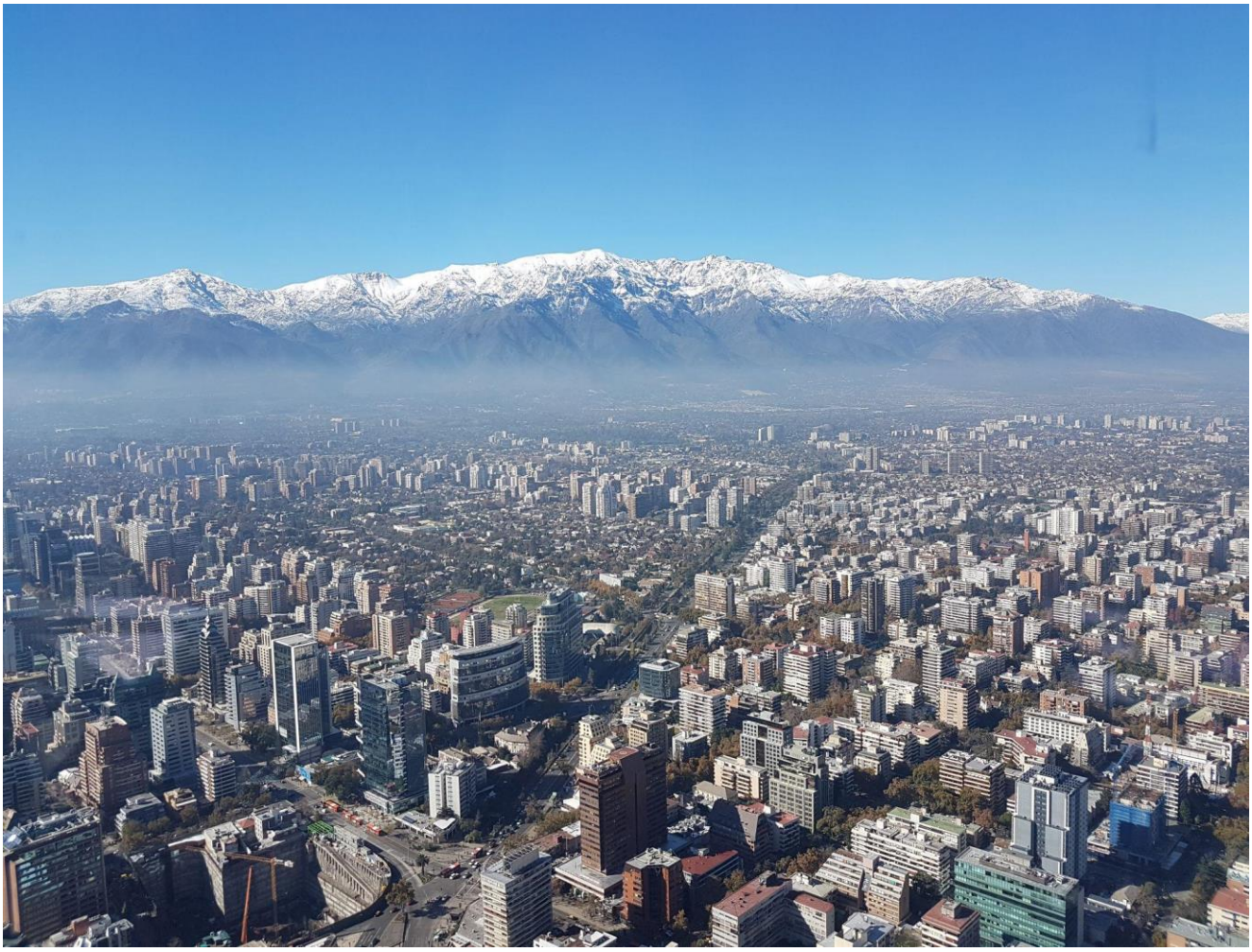
IFORS2023

The 23rd Conference of the International Federation of Operational Research Societies

July 10-14 · SANTIAGO, CHILE



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Proceedings of the 23rd International Conference of the International Federation of Operational Research Societies

Alice E. Smith, Jorge R. Vera, and Bernard Fortz (editors)

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Proceedings of the 23rd International Conference of the International Federation of Operational Research Societies

Alice E. Smith, Ph.D.
Auburn University
smithae@auburn.edu

Jorge R. Vera, Ph.D.
Pontificia Universidad Católica de Chile
jver@uc.cl

Bernard Fortz, Ph.D.
University of Liège
bernard.fortz@uliege.be

Instituto Chileno de Investigación Operativa (ICHIO)
Santiago, Chile
www.ichio.cl
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Preface

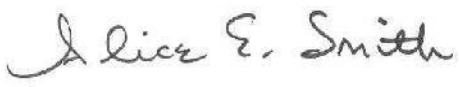
IFORS 2023 was a resounding success! The technical program had 946 submissions with 726 presentations actually given at the conference. Authors of submissions came from 55 countries. There were 36 clusters/streams headed by 55 cluster chairs. The program spanned four days with many parallel tracks spread over two nearby venues. The conference took place in Santiago, Chile in July of 2023.

The compilation herein contains the titles, authors, and abstracts of the presentations at the conference. These include four plenary addresses, six keynote speeches, six tutorials, and several special sessions such as panels and mini-workshops. The bulk of the abstracts come from the technical program, both invited and contributed (we make no distinction between these herein). The abstracts are grouped by session and thence into clusters/streams. Each session has between two and four abstracts, and these constitute a coherent set on the topic named in the session title. Each session is part of a cluster/stream, which is similarly titled with its focus.

If you reference or cite an abstract from IFORS 2023, please cite this online volume by its ISBN and DOI. We invite you to share these proceedings with your colleagues and students. It may be distributed freely to promote scientific and technical inquiry and to facilitate exchange and networking of the rich set of research presented at this conference.

To all the participants in the technical program of IFORS 2023, thank you! These include the authors, presenters, session chairs, cluster chairs, plenary and keynote speakers, and tutorial leaders. And, of course, to Bernard Fortz of University of Liège, who orchestrated the submission and program building software.

We can all be proud of the breadth and rigor of the work presented and the many conversations stimulated at the conference and going forward, which will no doubt enrich our operations research community and its work. Enjoy this volume which is the permanent technical record of the conference.



Program Chair

Auburn University

IFORS 2023 Program Committee / Cluster Chairs

Cluster Chair	Email Address	Title of Cluster
A.D. Amar, Seton Hall University, USA	AD.Amar@shu.edu	Knowledge and Technology Analytics in Organizations
Dries Benoit, Ghent University, Belgium	dries.benoit@ugent.be	Analytics and Data Science
Martin Bichler, Technical University of Munich, Germany	bichler@in.tum.de	Game Theory, Market Design, and Mathematical Economics
Hadi Charkhgard, University of South Florida, USA	hcharkhgard@usf.edu	Multi-Objective Optimization: Theory, Algorithms, and Applications
Kristof Coussement, IESEG School of Management, France	k.coussement@ieseg.fr	Analytics and Data Science
Patrick De Causmaecker, KU Leuven, Belgium	patrick.decausmaecker@kuleuven.be	Data Science Meets Optimization
Ali Emrouznejad, University of Surrey, UK	a.emrouznejad@surrey.ac.uk	Data Envelopment Analysis and its Applications
Bob Fourer, AMPL, USA	4er@ampl.com	Software for Optimization
Marcela Gonzalez , Universidad de Talca, Chile	mgonzalez@utalca.cl	Agrifood Supply Chains
Rosa Gonzalez , Universidad de los Andes , Chile	rgonzalez@uandes.cl	Maritime Logistics
Salvatore Greco, University of Catania, Italy	salgreco@unict.it	Multiple Criteria Decision Analysis
Ignacio Grossmann, Carnegie Mellon University, USA	grossmann@cmu.edu	Optimization of Power Systems
Yong-Hong Kuo, The University of Hong Kong, China (Hong Kong SAR)	yhkuo@hku.hk	Healthcare Management
Changhyun Kwon , University of South Florida, USA	chkwon@usf.edu	Urban Transportation

Eduardo Lalla-Ruíz, University of Twente, Netherlands	e.a.lalla@utwente.nl	Maritime Logistics
Janny Leung, University of Macau, China (Macao SAR)	jannyleung@um.edu.mo	Logistics
Alejandro Mac Cawley, Pontificia Universidad Católica de Chile, Chile	amac@ing.puc.cl	Agricultural Innovations and OR
Sebastian Maldonado, University of Chile, Chile	semaldonad@fen.uchile.cl	Analytics and Data Science
Vladimir Marianov, Pontificia Universidad Católica de Chile, Chile	marianov@ing.puc.cl	Location, Network Design, and Routing
Silvano Martello, Alma Mater Studiorum Università di Bologna, Italy	silvano.martello@unibo.it	Combinatorial Optimization
Timothy Matis, Texas Tech University , USA	timothy.matis@ttu.edu	Applied Probability and Statistics
Gonzalo Mejía, Universidad de La Sabana, Colombia	gonzalo.mejia@unisabana.edu.co	OR and Food Sourcing and Distribution
Rym M'Hallah , King's College London, United Kingdom	rym.mhallah@kcl.ac.uk	Discrete Optimization; Packing and Routing
Elise Miller-Hooks, George Mason University, USA	miller@gmu.edu	Sustainability Analytics and Modeling
Rodrigo Moreno, Universidad de Chile, Chile	rmorenovieyra@ing.uchile.cl	Energy
Stefan Nickel, Karlsruhe Institute of Technology (KIT), Germany	stefan.nickel@kit.edu	Production Management, Supply Chain Management, and Location
Alena Otto, University of Passau, Germany	alena.otto@uni-passau.de	Scheduling in Logistics
Dmitri Papadimitriou, 3nLab and N&O Dept., Belgium Research Center, Belgium	dpapadimitriou@3nlab.org	Continuous Optimization
Greg Parlier, U.S. Army (retired), USA	gparlier@knology.net	Military, Defense, and International Security

Erwin Pesch, University of Siegen, Germany	erwin.pesch@uni-siegen.de	Scheduling in Logistics
Lluís Miquel Plà-Aragonès, University of Lleida, Spain	lluismiquel.pla@udl.cat	Agricultural Innovations and OR
Celso Ribeiro, Universidade Federal Fluminense, Brazil	celso@ic.uff.br	Metaheuristics; OR in Sports
Roger Rios, Universidad Autonoma de Nuevo Leon, Mexico	roger@yalma.fime.uanl.mx	Metaheuristics
Enzo Sauma, Pontificia Universidad Católica de Chile, Chile	esauma@ing.puc.cl	Energy
Maximilian Schiffer, Technical University of Munich, Germany	schiffer@tum.de	Mobility and Transportation Systems
Cole Smith, Syracuse University, USA	colesmit@syr.edu	Multilevel and Stochastic Optimization Methods
Greys Sošić, University of Southern California, USA	sosic@marshall.usc.edu	Game Theory and Operations Management
Paolo Toth, Alma Mater Studiorum Università di Bologna, Italy	paolo.toth@unibo.it	Combinatorial Optimization
Wouter Verbeke, KU Leuven, Belgium	wouter.verbeke@kuleuven.be	Analytics and Data Science
Rene Villalobos, Arizona State University, USA	rene.villalobos@asu.edu	Agrifood Supply Chains
Juan Guillermo Villegas, Universidad de Antioquia , Colombia	juan.villegas@udea.edu.co	OR and Food Sourcing and Distribution
Alexander Vinel, Auburn University, USA	alexander.vinel@auburn.edu	Education in OR
Begona Vitoriano, Cumplutense University of Madrid, Spain	bvitoriano@mat.ucm.es	Use of Analytics in Forest Fires Management
Gerhard-Wilhelm (Willi) Weber, Poznan University of Technology, Poland	gerhard-wilhelm.weber@put.poznan.pl	Education in OR; Game Theory, Market Design, and Mathematical Economics; OR for Development and Developing Countries; OR and Ethics
Richard Weber, University of Chile, Chile	richard.weber@uchile.cl	Analytics and Data Science

Andres Weintraub, University of Chile, Chile	aweintra@dii.uchile.cl	Use of Analytics in Forest Fires Management
Hulya Yazici, Florida Gulf Coast University, USA	hyazici@fgcu.edu	Education in OR; Sustainability Analytics and Modeling

IFORS 2023 Highlights

By Rafael Epstein and Jorge Vera, Chairs of the Organizing Committee

(An extended version of this text has been published also in the September 2023 IFORS Newsletter)

IFORS 2023 attendants say hello to the rest of the world!

More than 950 persons attended the conference in Santiago, Chile, coming from 60 countries around the world. Conference activities spanned five days with talks, conferences, and many activities happening over two nearby venues at *Pontifical Catholic University of Chile* and *University of Chile*. The inaugural ceremony took place early Monday, with the presence of representatives from the two organizing universities and from the *OR* communities around the world. *Susana Mondschein*, president of the *Chilean Institute for Operations Research* (*ICHIO*) and *Janny Leung*, president of *IFORS*, greeted attendees and opened the conference. The Co-Chairs extended their gratitude to all persons and organizations supporting the event and *Alice Smith*, Chair of the Program Committee thanked all the cluster chairs and other people that helped create the scientific program.

Janny Leung (IFORS President), *Susana Mondschein* (ICHIO President), and *Alice Smith* (PC Chair) greet attendants at inaugural session.

A plenary occurred each day of the technical program. The four plenary speakers were the current Minister of Transportation of Chile and Professor at Pontifical Catholic University of Chile, *Juan Carlos*

Muñoz, *Margaret Brandeau* of Stanford University, *Paolo Toth* of University of Bologna (giving the *EURO Plenary*), and *Andres Weintraub* of the University of Chile. Each of these speakers spoke on the variety of important work that they have led which applied *OR* to solve difficult problems arising in diverse sectors including healthcare, natural resources, urban mobility, and logistics. These talks were inspiring and informative.

J.C. Muñoz and *Paolo Toth*, two of the excellent plenaries.

Six keynote speakers strongly added to the quality of the technical program - these were *Dolores Romero Morales* of Copenhagen Business School, *Andrea Lodi* of Cornell Tech and the Technion, *Tava Olsen* of University of Melbourne, *Brian Denton* of University of Michigan, *Rene de Koster* of Erasmus University, and *Anna Nagurney* of University of Massachusetts. The topics spanned from machine learning to agricultural supply chains to robotics to healthcare analytics.

In addition, *IFORS* had six 90-minute tutorials available to all attendees. *Kate Smith-Miles* of University of Melbourne led a session on stress-testing algorithms and *Andres Gomez* of University of California led one on machine learning. *Eduardo Lalla Ruiz* and *Rosa Gonzalez Ramirez* taught two tutorials on seaside planning. *Nesim Erkip* of Bilkent University was the tutor for inventory problems and the team of *Carleton Coffrin* of Los Alamos National Laboratory, *Fred Glover* of Entanglement Inc. and *Gary Kochenberger* also of Entanglement, Inc. led a session on quantum computing.

In addition to the technical sessions and keynotes and plenaries, some special events took place during the conference. On Tuesday, IFORS conducted the Ceremony of induction to the IFORS Hall of Fame. The inductees were Ailsa Land, Clovis Gonzaga, and Frederick Hillier. On Thursday, the IFORS Fellows ceremony took place before the plenary and awards and recognition diplomas were given to the new Fellows.

But there were many other activities in addition to the scientific program. Sunday was an arrival day for most, with a welcome reception very well attended in which people shared their travel experiences to Chile and greeted colleagues not seen for a long time due to the restrictions generated by the pandemic. The cultural tour day was Wednesday, and people had the opportunity to visit several places around Santiago de Chile, especially in the wine country, the mountains, and the coast.

The conference banquet was held on Thursday evening at an event center in the eastern part of Santiago, close to the mountains. More than 700 persons attended the banquet and had the opportunity to share experiences with old and new friends. The world famous Chilean traditional music group *Quilapayún* was present to entertain the presents with superlative music. After dinner dancing was the main activity, with music from a DJ.

Friday's closing ceremony, after the plenary by *Andrés Weintraub*, was very well attended. and It was great to see that most people stayed through the last day of the conference. At the ceremony, *EURO* announced the *Best Paper Awards* of the *EJOR* journal in various categories.


EURO journal prize recipients and the student support group receive acclaim from the attendees.

Various future conferences were also announced, including the *EURO 2024* in Copenhagen, the *CLAIO* conference in Guadalajara, México and, finally, the next *IFORS 2026* in Vienna.

