitable communities in Southeast Asia*

The United Nations Sustainable Development Goals (SDGs) are a universal call to action to end poverty, protect the planet, and improve the lives and prospects of everyone, everywhere. Operational Research has a major role to play in finding solutions to sustainable development challenges and helping the achievement of the SDGs. This talk discusses two projects, funded by the UK Global Challenges Research Fund (GCRF), to build more resilient, egalitarian, and inclusive communities in Southeast Asia. The first project (GCRF-OSIRIS) used OR tools integrated with models and output from the fields of meteorology, hydrology, and social science to minimise the impacts of severe flooding in urban areas of Vietnam. Because flooding disproportionately impacts the lives of women and poor communities, the views and concerns of these vulnerable groups were elicited and taken into account during the model building phase to identify community-responsive flood mitigation solutions. Building on the success of GCRF-OSIRIS, a recent follow-up project (CREST-OR) focused on fostering inclusive OR communities in Cambodia, Indonesia, Laos, Myanmar, and Vietnam by equipping future generations (including women) with the relevant OR expertise needed to tackle a range of sustainable development challenges. The talk will conclude by highlighting additional opportunities for OR to help realise an inclusive and sustainable future for Southeast Asian communities and accelerate progress of the SDG agenda.

Keynote

## Supply Chains and Inventory; Contributed Session

FR 15:40 PM1 001

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### *A Two-echelon Time-dependent Green Location-Routing Problem*

In a location-routing problem, the interdependency of facility location and vehicle routing is considered, and consequently, it avoids sub-optimal solutions to the logistics and

transportation design and planning. In this study, we formulate and solve a two-echelon time-dependent green location-routing problem (2E-TDGLRP) in which the optimal location of

intermediate hubs within a set of candidate locations, as well as the routing and scheduling of vehicles, are to be determined simultaneously by minimizing the economic and environmental costs. We consider the economic cost as the investment cost of facilities and vehicles and the drivers wage in this problem. The environmental cost is deemed based on the GHGs emitted by the delivery vehicles, which is calculated using a comprehensive modal emission model (CMEM). Another novelty of our model lies in explicitly considering the effect of traffic

congestion on travel times by assuming time-dependent speed functions. We develop a mixed-integer linear programming formulation of 2E-TDGLRP. We solve the problem exactly using

the Gurobi solver for several small instances. We then present an efficient heuristic algorithm to solve larger instances. Our results show the validity of our mathematical model and allow us to analyze the effect of considering time-dependent travel times in the green location-routing problem.

**FR 16:00 PM1 001****Tatiana Grimard** tatiana.grimard.1@ulaval.ca

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bec, Canada

*Supply chain design and cost allocation in a collaborative three-  
echelon supply network: A literature review*

Supply chains have been the focus of many studies. When warehouses or distribution centers must be located and allocated to customers and suppliers, a few key parameters can greatly affect the optimisation of the supply chain, for example, its flexibility, the inclusion of inventory management and the consideration for uncertainty. We first provide an overview of the impacts of these parameters on the network design process. The project that motivated this review concerns a supply chain that must be designed that will be used in a coalition. Therefore, the second part of our review concerns the different cost allocation methods used in collaborative networks. We then discuss the advantages of designing supply chain with a future collaboration in mind and how this consideration can affect the optimisation.



## Discrete Optimization; Contributed Session

FR 15:40 PM1 002

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ESSEC Business School of Paris; Serra, Domenico, Università degli  
Studi di Salerno; Sorgente, Carmine, Università degli Studi di Salerno

### *The collapsed $k$ -core problem*

In social networks, the departure of critical users can have a substantial impact on network participation, causing a huge number of additional users to quit. To identify such critical users, the Collapsed  $k$ -Core Problem, presented for the first time in [1], may be used. Given an undirected graph  $G = (V, E)$ , and a positive integer  $k$ , a  $k$ -core of  $G$  is a maximal subgraph of  $G$  in which all the nodes have degree at least  $k$ . Having a budget  $b$ , the Collapsed  $k$ -Core Problem aims to find the set of  $b$  nodes the deletion of which leads to the smallest  $k$ -core (i.e., the  $k$ -core with minimal cardinality), obtained from  $G$  by iteratively removing nodes with degree strictly lower than  $k$ . We propose two new formulations of the problem: the first one considers different time slots to model the progressive deletion rounds, while the second one is a bilevel formulation. The leader aims to minimize the cardinality of the  $k$ -core obtained by removing exactly  $b$  nodes. The follower wants to detect the  $k$ -core obtained after the decision of the leader on the  $b$  nodes to eliminate, i.e., to find the maximal subgraph of the new graph where all the nodes have degree at least  $k$ . To deal with this bilevel formulation we propose a single-level value function reformulation that we solve through a cutting-plane procedure.