Jorge Vera, Co-Chair of the Organizing Committee, thanked all attendants as well as all the organizing team and, specially, the group of students that helped and were present during all days of the event and at the airport, guiding attendees and supporting in an invaluable way the operations of the conference. Recognition was also given to the Chilean OR community and several persons that helped in many ways.

After the *Closing Ceremony*, attendees enjoyed a *farewell reception* with hot dogs and hamburgers, made in the Chilean way.

To close, the Organizing and Program Committees are very happy that *IFORS 2023* was such a great conference, that allowed us to be back to normal after the years of pandemic. We look forward to seeing everyone again in Vienna for *IFORS 2026*!

IFORS 2023

Technical Program and Abstracts

TECHNICAL PROGRAM

OR in Agriculture

Cluster: Agricultural Innovations and OR
Invited session
Chair: *Lluís Miquel Plà-Aragonès*

1 - Power indices of game theory and monetary value of forestry products in Brazil
Fernando Luis Garagorry, *Moacir Pedroso Junior*

A study on the evolution of forestry products in Brazil is being executed as a contribution to the formulation of a general policy for the forestry sector. It is based on annual data and covers the period of 2001 to 2021. Data are available on the produced quantity and the monetary value of production. In particular, in order to make a joint assessment with different products, the values of the following itens were considered: charcoal, firewood, logs for paper and cellulose, logs for other uses and other products (in fact, the addition of three products with minor weight). As a result, there were 336 percent distributions of the value of five items in sixteen territories (Brazil and fifteen states, here called regions) and 21 years. In each case, the five classes (items) have been interpreted as being players in a voting (additive) game, where each one has a value given by the percentage of its contribution to the total monetary value for the region, and the winning coalitions are those with a value of more than 50%. The Banzhaf power index of game theory was determined for each game and was used as a tool in order to identify clusters of regions with similar value patterns. In particular, since Banzhaf indices can be seen as new voting games, the procedure was applied repeatedly to them, up to reaching indices that were fixed points. In general, that happened in one or two stages. The regions were allocated to clusters defined by these final indices. The results will be presented in five-year intervals from 2001 to 2021. They include: a) clusterings in each year and distances between them; b) examples of important structural changes in the value distributions that happened along the years. Some of these changes were not detected by distances used frequently in clustering algorithms; that is, two distributions can be quite close according to some distance but have very different power indices. A special rounding method had to be implemented in order to ensure that successive power indices did not converge to a wrong fixed point.

2 - What can we learn by applying financial models to agricultural commodity prices? The case of corn, soybeans and wheat.
Gonzalo Cortazar, *Hector Ortega*, *José Antonio Perez*

Even though there is an extended literature applying no-arbitrage financial models to many commodity prices (such as oil, copper and gold), much less scrutiny has been undertaken on agricultural commodities. This paper uses data on futures prices and analysts' forecasts of corn, soybeans and wheat to calibrate a multi-factor stochastic no-arbitrage model providing historic and risk-neutral expected prices. Results include filtered expected prices and the term structure of the risk premium on investing in these agricultural commodities. Agricultural commodity prices have some special characteristics not found in other commodities, like oil, copper or gold. A seasonal behavior of prices must be addressed. Agricultural commodity prices are dependent not only on maturity, but also on their harvest cycles. Thus, our model provides prices and risk premiums which depend on maturity and crop year. Results for corn, soybeans and wheat are presented and discussed.

3 - Data envelopment analysis of operational efficiency in Chilean wine cellars
Alejandro Mac Cawley, *Isidora Hirmas*

The Chilean wine industry plays an important role in the national, and the world, economy. In fact, Chile has remained the world's fourth-largest wine exporter and the sixth-largest wine producer worldwide for four years in a row. It has been a challenge to measure and to compare productivity between wine-production cellars, however, due to differences in wine produced and possibilities of economies of scale in larger wine cellars. Most benchmarks today compare the quality of the wine produced by using sales price, but oenologists prefer wine tasting or even number of bottles exported; therefore, an objective assessment to compare operational performance does not exist, especially considering operational productive factors. In this research, we present data envelopment analysis (DEA) as a solution to fulfill this gap in the wine production industry. Moreover, the combination of this analysis with previous clustering and general efficiency analysis helps find more accurate improvement opportunities for inefficient cellars and better explanations for the efficient ones. We present the results obtained by, first, graphing the different efficiency frontiers; second, displaying new categories classifying cellars; and, third, making a personalized recommendation for each cellar having participated in this study and having made this research possible. Wine cellars could be classified into 3 categories depending on their productive situation: eternally small cellars, transitioning in the valley of death and stable production cellars. This categorization is backed by previous clustering analysis, and it includes a description of the category itself and a managerial insight or perspective of what a wine cellar should do in each category.

Optimization in Agriculture

Cluster: Agricultural Innovations and OR
Invited session
Chair: *Concepción Maroto*

1 - Multicriteria sorting method based on global and local search for supplier segmentation
Concepción Maroto, *Ivan Felipe Barrera*, *Marina Segura*, *Baldomero Segura*

This research aims to develop a robust multicriteria method to classify suppliers into ordered categories and a validation of it in real contexts. The proposed technique is based on a property of net flows of the PROMETHEE method and uses global and local search concepts, common in the optimisation field. The global search provides a first classification of the alternatives into categories, then modified and improved by two local search processes. First, an intra-category search by applying PROMETHEE to alternatives of each category generated in the first step. Secondly, an inter-category search by merging alternatives of adjacent categories. The sorting procedure proposed has been validated empirically by real data on supplier evaluation, allows problem solving with a high number of criteria and suppliers, and can be applied by managers using available PROMETHEE software. The results obtained are compared to those from the most cited sorting algorithm, and an empirical validation and sensitivity analysis is performed using real supplier evaluation data. An extension of the silhouette concept from data mining is also contributed to measure the quality of ordered classes. Both contributions, the Global and Local search of Net Flows (GLNF) sorting method and the SILS quality index, are easy to apply and integrate into decision support systems for automated decisions in supply chain management. Finally, this practical approach is also useful to classify customers and any alternatives or actions into ordered categories, having an increasing number of real applications.

2 - Decision Support System based in MILP for wineries' short term operation planning during harvest season
Carlos Monardes, *Bastian Ibaceta Díaz*, *Jhean Urizar*, *Felipe Varas*, *Ricardo Luna*

The harvest season represents a big challenge for wineries; this research studies how a Decision Support System (DSS), based on Operations Research models, can improve the operational decision-making

in wineries during the harvest season. Specifically, the DSS must generate a scheduling of the involved stages and machines during the planning horizon. Due to uncertainty about the grape trucks arriving at the winery, the DSS generates a weekly schedule. The batch nature of processing grapes at wineries allows applying a State-Task Network representation to create the Operational Research model of the winemaking process; this approach allows the entry of different quantities of grapes as they arrive at the winery, differentiating the corresponding grape variety. The stages covered initially in the model are Hopper, De-stemmer, Press, Pre-flotation, and Flotation; the Fermentation stage was not considered in the model, because its duration lasted more than a week. The knowledge of the enologist to form the mix groups (whether grapes could be mixed or not) and a batch process mathematical programming model are used to generate the schedules. This research has led to a DSS hosted in the cloud, utilizing JavaScript and react for the front end and python for the back end. Even though the mathematical programming model and the user interface are a prototype, it has proven to understand the functioning of the winery. The validation analysis with the "Viña Concha y Toro" (VCT) vintage 2021 data from Lontué Winery shows a little overestimate in the grape tons processed, but follows the same distribution made then. The following two factors could explain this positive deviation: (1) the tool improving production efficiency, and (2) the exception of the production waste. Further models with better resolution techniques would be helpful for the processing time of the tool itself, and they could also aim to include all the production waste in the model and the constraints they mean for the model.

3 - Small-scale farms food security and profitability promotion in developing countries: a case study from Paraguay

Jorge Vera, *María Margarita López*, *Lluís Miquel Plà-Aragonès*, *Jorge Recalde*

Peasant farmers play a predominant role in reaching food security; they represent 80% of worldwide establishments producing food. They are more affected by food insecurity, however, due to their high dependence on natural resources, their unsustainability, and the unprofitability of their operations. The self-consumption of crops leads to the uprooting of communities and inadequate diets with low-cost foods - highly energetic and poor in nutrients. Furthermore, in developing countries, small-scale farms' operations and work culture have limitations differentiating their decision-making process from large-scale farmers. Modeling the peasant operations is complex, given the many social and nutritional requirements to consider. Also, a system like this will present many alternatives to farmers regarding the use of their land and distribution of crops. Relying only on intuition and limited data will lead to suboptimal and poor-performing solutions. In this context, this research addresses, through a Mixed Integer Linear Programming model (MILP), the profitability and food security of peasant farmers, considering their strategic and tactical decisions. The first relates to supply purchasing, crop production, rotation strategies, and gathering center allocations. The second one comprises crop allocation, harvest, postharvest programing, and workforce planning. A base case study and three scenarios were developed for the Department of Caazapá, Paraguay, where peasants are assisted by the Local Agencies for Technical Assistance (ALAT), from the Ministry of Agriculture and Livestock (MAG). They produce 51 different vegetables and fruits, but 80% of the land is assigned to traditional crops (sesame, cassava, corn, and beans). Even more, 70% of production, is for self-consumption with low-profit expectations. The three axes of sustainability were also considered when carrying out the work. In economic terms, the results are obtained at the lowest possible cost by maximizing the total profitability for five years, considering the sale of products to external demand, and generating income for the farm. In the environmental area, crop rotation and obtaining a mix of products are considered, to not degrade the soil of producers in the long term. Finally, in the social aspect, the model satisfies a percentage of families' nutritional requirements with safe products, available on a timely basis.

Network Problems in Agriculture

Cluster: Agricultural Innovations and OR
Invited session
Chair: *Lluís Miquel Plà-Aragonès*

1 - Design of an agricultural network and rural schools: a case of Caazapá - Paraguay

Jorge Recalde, *Jorge Vera*, *Lluís Miquel Plà-Aragonès*, *María Margarita López*

According to UNESCO (2023), children and youth between the ages of 6 and 18 worldwide are still out of school; the causes can be complex - corruption, poverty, hunger, inefficient planning, and lack of public policies. Nations have discussed the issue, drawing sustainable objectives regarding the right to education, and the goals they wish to achieve by 2030. In this way, the Programs of School Feeding (PAE) have been created as support tools in public policies. The PAE tendency, at the Latin American and rural levels, has been to seek social protection to meet children's food requirements, as an accompaniment to attending schools and, on the other hand, to promote family farming. This project aims to support decision-making regarding the logistics network design linking the rural schools attached to the PAE with the farms of small local farmers who serve as food providers. To this end, we use as a case study the situation of rural schools and small agricultural producers in Caazapá City, located in Paraguay. In this region of the country, about 82% of the population lives in rural areas; the conditions lend themselves to the research project development, due to data availability. We expect to have a relatively high number of variables and constraints, and a mathematical programming model is formulated to address the problem. For a representative mathematical model, restrictions of sustainable agricultural planning must be addressed, such as crop rotation and crop selection, as well as meeting the demand for school lunches. Including only one primary objective is pertinent for the moment: minimizing costs in distributing and generating food rations for schools. Secondarily, a social objective is proposed: the maximization of benefits for small farmers. As the work is in progress, future work will merge the two objectives, treat the problem as a bi-objective, and include uncertainty in some relevant parameters.

2 - Math model for soybean transport in Argentina by fully electric and hydrogen fuel cell heavy-duty trucks

Maria de los Milagros Verrengia, *Aldo Vecchietti*, *Maria Laura Cunico*

The depletion of natural resources and the dire consequences of climate change are undeniable realities we are all facing; in recent years, environmental concerns have received significant attention from governments, organizations, and companies worldwide. Nonetheless, environmental supervision demands a continuous and global undertaking to mitigate the detrimental effects of human activity on our ecosystems. It is imperative to cultivate a renewed environmental consciousness necessitating fundamental modifications in the way everyone lives their daily lives, the policies governments implement, and the operational procedures of industrial systems. Moreover, developing environmentally responsible supply chains has become the subject of much research in academic and practitioners' literature, and it has given birth to new terms, such as "Green Supply Chains", "Eco-friendly Supply Chains", and "Sustainable Supply Chains". While recognizing the importance of coordinated decisions within supply chains, a further point promoted by Green Supply Chain Management (GSCM) is to optimize the strategic and operational decisions by taking into account greenhouse gas (GHG) emissions. The reduction of carbon emissions has sparked significant interest in supply chain management and given rise to a complex set of decisions, practices, and environmental activities, known as low-carbon supply chain management. In this context, the Argentine soybean supply chain is presented as a case study; the soybean complex in Argentina focuses on the export and industrialization of this primary crop and is the most important export chain in the country. Most of the transportation is done by trucks, requiring more than two million trips per year with several hundred kilometers each, having a strong impact on the amount of GHG emitted. Having this

context, this work presents a mathematical mixed integer program to represent the transportation of soybeans by means of fully electric or hydrogen fuel operated heavy-duty trucks. The model solves two problems: the location of fueling stations (electric and hydrogen) and the transport of soybean seeds in a country producing around 50 million tons per year. A multi-objective and multi-period (ten years) linear integer mixed model is proposed to minimize the investment cost of new fueling stations, the transportation cost of soybean shipments, and the amount of GHG emissions.

3 - The inventory routing problem of marketing fattened pigs to the abattoir
Lluís Miquel Plà-Aragonès, *Angel A. Juan*, *Javier Panadero*

Traditionally, knowledge based on experience has been the root of farm-level decision-making, but the increasing complexity of the pork industry requires the development of more formal planning methods. Nowadays, pigs are raised in large industrial-scale operations. The fattening process operates under an all-in-all-out management policy. In general, the fattening period depends on the starting weight, batch homogeneity, feeding system, growth curve, reward system and chain management policies. Although pigs are fed with the same diet, not all of them reach market weight at the same time. Hence, partial sales produce better economic rewards. Once the old batch leaves, and before the new batch arrives, the facilities are cleaned and sanitized. The viewpoint of an abattoir collecting fattened pig from many different farms belonging to the same pig supply chain (PSC) has not yet been considered. Farms vertically integrated sell their entire production to a single abattoir in agreement with the supplier contract signed with the integrator company in a long-term relationship. The routes to collect pigs and the arrival to the abattoir need to be balanced over time and scheduled beforehand with uncertainty in pigs' liveweight to avoid workload peaks and a fair operation for the PSC. This model falls into a multi-period inventory routing problem (IRP) with uncertain demand since the deliveries depend on the inventory of pigs on fattening farms and pigs live weight. Thus, the objective of this paper is to formulate a mixed-integer linear-programming (MILP) model to optimize daily routes of trucks and transports of fattened pigs to the abattoir. Given the complexity of the problem and the need to get good-enough solutions in seconds, a simheuristic algorithm is proposed to approximate the solution of the model and to efficiently plan transportation with robust routes, facing unforeseen contingencies.

Sustainable Agriculture

Cluster: Agricultural Innovations and OR
Invited session
Chair: *Tiare Torres*

1 - Sustainable feed production optimization
Adela Pages Bernaus, *Lluís Miquel Plà-Aragonès*, *Virna Ortiz-araya*

The emissions from the farm gate part within the agri-food system accounted for a total of 7.2 billion tonnes of Green House Gas in 2019, according to FAOSTAT. With the aim to reduce the environmental impact, we have analysed the feed production part - the preparation of food diets for animals have been traditionally elaborated from an economic perspective. While economics is always a key metric, in this work, we explore alternative diets with lower environmental impact.

We focus on how to formulate feed for pig meat production reducing the final environmental impact, taking into consideration the impacts generated from the production of raw ingredients, continuing with the production process and the resulting effects of the diet composition. The main environmental impact related to pig growth is the excessive excretion of phosphorous and nitrogen. Intensive pollution can happen when an imbalance of the contents of proteins is present in the feed; we model the protein balance from an ideal protein profile approach.

The traditional diet formulation minimizes the purchase cost of the combination of ingredients ensuring nutritional requirements are met. In this work we, extend the traditional multi-diet problem to account for several aspects, bringing closer the solution to the periodic task of veterinaries and nutritionists. The main characteristics are: a) reduction of the expected excretion of nitrogen and phosphorous, by reducing the protein imbalance, ensuring the final diet manages to meet the ideal protein profile; b) raw ingredients purchased at different locations, with different prices and associated transport emissions, c) different energy consumption for grinding the grains, and d) life-cycle CO2 emissions, accounted for each ingredient.

This problem is modelled as a bi-objective programming problem, since economic and emissions perspectives are two conflicting objectives. The model is implemented in Pyomo and tested for a Spanish middle-sized enterprise test case. The model and its results, together with the main insights, will be presented. The data gathering and the results output represent a large set of data, organized under a decision support system to facilitate the understanding of the results for a final user.

2 - Greening The Fields: A Novel Model to Guide Sustainable Agriculture
Vitaliano Fiorillo, *Maria Trindade*, *Vincenzo Tabaglio*, *Andrea Fiorini*

This study proposes a novel model, to calculate utilization, efficiency, and quality of soil in agroecosystems, while considering the additional provision of ecosystem services (Costanza, 2020). The model provides farmers, practitioners, and managers with a method for optimizing their operations, in the light of Sustainable Development Goals of FAO (FAO, 2011; FAO et al., 2022) and Farm-to-Fork strategy by EU (EC, 2020). The model was tested using a sample of data collected between 2011 and 2022. The proposed method offers a more comprehensive assessment of the potential of sustainable agriculture in comparison to what farmers can discern with traditional methods as OEE, typically used for industrial production. By integrating suitable agronomic metrics in the OEE, results show regenerative agriculture can bring significant improvements in the overall efficiency. Utilization, as measured by field utilization, reveals sustainable practices make a better use of fields in the available time, up to 36% more. Efficiency, as measured by yield, carbon sequestration, N-synthetic fertilizer replacement, and biodiversity, demonstrates regenerative agriculture outperforms traditional agriculture by up to 66%. Quality, as evaluated in terms of yield conformity, carbon sequestration conformity, N-synthetic fertilizer replacement conformity, and biodiversity conformity, highlights sustainable agriculture shows up to 58% higher performance in conformance metrics, respectively, with FAO and Farm-to-Fork targets. Thus, the overall field effectiveness can be up to 56% higher in sustainable agriculture. The time-series analysis of the results reveals regenerative practices yield better outcomes, starting from the second year of application. The proposed model offers a useful tool for evaluating agriculture practices, supporting the transition to more sustainable and resilient food systems. The study's findings underscore the critical importance of an interdisciplinary approach (agroecological and economic) to strike a balance between short-term gains and long-term sustainability perspectives in agricultural operations and supply chains. References Costanza, R. (2020). Valuing natural capital and ecosystem services toward the goals of efficiency, fairness, and sustainability. Ecosystem Services, 43, 101096. EC (2020) Farm to Fork Strategy. European Commission.

3 - Prospects for data analytics in dairy farming
Osvaldo Palma, *Lluís Miquel Plà-Aragonès*, *Alejandro Mac Cawley*, *Victor M. Albornoz*

The strong growth of world population will cause a major increase in demand for cow's milk, forcing the efficient use of various technologies to increase milk production. Data analytics can contribute to solving part of this challenge, thanks to recent developments in fields such as artificial intelligence, big data, IoT and sensor development. A scoping review is carried out to identify the main research topics and future trends in dairy farming resulting in 96 articles of interest. Artificial neural networks and convolutional neural networks are the most

promising methods for predicting milk production; conversely, simulation tools are scarcely used. Future research may benefit from the synergies generated by the combination of artificial neural networks and simulation methods to produce intelligent decision support systems.

4 - An optimization-based approach for the sensor location problem in precision agriculture
Tiare Torres, *Victor M. Albornoz*, *Rodrigo Ortega*

Precision agriculture is a discipline aiming to increase efficiency, yield and productivity and, simultaneously, to reduce the environmental impacts of usual agronomic practices in the agricultural industry, due to the use of technology and data analysis; data collection is the basis of all subsequent studies. In this field, satellite images, drones, and fixed sensors on the ground are primarily used, each recording different data of interest. Specifically, there is a wide variety of sensors, each with specific characteristics and an extensive price range. Due to the benefits use of the mentioned technologies bring, many farmers decide to implement them, but due to the costs, they can only have access to a limited number of devices and then can interpolate the information obtained to the whole extension of the farm. For this reason, it is interesting to determine where to locate a limited number of sensors, increasing the representativeness of the sample and, consequently, the reliability of the interpolation. In this study, we will develop an optimization-based strategy considering a discrete location model and a zoning model, widely studied in precision agriculture. The input data assumes a set of sample points of some soil properties, then, using a zoning model, a homogeneous partition of the field will be obtained. The resulting zones and their properties will be used as parameters for the p-median location model. With the implementation of the described problem, we can find the optimal location of a given number of sensors, to obtain data at specific points, and, by interpolating the information obtained, reliable data about new or future soil properties can be obtained. In the proposed approach, the maximum number of sensors to be installed for obtaining an efficient sampling will be equal to the number of zones obtained through the zoning problem, since, being homogeneous, it is enough to install one sensor to obtain more data of the complete management zone. On the other hand, the minimum amount to install could be one sensor, the implication for the application of our strategy in this case will be discussed in this study, because interpolation through a data sample of just one sensor is not representative. The proposed models are solved using an integer programming solver, and computational results from a set of instances are presented to show the impact of the adopted methodology.

Data Analytics in Agrifood Supply Chains

Cluster: Agrifood Supply Chains
Invited session
Chair: *Xaimarie Hernandez Cruz*

1 - Method based on machine learning for forecasting price volatility: case study of cherry price forecast
Myriam Gaete, *Marcela C. Gonzalez-Araya*

The price of products in foreign markets is relevant information for exporters, allowing them better negotiations with customers and producers, but these prices are characterized by high volatility and dependence on external factors, such as exchange rates and tax rates. This volatility produces uncertainty and increases market risk; to estimate price volatility would allow us to make a good price forecast. In this study, a three-step method for forecasting price volatility is proposed. In the first step, characteristic factors of a volatility time series are analyzed and selected using regulation techniques. In the second step, the volatility time series is decomposed applying seasonal and trend time series decomposition (STL). The obtained time series are used for training and testing a neural network to forecast price volatility. The proposed method is applied in a case study for estimating cherry prices in different markets for a harvest season.

2 - Incorporating Market Intelligence to Fresh Produce Supply Chains
Xaimarie Hernandez Cruz, *J. Rene Villalobos*, *George Runger*

In recent years, the occurrence of natural hazards, diet trends, and the COVID-19 pandemic have highlighted challenges in traditional fresh fruit and vegetable supply chains. Several factors have contributed to these challenges, such as little to no coordination among farmers, the absence of planning tools for agricultural production, and the lack of market data to determine produce demand.

In this work, we discuss the challenges related to the absence of adequate market information and unveil a set of tools, including market intelligence in the planning of fresh fruits and vegetables supply chains - to decrease food waste, reduce losses related to low market prices and demands, avoid scarcity events when food availability and affordability decrease, and aid small growers by alerting them of potential market opportunities. To this end, a layered system methodology is adopted to develop the proposed market intelligence framework.

The proposed framework decomposes the overall problem into several layers with distinct goals, such as data collection, processing, monitoring, diagnostics and forecasting. With the use of these layers, the market intelligence framework uses traditional and non-traditional market data to identify signals via monitoring techniques and to diagnose them.

Furthermore, the proposed layer system uses forecasting models to obtain predictions of future market prices, under normal or disruptive market conditions. The identified alerts are provided to supply chain participants as a set of recommendations, including the most promising crops in the future in terms of their price and demand. During the presentation, we will present case studies to illustrate the proposed techniques.

3 - Scenario-based operational planning of harvesting and first-mile logistics for small fresh produce growers
Nicolas Eduardo Palacios, *Felipe González-Cousiño*, *Rosa G. González-Ramírez*, *J. Rene Villalobos*

This work proposes an optimization model to support the operational planning of harvest and first-mile routing decisions, using a monolithic and scenario-based approach focused on small farmers. This agricultural sector faces various challenges, particularly expensive logistics for distributing their products and facing several limitations and uncertainties. We address an operational planning decision problem, considering multiple small farmers who can be coordinated by a supply chain articulator planning the consolidation of their products in shared vehicles and in a collaborative routing scheme to reduce logistics costs, analyzing various scenarios of factors considerably impacting operations, mainly harvest yields and available labor in the area. Majluf et al. (2021) addressed this problem based on the operational planning model Ahumada and Villalobos (2011) designed, considering a single producer. Consequently, Majluf et al. (2021) extended the model to consider multiple small farmers who coordinate with each other and consolidate their products, using a two-stage hierarchical approach. This paper extends the model to consider a set of scenarios to determine harvest decisions (when and how much will be harvested in each period of a planning horizon, given each scenario) and routing decisions related to the consolidation of products to a packing facility, in an integrated approach. The integrated planning of harvesting and routing consolidation schemes can improve the expected value of economic benefits for small growers, and the scenario-based approach can significantly improve decision-making in harvest and routing planning, since cost overruns can be managed (for example, in the case of a scenario of low harvest yield or labor shortage) or requirements for factors of production (in the case of high yield, a greater number of transport units and available labor) are required. Lastly, for comparison purposes, the results are contrasted with a direct shipment strategy and under a deterministic approach, where the managerial implications and the differences in the economic benefits derived for small producers are analyzed. References: DOI: 10.1007/978-3-030-76310-7_17 DOI: 10.1016/j.ijpe.2011.05.015

Planning Tools for Fresh Vegetable Supply Chains

Cluster: Agrifood Supply Chains
Invited session
Chair: *Omar Ahumada*

1 - Coordinating Coalitions of Complimentary Growers for Two-Sided Negotiation of Contracts
Miguel Peinado-Guerrero

This research supports development of a decision-support platform called TERRa-Fresh, to connect growers of fresh produce to attractive market opportunities. The platform utilizes advanced analytics tools, including optimization and machine learning models, to identify disruptive events and estimate their impact on future market demand and price. One key aspect of the TERRa-Fresh platform is coordination and negotiation between a set of small growers and a buyer, resulting in a contractual agreement - the focus of this research.

Small growers often have limited access to contracts, as buyers prefer larger growers who can provide required volumes. To address this challenge, we propose a framework for horizontal cooperation among small growers. Within this context, a supply chain articulator is introduced to facilitate coordination among a coalition of growers and to represent their collective interests during negotiations with a buyer. The supply chain articulator identifies and communicates market opportunities to the coalition, while the buyer purchases the produce.

The introduction of the figure of supply chain articulator allows the aggregation of resources from the growers while acting as a single, larger entity with enhanced negotiation power. Forming efficient coalitions is a complex problem, however, that must consider various factors, such as fairness of allocated tasks, risk tolerance, individual rationality, and revenue distribution. These factors influence the contract definition a coalition would accept and to which a buyer would agree. TERRa-Fresh proposes the development of tools to automate the process of contract building; it relies on traditional cooperative game theory frameworks to build optimal coalitions and on a mathematical programming framework for negotiation. This coordination and negotiation helps ensure small growers can participate in the market and benefit from emerging opportunities, while also meeting the needs of the buyer for product availability and affordability.

2 - Probabilistic model for assessing the effects of disruptive events on the viability of the agri-food supply chains: The case of Lithuania
Tomas Balezentis, *Dalia Streimikiene*, *Artiom Volkov*, *Mangirdas Morkunas*, *Erika Ribasauskiene*, *Vida Dabkiene*, *Agne Zickiene*

The recent outbreak of COVID-19 caused multiple disruptions of supply chains across the globe, through various channels; an integrated approach is needed to contain these challenges in the future. This paper develops an expert-based approach to assess the risk of facing a decline in the viability of a supply-chain, involving multiple stages and disruptive events. A Monte Carlo simulation is used to impute the unknown weight information, when constructing the composite indicators describing the change in viability due to a certain disruptive event; resulting distributions are then used to derive the measures of risk. The proposed approach is applied to the case of Lithuania, where experts assessed the effects of two recent disruptive events, namely the COVID-19 pandemic and the war in Ukraine. The different stages of the supply chain may face different effects; policy-makers may adjust support policies to address the most critical issues, accordingly.

3 - New Scheduling Model from Planting to Packing, using Water and Labor Requirements
Omar Ahumada

We present a planning model for fresh produce using a mix-integer program to give growing and scheduling recommendations for small growers, with the objective of maximizing profits for individuals or groups of growers while considering the benefits of crop rotation throughout the year. The model also considers price, yield distribution, labor cost, labor availability, and product decay. The results indicate changes in product mix to account for labor requirements and environmental services. High-value crops offer small growers better opportunities for sustainability, but also require large investments in technology, facilities, food safety, and labor, while subject to highly variable crop yields and market prices - thus making planning tools, like the ones presented in this research, a necessity for their long-term survival and profitability.

4 - Improved Logistics for Small Farmers of Fresh Fruits and Vegetables
J. Rene Villalobos, *Patrick Phelan*, *Hector Flores*

The existing infrastructure and logistics practices for fresh food sourcing and distribution should be re-conceived to adapt to dynamic micro consumption patterns and emerging technologies; during the COVID-19 pandemic, major supply chain disruptions of fresh fruits and vegetables (FFV) occurred. The problems experienced during the pandemic made clear most preexisting food supply chains were not ready to adjust to sudden demand shifts, particularly during the first mile of the supply chain. Many of these problems come from the reliance on push-based production, inventory and transportation strategies geared towards large-volume logistics and market demand. These prevalent supply chain strategies run contrary to emerging trends geared toward newer direct-to-consumer marketing strategies. Thus, the question becomes how technologies and logistics assets can be repurposed to handle smaller transportation units to address newer direct-to-consumer marketing strategies. It is time to revisit previously proposed concepts (e.g. the physical internet), unsuccessful because the right technological conditions did not exist when they were proposed. In this presentation, we introduce an approach focused on fully automated logistics infrastructure, such as autonomous freight vehicles, storage, and material handling systems, to incentivize small grower participation in fresh produce markets. Fully automated logistics networks would efficiently connect points of production to points of consumption through conditioned, sealed devices, holding small amounts of fresh produce.

Planning Tools for Fresh Fruit Supply Chains

Cluster: Agrifood Supply Chains
Invited session
Chair: *Nicolás Reyes*

1 - Comparing GRASP and a hybrid metaheuristic for scheduling cold chambers' opening and transportation in a fruit supply chain context
Nicolás Reyes, *Marcela C. Gonzalez-Araya*, *Wladimir E. Soto-Silva*, *Lluís Miquel Plà-Aragonès*

In the fruit supply chain (FSC), the management of cold chambers is relevant for controlling the physiological characteristics of the fruit, having a direct impact on its quality. Moreover, the plants are required to guarantee the fruit supply over a whole processing season, even when the fruit harvest season is over. In this way, most of the fruit export companies manage several cold chambers, with different refrigeration technologies, aiming to add to the supply. These cold chambers are not necessarily located near the processing plants. Once the fresh fruit is stored, the company managers need to define the fruit supply plan to the processing plants; they must decide the cold chambers to be opened along the processing season. For supporting these decisions, in this study, a multi-period mixed integer linear programming (MILP) model is proposed, determining a schedule for opening the cold chambers and for the fruit transport to the processing plants. The MILP model is solved by using two metaheuristics - Greedy Randomized Adaptive Search Procedure (GRASP) and a hybrid method, partially inspired by GRASP. Using GRASP, the integer variables of

the MILP model are calculated, and, then, the continuous variables are estimated using CPLEX. Therefore, CPLEX solves a linear programming model, corresponding to the original model without the integer variables and their related constraints. The developed metaheuristics are applied to 36 instances based on a real case study belonging to a Chilean fruit company. For these instances, the exact method (CPLEX) demands high computational time to find a good solution. GRASP found good opening cold chambers' schedule with gaps below 5%. On the other hand, the hybrid metaheuristic found optimal solutions with gaps lower than 2%, most of the time. In addition, the computational time for solving the biggest instance was reasonable (around six minutes for GRASP and eight minutes for the hybrid method). Therefore, the hybrid method is a more interesting approach than GRASP because, besides obtaining better solutions, the computational time does not increase in an exponential way.

2 - A Comparison of Multi-Objective a Posteriori Exact Methods for Planning the Tactical Fruit Harvest of Several Orchards

Marcela C. Gonzalez-Araya, *Javier Gómez Lagos*, *Luis Acosta*, *Wladimir E. Soto-Silva*

Because of the expected increase of food demand, it will be necessary to improve the coordination of the fruit supply chain (FSC), where one of the first stages is harvest. In this stage, the decisions are usually complex, because most of the fruit export companies manage several orchards with different species and varieties. In this study, a multi-objective linear programming model (MOLP) for supporting tactical fruit harvest planning decisions is developed, aiming to identify different harvest plans according to optimized objectives. The proposed MOLP model considers three conflicting objectives: the minimization of harvest costs, fruit loss and harvest days. The MOLP model is solved by using five 'a posteriori' multi-objective exact methods; the performance of each one is evaluated using cardinality, accuracy, and diversity metrics, and the method with the best performance is selected. Thus, the weighting method with normalization is selected, because it presents the best performance in the diversity and cardinality metrics; the weighting method shows the best performance in the accuracy metric, followed by the weighting method with normalization. Therefore, the weighting method with normalization and the ϵ-constraint method are used for solving a real case study; the ϵ-constraint method is used to improve the search of non-dominated solutions in the non-convex space of a Pareto frontier. The harvest plan varies significantly according to each objective prioritization.