In order to evaluate the proposed formulations, we successfully test different existing instances.

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**FR 16:00 PM1 002****Federico Della Croce** federico.dellacroce@polito.it

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*Operating rooms scheduling with a shared resource: a red-blue knapsack modeling approach*

Operating rooms scheduling has been widely investigated in the last 50 years. We mention here four main reference surveys on the topic published between 2010 and 2019, namely [1], [2], [3] and [4]. We denote this problem as the Shared Resource Operating Rooms scheduling (SRORS) problem. The SRORS problem can be formally expressed as follows. We have  $n$  surgical interventions (hereafter also denoted as jobs)  $1, \dots, n$  and  $m$  operating rooms  $OR(1), \dots, OR(m)$ . Each job  $j$  belongs to a specific surgical specialty that is univocally assigned to a given operating room  $OR(i)$ . Then, for each operating room  $OR(i)$ , there are  $n(i)$  jobs to schedule in the considered day, and we have  $n = \sum_{i=1}^m n(i)$ . We denote by  $J(i)$  the set of jobs schedulable in operating room  $OR(i)$ . Each operating room  $OR(i)$  is available for a common duration  $W$  for surgical interventions. Each job  $j$  may or may not require the use of a shared resource. We will denote as red jobs those jobs requiring the shared resource and as blue jobs the other jobs. Also, for each  $OR(i)$ , we will denote as  $R(i)$  ( $B(i)$ ) the set of relevant red (blue) jobs. Each job  $j$  schedulable in  $OR(i)$  has a nominal duration  $w(i,j)$  and a profit  $p(i,j)$  directly derived from the job priority. The goal is to maximize the total profit of the scheduled jobs. Besides, to avoid unnecessary moves of the shared resource from one operating room to another, it is assumed that every day this resource can spend at most one single time interval in each operating room. Correspondingly, for each  $OR(i)$  w.l.o.g. a blue-red-blue sequence with a first subset of blue jobs, then a subset of red jobs and finally a second subset of blue jobs holds. Notice that all these subsets may be empty. Being a generalization of the 0/1 Knapsack Problem, see for instance [5], the SRORS problem is NP-Hard, but it is of interest to determine whether it is in the weak or in the strong sense. We have the following results. The case when  $m$  is fixed is weakly NP-hard, while the case of an arbitrary  $m$  is strongly NP-hard (this last result is proved by reduction from 3-Partition). To solve to optimality the SORS problem, it is possible to derive a knapsack-based formulation exploiting the blue-red-blue sequence. This formulation is sufficient enough (by means of an ILP solver) to well solve in practice realistic instances of the considered problem. We also propose another ILP formulation exploiting a genuine combinatorial generation of all relevant

schedules for each operating room  $OR(i)$ : let  $S(i)$  be the set of schedules of the form red-blue-red. we define boolean variables  $x(I,k)$  to determine whether the  $k$ -th schedule in  $S(i)$  is selected or not. Then, the ILP reduces to determine the selection of one schedule per operating room such that the total profit is maximum and the constraints are satisfied. Clearly, this approach requires to generate all sets  $S(i)$  which is doable by means of dynamic programming. Experimental results will show the efficiency of the latter ILP formulation with respect to the first one.

[1] Cardoen B., Demeulemeester E., Belien J. 2010, Operating room planning and scheduling: a literature review, *European Journal of Operational Research*, Vol. 201 (3), pp. 921-932. [2] Guerriero F., Guido R. 2011, Operational research in the management of the operating theatre: a survey, *Health Care Management Science*, Vol. 14 (1), pp. 89-114. [3] Samudra M., Van Riet C., Demeulemeester E., Cardoen B., Vansteenkiste N., Rademakers F.E. 2016, Scheduling operating rooms: achievements, challenges and pitfalls, *Journal of Scheduling*, Vol. 19, pp.493-525. [4] Zhu S., Fan W., Yang S., Pei J., Pardalos P.M. 2019, Operating room planning and surgical case scheduling: a review of literature, *Journal of Combinatorial Optimization*, Vol. 37, pp. 757-805. [5] Pferschy U., Pisinger D, Kellerer H. 2004, *Knapsack problems*, Springer-Verlag.

## Machine Learning; Contributed Session

FR 15:40 PM1 003

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### *Maximum Margin Optimal Classification Trees*

In recent years there has been a growing attention to interpretable machine learning models which are able to give explanatory insights on the decisions made by the algorithm. Especially in healthcare applications, it is of great interest to find a hierarchy on the subsets of features which mostly affect the outcome of a classification algorithm. Thanks to their interpretability, decision trees have been intensively studied for classification tasks, and, due to the remarkable advances in mixed-integer programming (MIP), various approaches have been proposed to formulate the Optimal Classification Tree (OCT) problem as a MIP model (Bertsimas and Dunn, 2017). We present a novel MIP formulation for the OCT problem which exploits the generalization capabilities of support vector machines for binary classification. The Maximum MARGIn Optimal Classification Tree (MARGOT) selects at each node of the decision tree a maximum margin separating hyperplane using an  $\ell_2$ -norm linear support vector machine. The resulting model combines such multivariate hyperplanes minimizing the global misclassification error. In contrast to other similar approaches (Bennet et al, 1997, and Zhu et al, 2020), both the objective function and the classification constraints of the standard SVM primal formulation appear in our model. The key idea is that, given a node  $t$  of the tree and a sample  $i$ , if the hyperplane at  $t$  does not need to be trained to classify  $i$ , classification constraints related to  $t$  and  $i$  are deactivated through a special big-M constraint on the misclassification variable  $\xi_{t,i}$ . This way, each separating hyperplane can be trained on just a subset of samples. The model can also include feature selection constraints which improve the interpretability of our approach. MARGOT has been tested on non-linearly separable synthetic datasets in a 2-features space in order to provide a graphical representation of the optimal hyperplanes. Finally, we evaluate our model with the feature selection constraints on well-known datasets from the UCI repository.

Machine Learning; Contributed Session

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*GPS data mining to infer fleet operations for personalised product upselling*

Selecting the correct targets for a marketing campaign and personalising the content of the marketing material requires a deep understanding of the operations of potential customers. We present a system that mines raw GPS data from a fleet of vehicles with the aim of inferring fleet operations. The inference proceeds in subsequent steps of increasingly deeper understanding, from fleet hotspots to vehicle routes and daily work shifts and work stops. We present an application of our system where such information is exploited to select the best suited customers for vehicle routing software and to create personalised marketing material, based on the estimated savings for the fleet due to use of the routing software. Experimental results from an email marketing campaign confirm the effectiveness of our system and of the personalised marketing material it delivers.

## Transportation; Contributed Session

FR 15:40 PM1 Auditorium A

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*Vehicle routing at work: a real-world implementation and case studies*

Vehicle routing problem (VRP) and its variants are commonly and widely used in many areas of logistics and supply-chain industry to optimize the whole business process and providing significant savings in terms of development time and costs. Optit-logistics is a decision support tool designed for advanced transportation planning, its optimization core is based on fully customizable algorithms for VRP. The software offers multiple visualization tools for KPI analysis and solution validation, as well as full editing functionalities to update the routes generated by the algorithms. In addition to the classic capacitated VRP (C-VRP), the model can be enriched with several different features and constraints relevant for specific applications, such as: homogeneous and heterogeneous fleets (limited or not), multiple-depots and intermediate facilities, hard and soft multiple time windows, pickup & delivery, decision-making cross-docking, split-deliveries and many others. The algorithmic framework behind the Optit-logistics solver is the well-known Ruin and Recreate approach (Schrimpf et al. 2000). This method, combined with Threshold acceptance of the solutions, allows the exploration of very-large neighborhoods and combines implementation simplicity, which is fundamental in industrial deployments, and excellent effectiveness, as widely established in the scientific literature on VRP (see, e.g. Pisinger and Ropke 2006, 2019) The main construction operators implemented and integrated into the solver range from simple greedy insertion heuristics, to the well-known Clarke and Wright savings method, to route-first-cluster-second algorithms based on giant-tour approach. This general-purpose solver was used in several real-world applications ranging from pickup & delivery for retail distribution, to home delivery, closed-loops full-truckload daily transportation and on-demand waste collection. To guarantee the robustness and to validate the reliability of the implemented algorithms, an extensive experimentation phase was carried out taking into account a large data set of VRP benchmark instances, selected with the aim of covering the best-known variants of the VRP in literature. In this session, we focus on a recently addressed new variant of the VRP, for which we introduce a mathematical formulation and the adopted solution strategy. In addition, we discuss an extensive analysis of real-world instances of the problem. The problem under consideration contains considerable