3 - Analysis of Multi-objective Metaheuristics based on GRASP with Path Relinking for Planning Major Fruit Tactical Harvest

Javier Gómez Lagos, *Marcela C. Gonzalez-Araya*, *Luis Acosta*, *Wladimir E. Soto-Silva*

The tactical harvest planning for major fruits corresponds to an important decision made in the first stage of the fruit supply chain, involving establishing the required resources as labor, machinery, and bins. This is a complex decision because many major fruit species and varieties, with different ripening seasons, planted in many orchards, need to be harvested in a whole season. In this way, an optimized harvest planning could reduce costs, fruit losses, and the number of days for carrying out the harvest. These objectives are in conflict, however, because when one of them achieves its minimum, the other objectives worsen. Therefore, in this study, a multi-objective model for supporting tactical harvest planning of major fruit species is developed and multi-objective metaheuristics based on greedy randomized adapt search procedure (GRASP) with path relinking are proposed for solving it. The proposed metaheuristics include a method for eliminating non-dominated solutions, while the diversity of the Pareto frontier is maintained. The analyzed metaheuristics differ in the way the objective functions are considered for obtaining a feasible solution. Thus, two strategies are compared: sequential and weighted. A real Chilean case study of six orchards, having kiwi, pear, apple, and table grape trees, is used to evaluate the performance of these strategies. The non-dominated solutions obtained by the metaheuristics are compared with those obtained by an exact method, the weighted method with normalization. The performance comparison is carried out using data envelopment analysis and a meta frontier approach. Preliminary results show a weighted strategy has the best performance between the GRASP with path relinking metaheuristics.

Modelling Approaches in Agrifood Supply Chains

Cluster: Agrifood Supply Chains
Invited session
Chair: *Edgar Gutierrez-Franco*

1 - Analysis and Modelling of Food Supply Chain Resilience Challenges in Agriculture to Better Support Decision Making under Uncertainty

Jorge Hernandez, *Gabriela Sepulcri*, *Sachin Kumar Mangla*

The 21st century has effectuated a rising growth in both uncertainty and complexity aspects across food production and distribution networks. In fact, the concept of resilience in Agri-food supply chains has been established in literature as being an extremely important subject to be strengthened to meet the increasing demand of food consumption in an ever-growing global populace surrounded by prevailing supply chain volatility and uncertainties from exogenous disruptions. Thus, ever changing practices have been introduced and adapted to build, support and maintain resiliency across the agricultural ecosystem, so the food supply chain can continue to function even when challenged with unexpected crises, in addition to providing long-term relief and sustainability to those dependent on the system's end products. Based on the outcomes from the successful H2020 RUC-APS project, a systematic approach to identifying factors which are profoundly influential on the resiliency of food supply chains are presented in this paper. By employing the use of both a forward stepwise regression implementation and a Multi-Criteria Decision-Making application, a data analytics decision-based analysis to agri-food supply chains for a focused understanding of the elements of resilience across horticultural stakeholders from the UK, Argentina and Nigeria is considered. The core of this research is based on five identified dimensions of resilience. First, the Financial facet, concerned with food system income, taxation and subsidies; second, the assortment of Agri-Food procedures, which deal with aspects of social responsibility, environmental practices, new land management techniques and the generation of productive assets; third, the Human Resource factors, which pertain to fair working conditions and the inclusion of women in roles throughout food supply chains; fourth, the criteria associated with the concept of Marketing, with respect to tariff barriers and both formal and informal co-operation agreements; and last, the capacity of food supply chains to examine and implement External Factors, such as the management of waste and the willingness of supply chains to adapt to new innovations and initiatives. Collectively, the outcomes of this research help stakeholders to rethink their existing business practices and to adopt new technologies to become more efficient and productive in the agri-food industry from a practical point of view.

2 - Balancing Profit and Sustainability in Agribusiness: An Analytical Model for Network Design

Edgar Gutierrez-Franco, *Luz Helena Mancera*, *Alfonso T. Sarmiento*, *Christopher Mejia-Argueta*, *Luis Rabelo*

Recent technological advancements have diversified how natural resources are utilized as raw materials for manufacturing, consumed as food by humans and animals, and converted into biomass for biofuel production. As a result, competition for these products has intensified, creating a need to prioritize sustainable practices. The rule of not harvesting more than what the forest can regenerate is the foundation of sustainability and critical strategic and tactical decisions. Therefore, land allocation, sowing, harvesting schedules, production plant locations, distribution network design, and product mix are key components of a profitable and sustainable business. This research presents a case study of the palm oil industry to illustrate the interconnected nature of these decisions in a multi-echelon, agro-industrial supply chain.

A two-stage stochastic mixed integer linear programming model is proposed to identify the most efficient network design. We minimized overall supply chain costs while considering uncertainty in various scenarios associated with biofuel and regular oil demand. This flexible analytical model allows central planners, policy-makers, and agribusiness corporations to make informed decisions based on supply chain conditions. Additionally, this model could be adapted to evaluate other natural resources for biofuel production, where concurrent decisions regarding cropland, production, and strategic network design must be made. The model yields a result of 81 joint scenarios. The scenarios consider a blend of 5% to 30% of biodiesel with regular diesel. To supply this demand, the cultivated area should increase by 261% during the planning periods. According to the results, 39.7% of total hectares should be in the eastern zone, 30.3% in the central zone, 23.8% in the northern zone, and 6.2% in the western zone in the country where this research is applied. The Eastern region presents the largest cultivated area due to cultivation and production costs. Twelve biorefineries were selected among the possibilities in the network design during the planning horizon, and all transportation and production costs were minimized. A total of 22 million tons of palm oil were produced during the entire planning period - 28.8% of which was allocated to satisfy the demand of the traditional market, 0.1% for exports, and the remaining 71.1% to produce biodiesel.

3 - Optimization of the food distribution process using the goal programming technique
Daniela Cantane, *Letícia Godoi*, *Flávia Aranha*

The food distribution process performed by the Food Banks is a process that must be carefully evaluated and analyzed, since its objective is to assist people who are in a situation of food insecurity. The Brazilian Food Banks represent structures responsible for collecting food from donations and then distributing this food to charities that serve families or directly the community by preparing meals. There are two operational types of Brazilian Food Banks, the conventional one has a physical infrastructure for the allocation of donated food, as well as the selection. The other operational type is the urban/rural gather, and the Food Bank vehicle collects the donations and immediately delivers them to the charities. In both operational types, there is selecting and separating process of food, then it can be delivered according to the demand of each location. This process ought to be done with equity, which represents the quality of being fair and impartial, since the amount of food available for distribution may not be sufficient to cover all the demands from the community. However, there are scenarios that indicate that prioritizing the assistance of certain charities can be useful, since they serve families from poorer regions that have no other source of food but the ones coming from Food Banks. In terms of mathematical modeling and process optimization, there are several approaches that can be applied to formulate the problem, one of them is the Goal Programming technique, widely used in multiobjective optimization problems. This technique proposes the determination of goals for each objective of the problem, and then the minimization is done from the deviations of these pre-established goals. Motivated by the challenge of improving the efficiency of the food distribution process performed by Brazilian Food Banks, this paper proposes an optimization model applied to this process and also performs an analysis of the results found. For this purpose, data based on the reality of the Brazilian Food Banks were used, and the results indicate that the model is efficient when the search is for an equitable distribution but also when the objective is a distribution with a certain prioritization in attending certain charities.

Panel: Addressing Strategic Problems in Fresh Food Supply Chains

Cluster: Agrifood Supply Chains
Invited session
Chair: *J. Rene Villalobos*
Chair: *Marcela C. Gonzalez-Araya*

1 - Panel
J. Rene Villalobos

Data Science and Optimization for Prescriptive Analytics

Cluster: Analytics and Data Science
Invited session
Chair: *Luis Aburto*

1 - Machine Learning To Detect Feasibility in Vehicle Routing Problem
Rodrigo Morán, *Luis Aburto*, *Felipe Lago*, *Víctor Gonzalez*

Evaluating routing instance feasibility, a determining factor to solve VRP's, directly affects the time and quality of the solution for routing planners; it is critical if routing instances are big enough for the heuristics and the instances have definition problems in the data. The feasible region of a routing instance is determined by the parameters of the instance - depending on the case, the geographical distribution of the points, the requested demand and time windows to be fulfilled. This research uses machine learning to predict the feasibility of routing instances for SimpliRoute, a routing SaaS company; best models obtain an accuracy above 90% using variables describing the topology of the VRP instances. In addition, this research predicts not only the instance feasibility, but the possible causes influencing the unfeasible solution in terms of the nature of the constraints, such as service times, time windows and capacity constraints.

2 - Comparison of Machine Learning methods and Bayesian Hierarchical Model for estimation of elasticities and price optimization
Xavier Zuazagoitía, *Luis Aburto*, *Marcel Goic*

Product demand modeling is typically solved using a Hierarchical Bayesian modeling (HBM), based on information pooling across stores and impositing prior information to parameters. With this model, we estimate product demand elasticities of a multiproduct category to optimize prices and to maximize category performance. We compare this approach with black box models used in machine learning literature, such as Regression Trees, Random Forest and XGBoost. We evaluate and compare predictive capabilities in out of sample demand dataset, as well as economic sense of elasticity parameters extracted with the models. We evaluate the tuna can category with 12 SKU's in 28 different stores across the country. HBM obtained a better prediction in the test group, with an MAPE of 73.03%, compared with 84.27% for XGBoost, the best machine learning approach. Also, HBM obtains a better elasticities estimation related with economic intuition. In addition, implementing the optimization model, an increase of 34.13% of the projected sale was obtained by setting the recommended prices, versus expected sales with actual prices.

3 - Using Quantile Forest for Prescriptive Scheduling of Astronomic Image Processing
Luis Aburto, *Rodrigo A. Carrasco*, *Alfredo Manuel De Rodt Sanchez*, *Gianfranco Speroni*

This project recommends job scheduling to minimize the total flow time to process astronomic images at the ALMA observatory. The methodology proposed has two significant steps - first, machine learning models are calibrated to get precise estimations of processing times, and second, a MIP optimization model is applied to minimize the total flow time. The machine learning models estimate not only the expected processing time for each job, but also precise information about the confidence intervals or uncertainty of the prediction. We rely on a method called Quantile Forest to obtain interquartile distance as a measure of uncertainty of the predicted processing time, and we use the expected value and confidence intervals of the processing times as parameters for the MIP optimization problem to minimize total flow time. We compare the flowtime solutions obtained with the oracle flow

time obtained based on real processing times. Preliminary results reduced the average gap by 4% and 5%, improving the scheduling solution compared with the optimization model based only on expected values. Further results are related to finding out the scheduling instances where this gap is reduced.

4 - Creating pricing rules using a Support Vector approach for robust optimization
Ignacio Sanchez, *Luis Aburto*

The multi-product price optimization problem has been addressed through different econometric approaches based on own and cross price elasticities. By using these models in an optimization framework, it often attains extreme and unreliable solutions for the business, a problem known in the literature as optimization bias. The goal of this project is to use Support Vector Machines (SVM) to estimate hyperplanes or rules in space price attributes, to be used as constraints in the price optimization problem. These rules are defined as the hyperplanes separating the price space where better-than-average sell/profit scenarios are observed. When evaluating the method on different categories, robust solutions were obtained, reducing price optimization from divergent results up to 19% of sales increasing, using the created rules. These results not only allow more robust solutions, but also provide important insights regarding the expected sale when there are certain price scenarios between the products of the category.

Reinforcement Learning

Cluster: Analytics and Data Science
Invited session
Chair: *Sebastian Santana*
Chair: *Giorgiogiulio Parra*

1 - Automation of a comminution plant through memory-based deep reinforcement learning
Sebastian Santana

The integration of reinforcement learning and deep neural networks comes from decades ago, and thanks to this integration we have been witnessing breakthroughs in recent years. In this work, we study the application of deep reinforcement learning algorithms to a problem of optimal control. Based on real data, we simulate the operation of a comminution plant in the north of Chile and evaluate the performance of many different algorithms.

A good performance can be obtained only if memory, in the form of LSTM neural networks, is considered in the formulation of the problem; otherwise, the performance cannot beat a traditional controller. Even in time-discrete scenarios, the performance of the plant can be improved by at least 28%.

2 - Reinforcement Learning Applied to Dynamic Clustering
Ignacio Carvajal, *Richard Weber*

Clustering is a key technique in pattern recognition, data mining, and knowledge discovery; the goal is to discover the hidden structure underlying a given collection of objects. In addition, there are many situations where special treatment is required; one of the most important aspects to consider is dynamism, and, because of its importance, there is continuous research work on new methodologies to improve the available ones. The ability to predict changes in the underlying data structure, such as forecasting customer segmentation, is an open problem in dynamic clustering; in this paper, we address this problem in the cases where the samples in each period distribute Gaussian mixtures using a distribution prediction approach, the process of predicting the likelihood of different outcomes based on a set of known conditions. It is commonly used in business to forecast future sales, customer demand, and inventory levels. When we talk about multi-modal data, however, distribution prediction and dynamic clustering become closer since we are studying the data structure changes over time. This paper explores the use of Multi-Agent Deep Deterministic Policy Gradients (MADDPG) and Gaussian Mixture Model (GMM) for dynamic clustering using a multi-modal distribution prediction approach. Gaussian Mixture Model is a clustering algorithm used to represent a mixture of probability distributions. In this work, GMM clusters (components) are seen as agents in a Partially-observable Markov game where the agents output the variation of each parameter between periods. The agents are trained using MADDPG, an extension of the DDPG algorithm for multi-agent environments, enabling agents to learn decentralized policies coordinating with each other. During the training process, each agent can observe the states and actions of all agents and use this information to learn a centralized critic estimating the value of the joint action taken by all agents. In the execution process, each agent only has access to its own local observations and must use its learned policy to select actions. The main objective of this work is to predict the GMM parameters of the next period using information from the current period. Each critic sees the parameters of some past periods and the action of each agent to guide the agents to optimize the log-likelihood obtained with the predicted parameters clustering the data in the next period.

3 - A reinforcement learning approach to design fire-resistant forest landscapes
Tatiana Andrea Castillo Jaimes, *Jaime Carrasco*, *Andrés Weintraub*, *Lucas Murray*

Climate change has made a significant impact on terrestrial ecosystems, an example being forest fires. These have increased in the amount of area burned and their intensity globally, and wildfire suppression costs have risen significantly as a result. Various landscape treatments (e.g. burning, thinning, pruning, chipping, and mechanically removing vegetation) have been implemented in the past decade to prevent and mitigate these events. Determining the most effective allocation of these forest fuel management treatments is a challenging task, however, due to the complex nature of the phenomenon, resulting in modeling and dimensionality curses, making it difficult to solve the problem. To address this challenge, this investigation proposes the use of artificial intelligence algorithms to locate firebreaks as a treatment for forest fuel management in landscapes, to mitigate the impact of wildfires. We utilize Reinforcement Learning algorithms and Neural Networks to provide a novel tool for decision-making. The proposed approach overcomes the limitations of previous techniques, such as heuristics, graphs, and stochastic optimization, by employing algorithms combining policy gradients and value functions, such as actor-critic algorithms, convolutional neural networks, and a creative decomposition of actions into steps to solve dimensional complexity problems. The agent can learn optimal or really good policies in small landscapes, but its learning is sensitive to the reward function, the number of available actions, and the hyperparameters of the algorithm used. These first results suggest significant potential for using intelligent agents to solve operations research tasks, particularly in frameworks similar to wildfire mitigation.

Advancements of OR-Analytics in Statistics, Machine Learning and Data Science 1

Cluster: Analytics and Data Science
Invited session
Chair: *Gerhard-Wilhelm Weber*

1 - Semi-supervised clustering via nonsmooth optimization
Sona Taheri

In this talk, a new model for semi-supervised clustering with pairwise constraints is presented, where the objective function is expressed as a sum of three terms: the first term reflects the clustering error for unlabelled data points, the second term expresses the error for data points with Must-Link constraints, and the third term represents the error for

data points with Cannot-Link constraints. This function is nonconvex and nonsmooth, and, to find its optimal solutions, an adaptive semi-supervised clustering algorithm is developed. The algorithm is based on the combination of the nonsmooth optimization method and an incremental approach involving the auxiliary problem. The algorithm constructs clusters incrementally starting from one cluster and gradually adding one cluster centre at each iteration. The solutions to the auxiliary problem are utilized as starting points for solving the nonconvex semi-supervised clustering problem. The discrete gradient method is applied to solve the underlying optimization problems. The performance of the semi-supervised clustering algorithm is demonstrated, using some synthetic and twelve real-world data sets.