Transportation; Contributed Session

complexities that cannot be trivially modeled and which, to the best of our knowledge, their combination was not previously treated in the existing literature. In our problem it is possible to perform both pickup and delivery operations at customers, thus it belongs to the general family of Pickup and Delivery VRPs (PD-VRP). Furthermore, the other main characteristics of the problem are the presence of heterogeneous fleet, multiple-depots and multiple-time-windows. Finally, orders can be split over different trips, and at the same time the algorithm should be able to decide if each order can be shipped in direct-mode from pickup point to the delivery point or alternatively in cross-docked-mode appropriately selecting the so-called transit-point where the order is consolidated with others for the last-mile delivery. The overall solution approach is based on two phases. In a first one a min-cost-flow over the distribution network is solved to define the distribution strategy, while in a second step the detailed routing is determined through the above-described solver. Such, combined approach is extensively validated on real-world instances and proved able to determine very good results compared to the previously implemented solutions.

**FR 16:00 PM1 Auditorium A****Xuan Ren** renxuan@mail.nwpu.edu.cnSchool of Management, Northwestern Polytechnical University  
Jabali, Ola, Department of Electronics, Information and Bioengineering, Politecnico di Milano*The Truck and Drone Routing with Delivery and Optional Pickups*

Using drones for delivery services has been drawing much attention in the logistics industry. In this work, we study a new variant of the vehicle routing problem with drones (VRPD), where a logistics service provider (LSP) must serve customers having delivery requests, and may choose to serve pickup requests. The latter represents customers returning products. We assume that if such a request is served by the LSP, they generate profit. Both trucks and drones may be used to serve both delivery and pickup requests. We call the resulting problem the truck and drone routing problem with delivery and optional pickups (TDRP-OP). We assume that each truck is collaborating with a single drone. Since drones have limitations on payloads and battery capacities, they can only serve one customer each time. Different from most of the literature on the VRPD, this work considers both truck capacity and drone capacity. The objective is to minimize total operational costs, which include the transportation costs of both trucks and drones minus the total profit from picking up returning products. We present a MILP formulation for the TDRP-OP and introduce a variable neighborhood search (VNS) heuristic for it. A dynamic program is proposed to find the best drone sorties for a given sequence of customers. We generate new instances for the TDRP-OP. Computational results show that our method can find optimal solutions for small instances compared to the MILP solutions, and high-quality solutions within a reasonable time for large instances. Furthermore, we compare our heuristic on VRPD instances from the literature. In this respect, our heuristic yields competitive results and identifies new best-known solutions to several instances.



**FR 16:20 PM1 Auditorium A****Jean-Paul M. Arnaout** arnaout.j@gust.edu.kwLebanese American University, Byblos, Lebanon  
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Gulf University for Science & Technology, Mishref, Kuwait; Maria,  
Bassil*A Preliminary Assessment of the Traffic Operations of Connected  
and/or Autonomous Vehicles*

Autonomous vehicles are projected to eliminate human errors in the driving task, which means an increase in safety and a reduction in the number of crashes. In addition, autonomous vehicles can reduce traffic congestion and traffic delays leading to improved operational efficiency and smoother traffic flow. This research attempts to evaluate the improvement in the level of service and capacity of freeways and signalized intersections when their operation shifts from conventional vehicles (CVs) to fully autonomous vehicles (AVs). The increased efficiency and capacity of roadways and intersections operated by AVs is due to their computerization, their ability to travel at a steady desired speed, in addition to their ability to keep reduced headways between each other in the traffic stream. For this purpose, the effect of fully autonomous vehicles on the lane width, number of lanes and car following model parameters has been thoroughly examined based on the new vehicle setup. For a fully autonomous vehicle fleet, the driver related parameters are no longer a concern. Narrower lane widths and revised car following behavior were modeled using a well-known microscopic simulation software to simulate the fully autonomous vehicles environment. The results of the simulation scenarios show that the expected benefits of autonomous vehicles in reducing delay, increasing capacity, and improving the level of service are most evident when 100% of the traffic flow consists of autonomous vehicles. In particular, the results of the performed simulations on the freeway section has showed that low levels of AVs penetration can have an adverse effect on the traffic operations. Despite the ambiguity and unpredictability of the freeway transition phase from CVs to AVs, the intended benefits of AVs are expected to be fully achieved with the complete deployment of AVs. For the signalized intersection, AVs lead to a lower vehicle delay, lower queue length, and higher capacity. The results of the microscopic simulations have confirmed that when fully deployed, AVs are expected to improve the capacity, efficiency and Level of Service of freeways and signalized intersections.