2 - Optimization models and algorithms for finding compact and separable clusters
Adil Bagirov, *Sona Taheri*

Finding compact and well-separated clusters in data sets is a challenging task; most clustering algorithms minimize certain clustering objective functions, usually reflecting intra-cluster similarity and inter-cluster dissimilarity. The use of the functions alone, however, may not lead to the finding of well-separated and, in some cases, compact clusters. In this talk, we discuss optimization models for clustering, where objective functions are represented as a sum of two terms each reflecting compactness and separability of clusters; we design algorithms based on these models. The performance of these algorithms is evaluated using synthetic and real-world data sets and compared with several other clustering algorithms. The use of new models allows us to compute compact clusters, significantly better in comparison with those obtained by other algorithms.

3 - Machine learning and functional networks brain analysis with a low-cost EEG: Applying on training complex skills.
Guadalupe Pascal, *Julián E. Tornillo*, *Andrés Redchuk*

Brain-computer interfaces (BCIs) provide an alternative mode of human-computer interaction by capturing brain activity signals, such as electroencephalography (EEG), and converting them into output commands. In particular, medical diagnosis is the main applied field of EEG technology, mainly due to the high costs associated with expensive, high-quality equipment, limiting this technology. Recent advances in portable EEG devices have made these systems more accessible to end users, however, and have broadened their potential applications for non-clinical citations.

By now, the recent cognitive neuroscience evidence establishes there are advantages and disadvantages of using portable sensors and open-source software to build BCI systems at low cost. Despite challenges, such as unstable communication between the computer and the portable sensors, or the impact of environmental noise on the quality of the obtained signals, a robust filter bank-based methodology can achieve classification performance, comparable to clinical-grade devices.

This study applies portable EEG technology to analyze brain activity during memory and learning processes in complex cognitive abilities; it achieved a multisubject experimental design. Experimental electroencephalographic data were acquired using an Emotiv EPOC+ headset. The methodology involved using signal processing techniques and brain connectivity analysis, such as Butterworth filter application, adjacency matrix, graph theory, and machine learning, to classify cognitive states. Finally, a cross-validation approach and ROC analysis will evaluate the methodology's performance and classification task accuracy.

The results of this study provide valuable information to contribute to the use of wearable EEG devices to improve the technology in terms of usability, promoting large-scale research and experimental studies in previously unexplored situations.

4 - Using Shapley value-based estimation to explain the robustness curves for machine learning classifiers
Sajid Siraj, *Guilherme Pelegrina*

Most of the high-performing machine learning algorithms are too complex to be explained to decision-makers, and, therefore, there is growing research on how we can explain the predicted outcomes of these algorithms. While there is a focus on explaining the prediction itself, little has been done on explaining the robustness of these models. We propose the use of Shapley values to explain the contribution of each feature towards the model's robustness, measured in terms of a Receiver-operating Characteristics (ROC) curve and the Area under the ROC curve (AUC). With the help of an illustrative example, we demonstrate the proposed idea of explaining the ROC curve and visualising the uncertainties in these curves. The explanation of robustness can help analysts in several ways; for example, it can help in feature selection by identifying the removable, irrelevant features to reduce the computational complexity and can also help in identifying the features having critical contributions or negative contributions toward robustness.

Multidisciplinary Applications of Data Analytics

Cluster: Analytics and Data Science
Invited session
Chair: *Ramiro Saltos*

1 - Location of emergency services for traffic accidents considering congestion: A case study of the metropolitan area of Puebla
Ricardo Aceves-García, *Zaida E Alarcón Bernal*

Road traffic crashes are a serious public health problem - the leading cause of death worldwide among young people aged 15-29 years; they cause 1.24 million deaths per year and between 20 and 50 million people suffer serious injuries. In Mexico, the situation is similar; in 2019, 14,673 people died due to road accidents and it represents, for the population aged 20 to 39 years, the principal cause of death. It has been considered among the first ten causes of death in the country and as a safety and public health problem. In medical services, there is a protocol to attend the request of "first contact" with people injured on public roads or in homes; it considers the "Golden Hour" as the ideal time to attend accident patients and the "10 minutes of platinum" as the maximum time when a person with serious injuries and vital compromise must receive attention to have a chance to survive. A strategy to reduce mortality due to any accident can be obtained by optimizing the location of emergency services. As a case study, the state of Puebla is analyzed, where 10,270 road accidents, 685 deaths and 2050 injured people were registered in 2019. For the location of ambulances, the Double Standard Location Model (DSM) of Gendreau, Laporte, & Semet was used in this work, incorporating two modifications: a congestion factor and the maximum number of feasible facilities to be used. To estimate the congestion factor, the "operating speed" indicator was used, obtained from the field study of speeds, using a floating vehicle for the off-peak and peak hour periods, resulting in speeds of 49 km/h and 24 km/h, respectively. There are 22 ambulances for the central zone of the state of Puebla, serving 18 municipios, including the 4 in the study area, in circulation and not having fixed sites for waiting for a service request. To determine a set of feasible sites for their location, a selection methodology was implemented and 37 sites were obtained. The proposed algorithm was solved in GAMS, and, finding, for the analyzed scenarios and for off-peak hours, in 5 minutes 70% of the study area is covered with 4 ambulances, and for the 10 minutes of platinum, 98% of the area is covered with 5 ambulances. During peak hour, 5 ambulances, and, for the 10 minutes of platinum, 97% of the study area is covered with 6 ambulances.

2 - Generalized Black Hole Clustering for Earthquake Swarm Detection
Ramiro Saltos, *Richard Weber*

The Black Hole Clustering (BHC) algorithm is a density-based partitional clustering method inspired by DBSCAN; it does not require the number of clusters and the computation of the pair-wise distance matrix between the data points as beforehand. Also, it only needs one parameter, intuitively easier to set than the epsilon parameter of DBSCAN. BHC needs the allocation of the black holes linearly independent, however, making the algorithm in its current version suitable only for two or three-dimensional data sets. We propose a generalized black hole clustering algorithm (GBHC), by introducing a novel black hole allocation procedure for higher-dimensional data spaces. Furthermore, the proposed method is data-independent, so we run it once to obtain the black hole positions for all finite-dimensional metric spaces. We performed extensive computational experiments to compare GBHC with DBSCAN and applied it to earthquake swarm detection. Both algorithms obtain comparable clustering solutions; GBHC outperforms DBSCAN, however, in computational complexity and explainability.

3 - Optimization models for crime analytics applied to social networks
Richard Weber, *Alex Barrales-Araneda*, *Fredy Troncoso*

Groups of criminals can be considered social networks, studied using social network analysis and optimization models; we present a set of models applied successfully for crime investigation with the Chilean prosecutor. Approaches presented in the literature discover criminal associations embedded in a network of suspects, starting with at least two confirmed criminals; determining them requires a large deployment of information, time, and financial resources. In most real-world cases, little is known about a particular crime, however, especially at an early stage of its investigation. In this work, we present optimization models based on Steiner trees, using just one confirmed criminal, as well as models starting without any known individual. There are no significant differences between the proposed model and the state-of-the-art in literature, evidencing our models' potential to support crime investigations requiring fewer resources.

4 - Benchmarking methods on different text classification tasks
Manon Reusens, *Jonathan Tonglet*, *Alexander Stevens*, *Johannes De Smedt*, *Wouter Verbeke*, *Seppe vanden Broucke*, *Bart Baesens*

There are various methods available for text classification, but the effectiveness of these methods is not always clearly delineated, especially when it comes to deciding whether to use large language models or simpler models. Furthermore, there is a shortage of extensive and impartial benchmarks in literature comparing models of different complexity and over different text classification tasks. To address this gap, we present an extensive and impartial benchmark study over a wide range of methods, including logistic regression (LR), support vector machine (SVM), random forest (RF), XGBoost (XGB), bidirectional LSTMs (BiLSTM), convolutional neural networks (CNN) and RoBERTa. Moreover, we thoroughly analyze the results investigating the misclassifications of the different models trained and conducting statistical tests to draw generalizable conclusions. Overall, BiLSTMs are the best-performing method; its performance is not significantly different from LR with Term Frequency Inverse Document Frequency as pre-processing technique (TF-IDF) and RoBERTa on a 95% confidence level. When considering specific classification tasks, we see LR TF-IDF is the best-performing method for topic detection, because of the importance of identifying topic-related words. Moreover, XGB with FastText word embeddings is the second-best performing method for fake news detection, which is in line with existing literature. This method does not perform well, however, for other classification tasks. When looking into emotion detection and polarity detection, the second-best-performing method is RoBERTa. For sarcasm detection, however, RoBERTa does not perform well, potentially due to the small datasets and its pretraining on a mostly non-sarcastic text corpus. While these results are valuable, additional datasets are necessary to ensure the generalizability of our findings through detecting statistical differences between the performance of different methods.

Machine Learning for Business Analytics

Cluster: Analytics and Data Science
Invited session
Chair: *Sebastian Maldonado*

1 - Achieving Nonlinearity and Interpretability in Credit Scoring: The Penalised Tree Ensemble for Region Merging (PERM) Model
Belen Martin Barragan, *Rong Peng*, *Raffaella Calabrese*, *Jake Ansell*

Balancing predictive performance with interpretability is a critical issue in the application of machine learning (ML) to credit scoring. In this research, we propose a novel intrinsically interpretable classification model called Penalised Ensemble for Region Merging (PERM), effectively capturing potential nonlinearities in data. While existing methods in literature are either explainable without consideration of nonlinear structures (e.g. Logistic Regression) or nonlinear without explanations (e.g. Random Forest and Gradient Boosting), PERM is both intrinsically interpretable and capable of capturing potential nonlinearity.

The PERM model adopts an ensemble structure converting a series of weak learners into a strong learner, enhancing overall performance. A recently developed regularization term called SCOPE, originally addressing nominal data, is utilized to overcome the challenge of interpreting a high number of weak learners. This regularization term promotes similar coefficients to have the same value, merging tree-based rules or discretization regions in the weak learners, thus improving interpretability. The PERM modeling framework is also flexible for extension to meet legislative requirements, further increasing its resilience.

Empirical analyses were conducted on credit default datasets and compared to popular credit scoring models. PERM predicts credit risk competitively and consistently, while providing valuable insights for decision-makers.

2 - Incorporating Usage Data for BtoB Churn Prediction Modeling
Juliana Sanchez Ramirez, *Kristof Coussement*, *Arno De Caigny*, *Dries Benoit*, *Lauren Waardenburg*

Customer retention is particularly important in Business-to-Business (B2B) contexts, because of high customer acquisition costs and relatively high customer values; firms rely on churn prediction models for more targeted retention efforts. Usage data presents an interesting source of information for this aim, as it provides insights into how clients use the focal products to derive usage patterns. Despite usage data being a rich data source, it has not been fully explored for churn prediction. In this paper, we explore the added value of usage data for churn prediction modeling in the B2B context. We use a real-life dataset with 3,959 observations of a European software provider over 3 years. Our contributions to existing literature are fourfold. First, we compare the four most common machine learning classifiers in customer churn prediction (i.e. Decision tree, Logistic regression, Random Forest, and XGBoost), based on their predictive performance measured in AUC, Lift and EMPC. Second, we quantify the global impact of usage variables and demonstrate it as a crucial source of information for churn prediction. Third, we study the improvements obtained from usage variables for churn prediction, in terms of time, granularity, and expertise to answer whether, when, what or how customer use of the product has the greatest impact. Finally, we offer insights regarding the carbon footprint of the entire modeling process required to integrate usage data into different machine learning classifiers.

3 - Debt collection models based on traditional and causal machine learning
Catalina Sánchez, *Sebastian Maldonado*, *Carla Vairetti*

Banks and financial institutions face a significant percentage of debtors, entailing significant losses. One of the main interests of these entities is to recover the amounts owed in an economic and expeditious way. To solve this problem, banks and financial institutions hire Contact Center services to improve their debt collection strategies. These services cannot always deliver the expected results, however, as reflected in an increase in the number of debtors in recent years.

This study focuses on the use of predictive models applied to debt collection, to estimate the probability a certain debtor will pay its debt in the near future. Although collection models tend to exclusively consider debtor financial and sociodemographic information, this paper proposes to consider an additional source of information to complement these predictive models: the information on customer contacts obtained from the Contact Center.

Finally, the study presents an analysis of the performance of predictive causal models; they focus on identifying those clients having a positive response to the collection strategies carried out by a company. As a reference, the traditional approach seeks to predict who will pay their debts contracted with the company, but there is a significant percentage who pay without having been contacted; this approach is less effective than the causal predictive approach.

4 - An automated prioritization scheme for complaints and inquiries using transformer-based text classification and MCDM

Sebastian Maldonado, *Carla Vairetti*, *Alonso Leal*, *Juan Pablo Karmy*, *Ignacio Aránguiz*

Providing a prompt response to complaints and queries is key for companies because of their strong influence on customer experience; the manual intake process, however, can be very time-consuming. This talk proposes a scheme for complaints and inquiries using transformer-based deep learning models, including BERT and other variants, such as BETO or RoBERTa. In this project, the main challenge is the labeling process, requiring the input of experts. To balance the attributes created by the analysts for prioritization and the feature importance derived by experts, a simple weighting approach from the multiple-criteria decision-making (MCDM) literature was considered. This procedure facilitates complex decision-making, where multiple factors come into play. A binary classification problem was defined, with two priority levels (urgent complaints and other claims). The proposed scheme is presented as a general framework for dealing with complaints, claims, and enquiries in any company; it was applied to data from a Chilean nonprofit organization, providing coverage for occupational accidents and designing risk prevention programs. Chilean law mandates all employing entities must be affiliated with one of these social security agencies; with more than 73,000 affiliated employing companies and 2.6 million workers, this agency is the largest one in the country. The use of BERT and variants led to an accuracy and area under the curve above 90%, outperforming traditional statistical and machine learning methods. This study is novel, and contributes to the literature, because it is the first to do the following: (1) discuss prioritization schemes using state-of-the-art deep learning methods, (2) use MCDM for the labeling process of a prioritization scheme, and (3) discuss complaint prioritization in a social security agency.

Deep Learning Applications

Cluster: Analytics and Data Science
Invited session
Chair: *Carla Vairetti*

1 - Chilean confederations' BERT latent topic modelling of social media: towards rejuvenating their discursive power.

David Díaz, *Daina Bellido de Lina*, *Carolina Martínez*

As the Chilean labour movement shows signs of revitalisation with growing trade union affiliation rates, sectoral confederations seem to be reclaiming their prominence by driving forward and maintaining critical labour-related discussions at the national level. By examining the Twitter accounts of the largest Chilean confederations from the mining, banking, and health sectors (n=14.863), the article aims to explore the nature of the content posted during the last 5 years (from 2017 to 2021) as a way to assess their revitalization efforts.

Bidirectional Encoder Representations from Transformers (BERT) models are used to generate rich embeddings from texts, further clustered into groups of twits with similar meaning, i.e., performing what is typically known as latent topic modelling. Our methodology consists of five steps: i) BERT embeddings are generated for each twit in the sample; ii) these large embedding vectors are reduced in size using the UMAP dimensionality reduction algorithm; iii) HDBSCAN is applied over reduced vector embeddings to find natural occurring groups of twits with similar semantic meaning; iv) c-TFIDF vectorizer models are applied to each of the previous clusters (topics) to find keywords to help understand the nature of each topics; and v) Human Labelling is executed using these clusters (topics) and topic keywords. The resulting topics and corresponding descriptive keywords were richer in meaning and more diverse than the ones found using LDA and LSA and are finally used by domain experts to generate insights of what Chilean confederations are posting in social media.

Insights showed confederations concentrated their online content around Labour Issues - campaigning for pensions, gender equality within workplaces, and the importance of social security, also emphasising democratic processes within the Chilean labour movement. These findings can suggest a rejuvenation of their discursive power bringing forward an action-oriented strategy, unprecedented since the military dictatorship. These findings contribute to the literature on the trade union movement revitalisation strategies and new technologies emphasising how sectoral actors can and are using social media to secure renewal. These findings also help validate the use of BERTopic as a new toolset for analysing large text corpuses, producing rich insights and informing theory and practice in diverse fields of knowledge.