## Applications of OR; Contributed Session

FR 15:40 PM1 Auditorium B

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*Machine Learning heuristic for Variable Cost and Size Bin Packing  
Problem with Stochastic Items*

Third-party logistics becomes an essential component of efficient delivery, enabling companies to rent transportation services instead of keeping an expensive fleet of vehicles. However, the contracts with the carriers usually have to be booked beforehand when the delivery demand is unknown. This decision process is strongly affected by uncertainty, provided with a long (tactical) planning horizon, and can be expressed as choosing an appropriate set of bins (fleet contracts). Formally, it can be modeled as the Variable Cost and Size Bin Packing Problem with Stochastic Items [1]. It consists of packing the set of items (goods) with uncertain volumes and quantities into containers (bins) of different fixed costs and capacities. This problem is described via a two-stage stochastic programming approach, where the cost of the bins of the second stage is significantly higher. Since it cannot be solved for large realistic instances by means of exact solvers for a reasonable time and memory consumption, this paper introduces a Machine Learning heuristic to approximate the first stage decision variables. Several numerical experiments are outlined to show the effectiveness of the proposed approach to deal with realistic instances of up to 3000 items. Further, the proposed heuristic is compared to the recent Progressive Hedging-based heuristic and showed a significant computational time reduction. Finally, different classification approaches are compared, and the feature selection process is explained to gain insight into heuristic performance to deal with the outlined problem.

[1] Crainic, T. G., Gobbato, L., Perboli, G., Rei, W., Watson, J. P., & Woodruff, D. L. (2014). Bin packing problems with uncertainty on item characteristics: An application to capacity planning in logistics. *Procedia-Social and Behavioral Sciences*, 111, 654-662.

**FR 16:00 PM1 Auditorium B****Mikele Gajda** `mikele.gajda@unil.ch`

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*Last-mile delivery with vans and autonomous robots: an analysis on the impact of the return policy*

In recent years, technological advancements have shaped innovative and promising last-mile delivery solutions. One of these approaches involves the employment of autonomous delivery robots (ADRs) in conjunction with vans from which the robots can be picked up and released. These robots operate at pedestrian pace on the sidewalk, providing a reliable operator for the last delivery step. In our research, we study a multi-modal transportation system in which vans convey ADRs from depots to prospective drop-off places, with the final portion of the delivery being handled autonomously by the robots, which then return to one of the available depots. The goal of this contribution is to investigate and compare different policy approaches for the return of the robots to the depots. Indeed, the choice of the return policy has a direct impact on the number of robots required to perform a given delivery plan. Our main objective is to minimize the number of used robots to complete a certain amount of delivery jobs. We define and analyze three possible robot return policies in detail (dedicated-station policy, closest-station policy, most-suitable-station policy), and we propose suitable optimization algorithms for each of them in order to find optimal solutions in polynomial time. Our findings, obtained from computational experiments performed on an extensive set of realistic instances, demonstrate that the robot return policy should be carefully chosen in order to achieve the targeted delivery plan with a minimum number of robots.

**FR 16:20 PM1 Auditorium B****Roberto Musmanno** roberto.musmanno@unical.it

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*Selection of Cultural Sites via Optimization*

We focus on a combinatorial optimization problem arising in regional tourism management. The problem consists in selecting cultural sites to be promoted among others distributed in a regional geographic area. Specifically, when a cultural site is selected, the potential visitors who decide to travel by train have the opportunity to take advantage of a free-of-charge shuttle dispatched from the closest railway station to the site. For the solution of this problem we propose an optimization framework based on the formulation of a bi-objective mathematical model. The computational results are presented by considering a case study derived from a regional project.

## **Closing Session**

**FR 17:00 PM2 Auditorium A**

**Paola Cappanera**  
Fabio Schoen

*Closing session*

**\*\* NO ABSTRACT PROVIDED \*\***

**Closing Session**

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