2 - Optimal header-body combination for the classification of social media opinions using transformer-based deep learning.

Alonso Leal, *Carla Vairetti*, *Sebastian Maldonado*

In the field of text classification, specifically using transformers, common practice is to use a string input, with a label assigned to it, the former normally coming from one of the rows available in the dataset. A widely recognized area where this technique and models are used would be review classification - giving a rating to a certain review. There is a prevalence of these datasets because of the amount of e-commerce and customer feedback, but, in some cases, the dataset might include more rows reflecting extra information about the sample; some examples of these rows could be time, customer id, and/or a header, the latter being the main focus of this investigation. The methodology we propose incorporates this new data to achieve better results, by training two separate transformers - one for the header of the sample, and the other for the review or the body. Each model is independently trained, meaning they will take in the same dataset, but the string input for the training batches will be extracted from the header and body columns, respectively. With these two models, one can create a linear combination between the logits outputted to improve the performance of the classification. The two coefficients, needed to adjust how much each of the model's logits are being taken into account for the final result, have to be experimented with to find the optimum values. There will also be a third model trained to validate the results of the ensemble; it will have as its input string a combination of the header and the body with the corresponding tokenizers separator token in between them. Experiments have been run with several different datasets, pre-trained transformers and languages, where the optimum combination of the header and body models have greater performance compared with the three others by themselves. The datasets used were only about reviews in different areas, but this methodology can be used for other text classification datasets, where there is at least more than one text column correlating with the final label. Because of the prevalence of samples, there has been experimentation with balancing and unbalancing datasets to see the impact on all the models. Finally, it

can also be extrapolated to datasets having more than just two significant columns, creating one model per column and creating the linear combination between all of them.

3 - Comparing LSTM, ARIMA, and MLP Models for Stock Price Prediction and Profitability in the IPSA Stock Market Index Components

Tomas Carlos PeÑa Vargas, *David Díaz*

The study of price prediction and market trends in stocks is a relevant topic for professionals in finance, data science and industry. Since 2012, 85% of operations in the US are carried out through algorithmic trading; however, few empirical studies have dedicated attention to emergent markets, such as Latin America. This research proposes using LSTM (Long Short Term Memory) neural networks to model Chilean IPSA Stock Market Index Components. Prices and returns of its 30 constituents are modelled using LSTM architecture, comparing them to auto-ARIMA (Autoregressive Integrated Moving Average) and auto-MLP (Multilayer Perceptron) models. IPSA stocks between 2010 and 2021 are analyzed, comparing the directional accuracy (DA) and root mean square error (RMSE) in one-step ahead, closing price predictions. Technical Indicators, lagged prices and returns are used as inputs for the models. LSTM, MLP and ARIMA architectures and hyperparameters are optimized using a Bayesian tuning approach to find the best configuration of each modelling technique. The models' profitability is evaluated following different investment strategies through backtesting between 2019 and 2021. In terms of DA, LSTM outperforms other models in 70% of the analyzed stocks, while ARIMA and MLP do so in the remaining 20% and 10%, respectively. The SMU stock shows the highest accuracy with 59.7% and 58.8% DA in price and return models. Although LSTM models perform better in terms of DA, in 80% of the stocks, they do not significantly outperform the ARIMA model in terms of RMSE, according to the Diebold-Mariano test. In fact, ARIMA achieves better predictions in 20% of the stocks. Despite the predictive capabilities of these models being lower than the best in the literature (above 80%), all analyzed stocks surpass both their own buy-hold strategy and IPSA, in profitability.

4 - Dealing with noisy labels in text classification: an application in social security

Carla Vairetti, *Sebastian Maldonado*, *Richard Weber*

Deep learning (DL) has received increasing attention in the last decade, becoming the de facto solution for several machine learning tasks, including text analytics. For this application, attention mechanisms based on transformers have significantly improved the performance of natural language tasks. One area benefiting from DL is crime analytics, where the goal is to model crime patterns and trends from data. DL can be used as an automation tool, e.g. by classifying text into predefined categories - important when the manual labeling process is inaccurate and/or time-consuming. Crime apps are one example of a noisy data source, allowing users to report, communicate and find out about thefts, suspicious activities, and other important notices. This information can be analyzed and used by the police or other agencies to increase the safety, providing a prompt response to high priority events. Crime app users categorize their safety reports by choosing one of the various options provided by the app. The users tend to provide incorrect labels, however, either because it is easier for them, e.g. by choosing the first alternative, or they intentionally exaggerate the importance of their reports, by choosing crime categories having a significant impact on the community. There are several solutions for learning with noisy labels, including (1) data preprocessing by creating clean datasets for training, (2) data reweighting, (3) robust loss functions, such as the Mean Absolute Error (MAE), or (4) model-based solutions introducing modifications to the learning algorithms. The proposal considers a combination of different strategies, resulting in a tailored solution for the problem at hand. The main goal of this study is to design a prioritization scheme for crime apps using robust DL classifiers for text analytics in the presence of noisy labels. Recent robust machine learning developments are adapted to this issue, resulting in novel methodological contributions for the state-of-the-art in text classification. Furthermore, this proposal is used to automate and to correct the labeling process of safety alerts reported on a Chilean crime app, defining a prioritization scheme for efficient crime response. With an overall F1 (macro) of 0.65 for a 14-level multiclass problem, the DL model successfully recognizes incorrectly labeled reports.

Novel Developments in Machine Learning

Cluster: Analytics and Data Science
Invited session
Chair: *Julio López*
Chair: *Sebastian Maldonado*

1 - A prescriptive analytics approach to staffing via hierarchical time series and stochastic optimization

Juan Pablo Karmy, *Juan Perez*, *Sebastian Maldonado*, *Carla Vairetti*

Usually, time series can be disaggregated, based on their hierarchical structure; for example, a certain product sales can come from certain cities or stores, while being grouped in categories or sub-categories. This hierarchical structure can often help to improve predictions. This technique is known as Hierarchical Time Series.

In this work, machine learning techniques, such as Support Vector Regression and Artificial Neural Networks, are used to obtain hierarchical time series predictions in a Chilean Contact Center. In particular, time series were constructed based on daily phone calls for demand forecasting. We can disaggregate this information based on origin number and company area being reached.

Machine learning techniques performed better on average than traditional approaches, such as ARIMA and Holt-Winters. Our goal is to use these predictions as input for a stochastic optimization model, allowing us to define how much staff the company needs to run their Call Center efficiently.

2 - Comparing decision-focused learning and optimization under uncertainty in the decision-making process.

Victor Bucarey

Decision-making processes involving uncertainty in the input parameters is commonplace; a typical two-stage approach is to train a machine learning (ML) model to obtain an estimate of the uncertain input and, then, perform the decision task, typically an optimization problem. Classical ML approaches consist of minimizing prediction errors without considering their impact on the downstream optimization problem. This approach ignores how predictions may affect the solution of the optimization task, leading to poor quality and sometimes infeasible decisions.

A classical approach used in the operational research community is to model uncertainty using probability distributions and/or uncertainty sets; risk-averse optimization, stochastic programming, and robust optimization lie in this category. The decision is made after solving an adapted optimization problem. Another principled "smart-predict, then-optimize" approach is proposed by (Elmachtoub 2021), where unknown parameters are estimated by an ML model, integrating the prediction and the optimization task. This ML model is trained by using a decision-focused loss, an approximation of regret.

In this talk, we present a discussion comparing the main features of these approaches and give some numerical examples, showing the impact on the decision-making process when adopting each approach.

3 - The Cobb-Douglas Learning Machine

Miguel Carrasco, *Julio López*, *Sebastian Maldonado*

In this work, we propose a novel machine learning approach based on robust optimization; it defines the task of maximizing the two class accuracies of a binary classification problem as a Cobb-Douglas function. This function is well known in production economics and is used to model the relationship between two or more inputs, as well as the quantity produced by those inputs. A robust optimization problem is defined to construct the decision function. The goal of the model is to classify each training pattern correctly, up to a given class accuracy, even for the worst possible data distribution. We demonstrate the theoretical advantages of the Cobb-Douglas function in terms of the

properties of the resulting second-order cone programming problem. Important extensions are proposed and discussed, including the use of kernel functions and regularization. Experiments performed on several classification datasets confirm these advantages, leading to the best average performance in comparison to various alternative classifiers.

4 - Formulations for classification problem based on minimax probability machine
Julio López, *Sebastian Maldonado*, *Miguel Carrasco*

In this work, we present novel robust formulations for binary classification based on the Minimax Probability Machine (MPM) approach. The idea is to introduce a regularization term the MPM and Minimum Error Minimax Probability Machine approaches. This inclusion reduces the risk of obtaining ill-posed estimators, stabilizing the problem, and, therefore, improving the generalization performance. In addition, inspired by the twin support vector machine method, we study a twin version in this context. Finally, some experiments on well-known binary classification datasets demonstrate the virtues of these novel formulations in terms of predictive performance.

Mathematical Optimization for XAI IV

Cluster: Analytics and Data Science
Invited session
Chair: *Jasone Ramírez-Ayerbe*

1 - Contextual uncertainty sets in Robust Optimization
Nuria Gómez-Vargas, *Rafael Blanquero*, *Emilio Carrizosa*

In real-world decision problems, the usual scenario includes the presence of uncertainty in multiple parameters modeling either the optimizable objective function (e.g. minimizing travel times) or some of the satisfiable constraints (e.g. demands). In Robust Optimization, we handle a collection of problems of a common structure, but with the parameters of the model varying in some uncertainty set. We study an approach to build these uncertainty sets by leveraging the contextual information provided by a set of covariates (e.g. weather or traffic congestion). Specifically, we design ellipsoidal uncertainty sets, defined by the maximum likelihood estimated parameters of the assumed Gaussian distribution, resulting from conditioning the uncertain parameters to the given values of the covariates, and provide both theoretical and empirical guarantees for the coverage provided. Finally, we implement our approach on synthetic data to demonstrate the value of exploiting contextual information in Robust Optimization.

2 - Fairness in Bayesian Logistic Regression through Variational Inference
Rafael Jiménez-Llamas, *Emilio Carrizosa*, *Pepa Ramírez-Cobo*

Fairness in machine learning is gaining increasing importance due to the need of decision-makers to be sure algorithms are not influenced by biases in the training data. In this work, we show a novel approach to get fair predictions in Logistic Regression under a Bayesian strategy. Specifically, we use Variational Inference to approximate the posterior distribution, where the usual ELBO maximization is modified by a penalization term related to the unfairness degree of the solution. The method results in a tradeoff between the accuracy and the fairness of the solution. Additionally, this approach only calls for "class tags" in the training set, meaning there are no privacy concerns for any individual.

3 - Counterfactual Solutions Plans
Emilio Carrizosa, *Jasone Ramírez-Ayerbe*, *Dolores Romero Morales*

Assume we are given a classifier for a binary classification problem. A counterfactual solution to a record is a feasible solution, close (in a given metric) to the record and having a high probability of being labeled in the positive class by the classifier. Finding a counterfactual solution for a given record amounts to finding a Pareto-optimal solution to the problem of simultaneous optimization of closeness and the probability of classification in the positive class. In this talk, we address the problem where, instead of one counterfactual solution, we seek a counterfactual solutions plan, i.e., a sequence of T solutions with increasing probabilities of positive and minimizing (a function of) the overall distances. The so-obtained optimization problems will be analyzed for different choices of the classifier and metric.

4 - Counterfactual Analysis for Benchmarking: a bilevel optimization approach
Jasone Ramírez-Ayerbe, *Peter Bogetoft*, *Dolores Romero Morales*

One of the most popular management tools is benchmarking, i.e., the systematic comparison of the performance of one firm against other firms. DEA (Data Envelopment Analysis) is a tool to perform benchmarking capturing the complex relationship between multiple inputs and outputs in most firms. Using linear programming, the best practice performance frontier is calculated and the efficiency of an entity relative to this frontier is evaluated. This method can be seen as a black-box and may be hard to understand by managers. In this talk, we propose the use of counterfactual explanations as they are used in Machine Learning to get insights from the DEA model. For DEA models, counterfactual explanations are changes in the inputs (or outputs) of a firm with minimum cost leading them to have higher efficiency. We formulate the problem of generating counterfactual explanations for DEA as a bilevel optimization model. Our methodology is flexible enough to use different distance measures and to have sparsity. We illustrate our method using a small numerical example and a real-world dataset on banking branches.

Mathematical Optimization for XAI V

Cluster: Analytics and Data Science
Invited session
Chair: *Thomas Halskov*

1 - Algorithm Selection: Learning for Spatial Branching
Brais González Rodríguez, *Bissan Ghaddar*, *Ignacio Gómez-Casares*, *Julio González-Díaz*, *Beatriz Pateiro-López*, *Sofía Rodríguez-Ballesteros*

The use of machine learning techniques to improve the performance of branch-and-bound optimization algorithms is a very active area in the context of mixed integer linear problems, but little has been done for non-linear optimization. To bridge this gap, we develop a learning framework for spatial branching and show its efficacy in the context of the Reformulation-Linearization Technique for polynomial optimization problems. The proposed learning is performed offline, based on instance-specific features and with no computational overhead when solving new instances. Novel graph-based features are introduced, playing an important role for the learning. Experiments on different benchmark instances from the literature show the learning-based branching rule significantly outperforms the standard rules.

2 - Non-convex optimization methods for finding regret-minimization predictions
Sophia Calderón Pimienta, *Gonzalo Munoz*, *Victor Bucarey*, *Frédéric Semet*

Optimization problems often involve unknown parameters; a commonly applied approach to circumvent this issue is to use observations of these parameters and predict them before optimizing. This "Predict, then Optimize" framework optimizes prediction error, not necessarily

yielding the best decisions under parameter uncertainty. As an alternative, Elmachtoub and Grigas (2021) proposed the "Smart Predict, then Optimize" framework to generate prediction models minimizing decision error, instead. Here, a prediction model is designed by minimizing a "regret" function, capturing the error of making a sub-optimal decision due to an inaccurate prediction. The resulting problem can be formulated as a pessimistic bilevel optimization problem - inherently non-convex; Elmachtoub and Grigas thus propose a convex surrogate to obtain tractability.

In this talk, we focus on solution methods for the exact non-convex pessimistic bilevel optimization problem. We reformulate the problem as a quadratically-constrained problem and show an extensive computational study in shortest-path instances comparing various solution methods, both existing and new.

3 - Valuing Data Using Multi-Source Distributionally Robust Optimization
Juan Miguel Morales, *Robert Mieth*

In this talk, we show how Distributionally Robust Optimization (DRO) offers a natural framework to factor in the quality of data in data-driven stochastic optimization and value different data sets according to their contribution to the decision cost. For this purpose, we first discuss the ability of the Wasserstein metric to quantify data quality and, then, construct a Wasserstein DRO problem accommodating data from multiple sources using individual transport budgets. We illustrate the proposed framework using an application from power system operations, where we show how the resulting optimization problem implicitly computes the value of data given its quality and the context of the decision-making problem at hand.

4 - Wasserstein SVM: Support Vector Machines Made Fair
Thomas Halskov, *Dolores Romero Morales*, *Emilio Carrizosa*

In this talk, we show how to introduce fairness in a Support Vector Machine (SVM) classification model. Assuming a group of individuals need to be protected against discrimination, we address the problem of training the classifier by jointly maximizing the classification performance (SVM margin) and equity (closeness between the distribution of the predictions in the protected group and the remaining individuals). We modify the dual formulation by penalizing the empirical Wasserstein distance between the distribution of the SVM scores from the two groups; this corresponds to the original dual formulation with a modified kernel. We illustrate our novel SVM on classic benchmark datasets in the Fair Machine Learning literature. With a mild penalization of the Wasserstein distance, we can dramatically reduce the unfairness, while keeping a similar level of accuracy.

Mathematical Optimization for XAI VI

Cluster: Analytics and Data Science
Invited session
Chair: *Connor Lawless*

1 - Fairness without Imputation: A Decision Tree Approach for Fair Prediction with Missing Values
Haewon Jeong, *Hao Wang*, *Flavio Calmon*

We investigate the fairness concerns of training a machine learning model, using data with missing values. Even though several fairness intervention methods exist in the literature, most of them require a complete training set as input. In practice, data can have missing values, and data missing patterns can depend on group attributes (e.g. gender or race); simply applying off-the-shelf fair learning algorithms to an imputed dataset may lead to an unfair model. In this paper, we first theoretically analyze different sources of discrimination risks when training with an imputed dataset. Then, we propose an integrated approach based on decision trees not requiring a separate process of imputation and learning. Instead, we train a tree with missing incorporated as attribute (MIA), not requiring explicit imputation, and we optimize a fairness-regularized objective function. Our approach outperforms existing fairness intervention methods applied to an imputed dataset, through several experiments on real-world datasets.

2 - Interpretable Clustering with Constraints
Eldan Cohen, *Pouya Shati*, *Sheila McIlraith*

Clustering is a core unsupervised machine learning problem aiming to partition an unlabelled dataset into K groups of similar data points; in practice, it is often used to discover meaningful sub-populations such as customer segments or groups of related documents. Constrained clustering is a semi-supervised machine learning task exploiting small amounts of labelled data, provided in the form of constraints, to incorporate domain-specific knowledge in the clustering and to improve performance. Most clustering algorithms, as well as constrained clustering algorithms, do not provide any explanation or interpretation for the obtained partition, and a post-hoc analysis is often required to characterize the discovered sub-populations. We are interested in developing a constrained clustering approach - interpretable and providing strong solution quality guarantee. While recent approaches could provide interpretable clustering solutions via decision trees, these approaches do not support the incorporation of clustering constraints. In this work, we develop a novel SAT-based encoding of optimal constrained clustering, interpretable via a decision tree, and we study the trade-off between interpretability and satisfaction of clustering constraints. We evaluate our approach over real-world and synthetic datasets and show it leads to high-quality and interpretable clustering solutions satisfying the given set of clustering constraints.

3 - Explaining decisions in contextual stochastic optimization
Alexandre Forel, *Thibaut Vidal*, *Axel Parmentier*

Contextual stochastic optimization leverages auxiliary information and machine learning to solve problems subject to uncertainty; this integrated approach can improve performance and reduce costs by dynamically adapting decisions to the context, but it leads to complex decision pipelines lacking transparency. Yet, practitioners need to understand and trust new solutions to replace an existing policy, possibly based on both expert knowledge and quantitative methods. To explain the decisions obtained by solving contextual stochastic problems, we revisit the concept of counterfactual explanations used extensively to explain the predictions of machine-learning algorithms. A counterfactual explanation of a decision is an alternative context, where the expert-based decision is better than the optimal decision currently recommended. By contrast, the explanations highlight the key features requiring decisions to be adapted. We develop mixed-integer linear models to find optimal explanations of decisions obtained using random forest and nearest-neighbor predictors. We apply our approach to fundamental operations research problems, such as inventory management and routing, and show the value of the explanations obtained.

4 - Cluster Explanation Via Polyhedral Descriptions
Connor Lawless, *Oktay Gunluk*

Clustering, an unsupervised learning problem, aims to partition unlabelled data points into groups with similar features. Traditional clustering algorithms provide limited insight into the groups they find; their main focus is accuracy and not the interpretability of the group assignments. This has spurred a recent line of work on explainable machine learning for clustering. In this paper, we focus on the cluster description problem where, given a dataset and its partition into clusters, the task is to explain the clusters. We introduce a new approach to explain clusters by constructing polyhedra around each cluster while minimizing either the complexity of the resulting polyhedra or the number of features used in the description. We formulate the cluster description problem as an integer program and present a column generation approach to search over an exponential number of candidate half-spaces used to build the polyhedra. To deal with large datasets, we introduce a novel grouping scheme - first forming smaller groups of data points and, then, building the polyhedra around the grouped data, a strategy out-performing simply sub-sampling data. Compared to state of the art cluster description algorithms, our approach can achieve competitive interpretability with improved description accuracy.

Learning Analytics

Cluster: Analytics and Data Science
Invited session
Chair: *Sebastian Maldonado*

1 - Investigating stability of student-at-risk prediction model across years by means of XAI
Elena Tiukhova, *Pavani Vemuri*, *Nidia Guadalupe Lopez Flores*, *Anna Sigríður Islind*, *María Óskarsdóttir*, *Stephan Poelmans*, *Bart Baesens*, *Monique Snoeck*

Learning analytics (LA) is a fast-growing research domain focusing on modeling future learner outcomes, with student-at-risk prediction being among its most popular applications. According to Self-Regulated Learning (SRL) theory, a motivated learning choice can be represented with trace data collected by a Learning Management System (LMS), where higher-level indicators representing different aspects of learning can be engineered. Contemporary black-box predictive models using these indicators have limited usability towards explanatory LA. There is a difference between predictive and explanatory LA, with the former focusing on maximizing empirical precision at the cost of being in line with theory and having high transparency - more the focus of the latter. Our study aims to bridge the gap between predictive and explanatory LA modeling by combining advanced feature engineering based on SRL and predictive machine learning for student-at-risk prediction enriched with explainable AI (XAI) in an innovative way. Moreover, in the ever-changing contexts of learning, it is vital to ensure not only explainability, but also stability of models across time. Hence, we assess the robustness of models developed for a particular course across years using XAI techniques, extending existing research on stability of LA models and XAI in LA. Overall, our study proposes a novel approach to predictive LA incorporating explainability and robustness for long-term applicability.

2 - Engineering students' strategies and tactics observed through LMS interactions
Sergio Celis, *Esteban Villalobos*, *Juan Ross*

Supporting first-year engineering students in their learning process is daunting; courses, such as physics and mathematics, demand students to rapidly adapt to the university pace, acquiring a significant amount of new content through continuous problem-solving and examinations. This context usually results in higher failure rates and dropouts than in other fields. To support students, universities launch initiatives based on well-established theoretical frameworks, such as self-regulation and learning approaches. These frameworks rely mainly on filling self-report questionnaires, facing low response rates and not necessarily well-tailored to particular courses. In response to these challenges, learning analytics has used student data to classify students and recommend specific actions. Defining strategies and tactics is one approach to model learning data; learning strategies consist of the collection of actions students frequently use over a certain period, for instance, over a semester. Tactics are students' actions to address a specific task, such as assignments or examinations. Here, we seek to classify strategies and tactics in a traditional first-year engineering course, by analyzing their daily and weekly interaction with their learning management system (LMS).

The sample includes 52 students from a first-year course, "Introduction to Modern Physics." This course follows a traditional setting. Both courses used the same LMS. Thus, during the rest of the semester, students were separated only into two groups to send messages. The first group combined the deep-learning students and the first quantile of students with the highest reading interaction level.On the other hand, the second was composed of the students who belong to the three lower quantiles of reading interactions.

Regarding student tactics, we found four distinctive groups. The most commonly used tactic was reading mildly, which can be interpreted as following the course progress with a low level of engagement. Then, administrative-mild shows a lower level of engagement since the variable is unrelated to course content. On the other hand, reading intensely suggests a high level of engagement, usually expanded in the time previous to examinations. Reading and testing demonstrate an even higher level of engagement because those students used the LMS not only as an informative platform.

3 - Data-driven dynamic predictive model, to assess the probability of students failing online/blended courses
Cecilia Saint-Pierre, *Thomas Peet*, *Galina Deeva*, *Richard Weber*

Learning management systems (LMS), massively popular in higher education institutions, whether for online or blended courses, and with large amounts of data, have led to the development of computational models to help instructors improve student learning experiences and monitor student progress through various indicators and visualizations, based on learning analytics techniques.

In this study, a sequential classification technique was applied on event log data, collected by the LMS platform implemented at the University of Chile and analyzed by time windows, reflecting student behavior during a course. The presented algorithm generates a pass/fail probability with a predictive model trained by behavioral data from previous versions of the same course and the consequent final student scores. The daily addition of student-generated data to the platform allows the model to create dynamic predictions helping instructors identify underperforming students early in the course.

Advancements of OR-Analytics in Statistics, Machine Learning and Data Science 2

Cluster: Analytics and Data Science
Invited session
Chair: *Gerhard-Wilhelm Weber*
Chair: *Dolores Romero Morales*

1 - Automatizing abstract screening in literature reviews
Angel Ruiz, *Julia Isabel Serrato Fonseca*, *Ana María Anaya-Arenas*

Literature reviews, as the pillar of scientific work, should be valid, reliable, and repeatable. In particular, the methodology to conduct systematic literature reviews is well identified and defined, involving three major stages (planning the review, conducting the review, and reporting the review). The second stage in the methodology includes very time consuming activities, particularly screening for inclusion, where the researchers screen the abstract of each article produced by the search of the literature to decide whether it should be included for further data extraction and analysis. Some recent papers have proposed the use of Machine Learning (ML) tools to help researchers in this task, demonstrating the usefulness of the tools filtering and selecting papers fitting inclusion criteria. These papers address mostly technical aspects of the tools, however, and focus on their performance, providing little or no information on the process involving configuration, validation and verification. To fill, at least partially, this gap, this talk focuses on the implementation of Machine Learning tools for automatizing of the abstract screening and provides some insights on how to improve the performance of the tool and how to deal with the inconveniences encountered in the process.

2 - An exploratory study with roll rate analysis on current/checking account balance: is there an absorbing state of distress?
Rui Ying Goh, *Galina Andreeva*, *Yi Cao*

Financial behaviour of individuals fluctuates in line with their circumstances, income and changing economic conditions. Before experiencing a serious financial distress, individuals may face varying levels of transient financial difficulty. There are no universally accepted guidelines for an objective measurement of distress or for defining different stages of financial difficulty. This presentation proposes financial difficulty levels based on a negative balance of current (checking) accounts. We define four ordinal states of increasing dependence on overdraft

use implying incremental financial difficulty risk. Roll rate analysis is conducted to examine the proportion of accounts transitioning from one state to another and to investigate whether there exists a state of persistent negative balance, defined as 'distress'. The accounts have a higher tendency to stay in the initial state or improve to a relatively lower risk state instead of deteriorating. Accounts could always recover to the lowest risk state, despite being in the highest risk state previously. Overdraft use scenarios observed from cashflow transactions do not explicitly relate to distress, but can better depict transient vulnerabilities, i.e., temporary financial struggles. Further work will focus on identifying early warning signs of deteriorating financial conditions and predicting the transitions between the financial states from past transactional behaviour.

3 - Graph neural network-based sparse aware recommendation system

Dong Hyun Lim, *So Young Sohn*

Recommender systems, designed to suggest items to users based on their past behaviors and preferences, are widely used in various platforms such as e-commerce and social networking. These systems have been developed with the progress of machine learning, taking advantage of large volumes of user-item interaction data represented as a network. Not every user leaves a review, however, and only a small percentage of the items available are rated or purchased. Many user-item pairs are missing, and those with recorded interaction data in the real world are sparse. This feature makes it difficult to predict the preferences of users accurately, and especially in the case of new users; they cannot make more accurate recommendations due to limited or little past data - a cold-start problem. To solve this problem, various approaches, such as collaborative filtering, have been proposed, but, unfortunately, existing recommendation systems suffer from sparsity to provide appropriate recommendations. In this study, we propose a graph neural network-based sparse-aware recommendation system by adopting Randomized Embedding (RE) through graph perturbations to compensate for the sparse points of the user-item interaction network. Our proposed framework is experimented on three real-world datasets from Yelp, the largest U.S. review site, to prove the effectiveness of the recommendation system. To demonstrate its competence in the cold-start problem, the evaluation is conducted by both the entire user and the light user with a relatively small number of interactions. The proposed framework can provide users with more relevant and interesting recommendations, improving customer satisfaction with increased revenue.

4 - DyLoPro: Profiling the Dynamics of Event Logs

Brecht Wuyts, *Hans Weytjens*, *Jochen De Weerdt*, *Seppe vanden Broucke*

Modern business processes are often characterized by continuous change, leading to bias in the results of process mining techniques assuming a static process, caused by concept drift, manifesting in many forms and affecting various process perspectives. Current research on concept drift in process mining has focused on drift detection techniques in the control-flow perspective, with limited capabilities for comprehensive dynamic profiling of event logs. To address this gap, this paper presents the DyLoPro framework, a generic approach facilitating the exploration of event log dynamics over time, using visual analytics. The framework caters to all event logs and allows for the exploration of event log dynamics from various process perspectives, both individually and combined with the performance perspective. Additionally, the framework is accompanied by an efficient and user-friendly Python library, rendering it a valuable instrument for both researchers and practitioners; a case study using large real-life event logs demonstrates its effectiveness.

Advancements of OR-Analytics in Statistics, Machine Learning and Data Science 3

Cluster: Analytics and Data Science
Invited session
Chair: *Gerhard-Wilhelm Weber*
Chair: *Emilio Carrizosa*

1 - Enhanced Terrain Classification: Supervised Autoencoder and Bayes Optimization Approach

Tiny Du Toit, *Hennie Kruger*, *Annette van der Merwe*

Terrain classification refers to the classification of different surfaces based on similarities in terrain properties and characteristics unique to a specific surface. A popular approach to terrain classification is using automated robots fitted with various sensors to record data while the robot travels over a particular surface. These sensors may include barometers, accelerometers, gyroscopes, magnetometers, etc. The data collected from the sensors are then used for terrain classification purposes. In this study, the feasibility of a supervised autoencoder (i.e., an autoencoder combined with a multilayer perceptron) is evaluated as an alternative approach to the problem of terrain classification. The proposed supervised autoencoder used a Bayes optimization methodology to determine the hyperparameter values and proved to be more advantageous than the traditional approaches. The dataset used for model development was obtained by driving a Lego Mindstorm EV3 mobile robot fitted with a Raspberry Pi computer and a Sense HAT inertial measurement unit (IMU) over six different terrain surfaces for 30 minutes on each surface. The sensors collect data on 16 different terrain properties, serving as input to the proposed classification model. The final dataset contained 281,232 data points. The six terrains include stone, dirt, paving, epoxy, grass, and asphalt surfaces. To evaluate the new proposed classification model, the model's results are compared with three other modelling techniques, i.e., an SVM, a logistic regression model, and an XGBoost model. Based on the comparison with these three models and standard accuracy measures computed, the proposed supervised autoencoder performs well and is a feasible and desirable modeling option for terrain classification. Furthermore, using a Bayes optimization hyperparameter value identification technique further contributes to the success; it provides additional insight into aspects, such as identifying the importance of the various hyperparameters.

2 - Evaluation of performance indicators based on Machine Learning models compared to traditional indicators to perform ICU efficiency analysis

Igor Peres, *Guilherme Ferrari*, *Amanda Quintairos e Silva*, *Vicente Dantas*, *Jorge Salluh*

Introduction: Intensive Care Units have standard indicators for measuring resource use efficiency, such as the SRU (Standard Resource Use). These measures were developed decades ago, however, and used traditional predictive modelling.

Purpose: The research objective was to use Machine Learning models to generate more accurate predictions than the existing traditional models, thus enabling the development of more calibrated efficiency indicators.

Materials and Methods: We evaluated a new efficiency indicator using a recently developed stacking model trained with about 100,000 admissions of 109 Brazilian Intensive Care Units. The analyses were performed for all ICU patients and other subgroups.

Results: The proposed SLOS indicator reported a median (Q1-Q3) calibration equal to 0.99 (0.87-1.08), compared to 0.79 (0.69-0.90) from the traditional SRU measure. Moreover, the coefficient of determination was 0.92 compared to 0.57. The greater calibration was also noted when analyzing the subgroups.

Conclusions: The SLOS (proposed indicator to perform ICU efficiency analysis) reported better calibration than the traditional SRU. Future research should investigate whether this indicator could improve efficiency analysis in other contexts.

3 - Machine Learning Prediction of University Degree Dropout: Which role plays the student's preference?

Marina Segura, *Jorge Daniel Mello-Román*, *Adolfo Hernandez*, *Baldomero Segura*

University dropout rates, a problem presenting many negative consequences, are an academic issue carrying an unfavourable economic impact. In recent years, significant efforts have been devoted to the early detection of students likely to drop out. This paper uses data corresponding to dropout candidates after their first year in the third largest face-to-face university in Europe, with the goal of predicting likely dropout either at the beginning of the course of study or at the end of the first semester. In this prediction, we considered the five major program areas. Different techniques have been used: first, a Feature Selection Process to identify the variables more correlated with dropout; then, some Machine Learning Models (Support Vector Machines, Decision Trees and Artificial Neural Networks) as well as a Logistic Regression. Dropout detection works not only with enrollment variables, but it improves after the first semester results. Academic performance is always a relevant variable, but there are others, such as the level of preference the student had over the course finally studied. The success of the techniques depends on the program areas. Machine Learning obtains the best results, but a simple Logistic Regression model can be used as a reasonable baseline.

4 - Evaluating Time-Frequency Transforms in a CNN-based Algorithm for the Detection of Gravitational Waves from core-collapsed Supernovae

Lucas Villavicencio, *Benjamín Ramos Tapia*, *Patricio Maturana*, *Mauricio Moyano*, *Guillermo Cabrera-Guerrero*

The detection of gravitational waves has opened up a new era in astrophysics, providing insights into the universe's most violent and energetic phenomena. The detection of gravitational waves from core-collapsed supernovae is of particular interest, as it offers a unique window into the physics of supernova explosions and the formation of neutron stars and black holes.

Various methods, such as Bayesian detection algorithms and Convolutional Neural Networks (CNN), have been proposed, aiming to detect core-collapsed supernovae; CNN algorithms have been shown to perform particularly well in this problem. Recently in the literature, a CNN-based algorithmic framework has been proposed to solve this problem using a discrete wavelet transform.

In this work, we aim to evaluate the proposed CNN-based algorithmic framework using various time-frequency transforms. More specifically, we implemented the algorithm using continuous wavelet transform (CWT), fast CWT and Short-Time Fourier's transforms.

We train our models using simulated gravitational wave signals from numerical relativity simulations of supernova explosions detected by the interferometer LIGO. The transform's choice can influence the models' behaviour and, therefore, their efficiency in detecting gravitational wave signals from core-collapsed supernovae with high sensitivity and specificity.

Analytics in Retail

Cluster: Analytics and Data Science
Invited session
Chair: *Bárbara Díaz*

1 - The Effect of Pregnancy and Childbirth on Consumption Behavior

Veronica Diaz, *Ricardo Montoya*, *Oded Netzer*

Major life transitions, such as relocation, a new job, pregnancy, and the birth of a child, can have significant implications on one's lifestyle and consumption patterns. In this research, we study how the consumption behavior of first-time parents is affected, both during pregnancy and after birth. We combine a unique dataset identifying precisely the date of childbirth with supermarket credit card data. We use detailed supermarket transactions and aggregated purchases made at different external companies using the credit card to investigate the causal relationship between pregnancy/childbirth and consumption. We combine a difference-in-differences approach with a causal random forest model matching each first-time parent with comparable non-parents. Grocery purchase behavior is significantly affected during pregnancy and after childbirth; in particular, we identified a significant decrease in total spending and purchasing frequency during the first quarter of pregnancy, and these purchase behaviors increased from the last quarter until the baby was one year old. We also identified significant changes in spending on diverse categories, such as beauty care and pet-related products, decreasing after birth.

2 - Synthetic control evaluation as a predictive tool for estimating the demand of new sellers in e-commerce platforms

Bárbara Díaz, *Luis Aburto*, *Felipe Lago*, *Diego Machado*

Making accurate and reliable sales forecasts is a crucial element for any e-commerce platform, where there are several factors influencing its assertiveness considering the high volatility of the time series. Univariate prediction models have been used in the e-ecommerce platform analyzed, modelling new sellers with poor accuracy due to the little information they have about their sales. The proposed solution is based on synthetic control, where information from the rest of the sellers is used to make predictions for the new seller, assigning different weights according to how similar they are, also related with initial characteristics. As a result, the model can reduce the average WMAPE by 29.73% over the first 10 weeks, compared to the current solution based on LightGBM, observing sellers from an out-of-sample set. In addition, information regarding prices and certain categories of economic activities improves the fitting capacity for prediction.

3 - Applying machine learning in product categorization for e-commerce. A Latin American technology-based case study.

Pablo B. Savian, *Andrea G. Seminario*, *Milagros Tevez Sauco*, *Julián E. Tornillo*, *Guadalupe Pascal*

The epidemiological context caused by COVID-19 has strongly influenced the e-commerce industry; during 2020 and 2021, several health regulations were implemented, with critical impact on commercial activities, generating constraints and limitations. In this context, e-commerce has positioned itself as convenient for established and emerging businesses. This sales channel has experienced a growth rate of 27.6% and 37% in Latin America; it has been sustained to the present day, despite certain restrictions left behind. Most experts predict a sustained growth of the e-commerce sector in the following years, with the digital transformation of businesses and enterprises serving as a critical driver. Indeed, they expected the trend to continue well into 2023 and beyond, highlighting the ongoing importance and relevance of e-commerce in the global marketplace. In light of this growth, many challenges and issues have emerged across various sectors to meet end consumers' expectations and demands. Market research has demonstrated consumers are becoming increasingly exacting in their requirements over time, with logistics playing a pivotal role. Likewise, the growing range of products available through e-commerce channels and the heightened emphasis on rapid delivery times necessitate the development of a rigorous product categorization system, capable of providing effective classification and analysis. Consequently, decision-making in both operational and commercial domains has become increasingly complex. As a preliminary step, we propose improving an algorithm to categorize products into distinct categories based on the non-standardized field of product descriptions available in online publications, using text mining and NLP. Once the categorization process is complete, we could apply advanced descriptive and predictive techniques to gain a comprehensive understanding of the behavior of each category over time. The dataset is from a Latin American technology-based start-up, providing a platform to centralize purchase orders generated across several e-commerce channels; it provides extensive logistical services, spanning the entire supply chain from the first mile to the last. The dataset provides five million shipments in the last three years from more than 1500 sellers. The nature of the sellers is diverse, ranging from small-scale entrepreneurs to large-scale corporations, with products and sizes spanning the spectrum.

Predictive Analytics of Time Series

Cluster: Analytics and Data Science
Invited session
Chair: *Olga Usuga*

1 - Predictive analytics for the remaining useful life of electric vehicle batteries
Olga Usuga, *Catherine Rincón*, *Carmen Patino-Rodriguez*, *Fernando Guevara*, *Freddy Hernandez*

Predicting the remaining useful life (RUL) of an electric vehicle battery is a complex challenge and fundamental, since its modeling and prediction imply the degradation of the battery over time. The degradation is carried out by different physicochemical reactions, and it presents a non-linear behavior making its modeling and precision difficult. The prediction of the RUL has been carried out using different methodologies; however, it has not been integrated into a methodology combining architectures reducing noise in the data taken from sensors.

In this research, we used supervised methods, such as support vector regression, decision tree regression, Long Short-Term Memory Units (LSTM), neural networks, convolutional neural networks (CNN), and CNN-LSTM neural networks, enabling data noise reduction and capturing long-term dependencies for prediction.

The models were validated through data collected in real-time from the critical component of an electric two-wheeled vehicle from Medellín, Colombia, containing topographic, environmental, and vehicular variables used to predict the RUL. The CNN-LSTM model predicts RUL with high precision, with RMSE values below 8%. This research compares the results from supervised models, showing high precision in using two neural networks.

2 - Nowcasting GDP by prefecture using monthly data
Nariyasu Yamasawa

Nowcasting GDP is important for a policy-maker and a business person, especially under the pandemic situation. We estimate monthly GDP in Japan by 47 prefectures by monthly data. For the manufacturing and construction industry, official monthly data are available by prefecture, but, for the service industry, we have only country level data. To make prefecture data, we conduct Cluster Analysis and estimate each prefecture data by regression. For the latest month, we estimate monthly GDP in Japan by official survey data and can provide useful information about the present economic situation by region.

3 - Time Series Forecast Model Accuracy and Validation: A Case Study
Xin James He

This research investigates time series forecasting models with respect to model accuracy and validation; their validation is one of the major challenges to more accurate forecasting results in business finance, social economics, and stock and oil markets performance. Even with the help of recent development in deep learning and big data algorithms, there has not been a consensual strategy applicable to all time series forecasting models in terms of forecasting accuracy and validation. Since time series data is not necessarily independent and identically distributed in general, it does not guarantee the future performance will repeat in the same pattern as in the historical data, regardless of how well the forecasting model fits the training data. As a case study, we first forecast the U.S. gasoline price, both in terms of univariate time series forecasting models, such as exponential smoothing and autoregressive integrated moving average, and multivariate time series forecasting models, such as time series regression models. We then compare the forecasting model accuracy either using Out-of-Sample or Cross Validation methods on the data January 2002 through November 2022. For Out-of-Sample validation, the forecast accuracy is computed by comparing the RMSE on the training data (2002-2021) against the test data (Jan 2022 - Nov 2022). The cross-validation method in this research consists of a series of test sets, each with a single observation during the period Jan 2022 - Nov 2022. The corresponding training set consists only of observations occurring prior to the observation forming the test set, and the forecast accuracy is computed by averaging over the test sets. Managerial implications and future research directions are also discussed.

Risk Prediction

Cluster: Analytics and Data Science
Invited session
Chair: *Hector Cancela*

1 - Uncertainty and scenario reduction in material resources allocation in the scheduling of offshore rigs: a machine learning approach
Rachel Ventriglia, *Leonardo S. L. Bastos*, *Luana Mesquita Carrilho*, *João Gabriel Gelli*, *Gabriela Ribas Klein*, *Guilherme Almeida*

Material resource planning is an important part of supply chain management; tasks in the supply chain need materials and resources to be executed, thus allocating resources correctly is an important part of task scheduling. In real scenarios, tasks' execution is subject to uncertainties affecting schedules, however, due to various factors, such as material availability, task demand or external factors. For this reason, allocating materials stochastically, considering various scenarios of scheduling, could assist companies to make better planning decisions. On the other hand, an increase in the number of scenarios could result in computational times being extremely high and impacting operational decision-making. We propose a methodology to evaluate and to identify representative scenarios of uncertainty in strategic planning schedules in a large oil and gas company. Construction tasks for subsea wells require the use of resources, such as rigs, and planning the schedule of these operations involves the sizing of various materials and services necessary for their execution. Allocating tools and services to rig tasks is an important part of the rig scheduling in the oil and gas industry and involves several factors, such as tool availability and demand for each task. In addition, there are uncertainties associated with planning, due to changes in the start date and duration of tasks. To deal with the risk and uncertainties of resource availability, the company calculates the demand for tools and services stochastically, considering different scenarios of the rig schedule. Currently, there is a large number of scenarios and little understanding of their impact in terms of resource allocation decision, leading to conservative solutions to achieve the desired service level. With the use of unsupervised techniques, such as k-means, and similarity measures, such as Wasserstein and Dynamic Time Warping, we compared and identified scenarios under the uncertainty of task release dates and duration, considering serial correlation of tasks in the rig schedule. We performed analysis of scenarios generated by the company; developed a scenario reduction methodology applied to assess the stochastic nature in rig schedules; and applied scenario reduction models capable of better assisting the company in its decision-making process.

2 - Improving Bayesian Network Learning for Project Risk Management Using Deep Generative Models on Small Datasets
Duvan Camilo David Higuita, *Ken-ichi Suzuki*

Project risk management can benefit from Bayesian Network (BN) models, but learning BNs from small datasets, common in this field, is challenging. Current approaches, such as bootstrapping, Noisy-OR gates, bi-objective optimization, and prior knowledge constraints, have been explored to tackle this issue. This paper investigates an alternative method: using Deep Generative Models (DGMs) to approximate the underlying data distribution and generate synthetic data for dataset augmentation.

This research determines whether DGMs can improve BN structure and parameter learning for project risk management and identifies the

optimal dataset size, number of synthetic data points, and DGM architecture. We evaluate the effectiveness of this approach on synthetic benchmark BNs (Asia, Sports, Alarm, Insurance, and own synthetic BN) and real-world project data from a mining company. The datasets were augmented using TVAE, CTGAN, and a commercial DGM (Mostly AI).

Augmenting with five times more synthetic data than the original dataset produced more consistent outcomes. For structure learning, augmented datasets led to better Bayesian Information Criterion (BIC) scores, but not necessarily better Structural Hamming Distance (SHD) scores. Parameter learning improved for small networks, and the performance of the DGMs was influenced by their ability to approximate the true data distribution. In the real-world project risk case, prediction accuracy improved using the augmented data.

Deep generative models offer a promising alternative for improving BN learning and fitting in project risk management and possibly other disciplines. Further research should explore the generalizability of this approach across various domains.

3 - Prediction of Rail Remaining Lifetime Using Machine Learning

Rodrigo de Alvarenga Rosa, *Gledson Rocha*, *Bruna Santos Neves*

Rolling stock wheels touch the rails forcing them to be changed, leading to high maintenance costs; methods to predict the remaining lifetime of the rail are very important, but the available methods cannot reflect all specific railway characteristics. This paper uses a K-Nearest Neighbors (k-NN) algorithm to predict the remaining lifetime of the rails. For the training, test, and validation, it used data from Vitória Minas Railway (EFVM), Brazil, gathered in the period of April 2011 to November 2017 (6 years and 8 months). Twelve k-NN configurations were tested using a dataset with 11,187,480 records; after cleansing, 1,275,034 records were used: 1,100,000 for training and validation and 175,034 for testing. The remaining lifetime is calculated in 4 categories: month; quarter; semester; and year. Data was normalized, because variables have different numerical quantities, presenting no outlier. Pearson correlation analysis was conducted and indicated low correlations values. Python v.3.7 with Scikit-Learn v.0.20.3 were used to implement k-NN. The following five metrics were used: Accuracy; F1-score; Hit rate; False positives; and False negatives. k-fold cross-validation with f=10 was used. The k nearest neighbors investigated were k=5 (the best after validation), 7 and 9. Configurations with k=5 were tested using the weights saved in the training and validating process. False positives represent the need to change the rail after its lifetime, leading to a possible rail failure (very dangerous); false negatives represent the need to change the rail before its lifetime, leading to a possible financial impact, but it is not critical. Accuracy values were between 0.93274 and 0.97427 and F1-scores between 0.93276 and 0.97329. The best Accuracy and F1-score were obtained for the category year. k-NN hits were found concentrated in the diagonal of the confusion matrix, the most desirable outcome. False positives were between 1.31% (year) and 3.14% (month); although an undesirable outcome, their values are very low; false negatives were between 1.26% (year) and 3.59% (month). Distances from the diagonal of the confusion matrix to the false positive and false negative were less than 2 semesters, a safe period to change the rails. These results are more expressive when considering a prediction period of about 7 years, while in the actual manual process they predict only 3 years ahead. For future research, we suggest testing XGBoost and ROC curve metric.

4 - Variance and computational effort of the Creation Spectrum and the F- Monte Carlo network reliability estimation methods

Hector Cancela, *Leslie Murray*, *Gerardo Rubino*

The context of this work is the classical static homogeneous network reliability model, where the network topology is given by a graph G = (V,E), with |V| = n and |E| = m. The links can fail with identical distributions (failure probability q=1-p), the nodes are perfect. The network is operational when a given condition is fulfilled; usually, network up means a subset K of the nodes is connected by means of the operational links, and network down means the subset K is disconnected. The network reliability is the probability the network is in an operational state (or configuration); as its computation is an NP-hard problem, an alternative, much explored in literature, is the use of Monte Carlo methods to estimate its value.

We revisit the standard Monte Carlo method and two variance reduction methods from literature, the Creation Spectrum and the F-Monte Carlo methods. We present analytical expressions for the variance of the reliability simulation estimators - useful to understand the precision attainable. We also present analytical expressions for the computational effort of these methods, under the hypothesis the main cost of the methods is related to the step of computing the network up condition (usually a DFS or BFS search), contributing to the study of these methods and their performance. Having analytical formulas for the variance and the computational effort is significant to understand the tradeoffs between precision and computing time of the methods.

Analytics for Decision Making

Cluster: Analytics and Data Science
Invited session
Chair: *Mariko Ito*

1 - Characteristics in point process of collective decision-making and group performance

Mariko Ito

The timing of an individual to make a decision significantly depends on their confidence or the amount of information they have [1]. Kurvers et al. (2015) empirically examined the self-organisation of individuals' timings to express their opinions in collective decision-making [2]. They conducted an experiment where subjects were allowed to respond at any time for a binary choice problem and showed informative individuals tend to answer earlier than others. While the decision order among individuals and its effect on group performance were mainly investigated in the previous study, I focused on the temporal distribution of their decision timings in the present study. For example, the situation where many individuals express their opinions in a short period could indicate the existence of important, relied upon information, and it could also be associated with the credibility of their decision-making. I analysed the data in Kurvers et al. (2015) [2] by considering the point process of individuals' respondence, the series of times each individual responded to a given problem. For the evaluation of the point process, I investigated the strength of burstiness, standing for the situation where events frequently occur in short periods while they rarely occur in long periods, i.e., the temporal heterogeneity in event occurrence. I found the strength of burstiness was correlated with the group performance, indicating individuals' decision timings can reflect the quality of collective decision-making. I also determined opinion expressions significantly triggering responses of other individuals by considering a Hawkes process model, where an excitation relationship between events is assumed. I evaluated the characteristics of these triggers based on their opinions against their predecessors'. [1] Ratcliff et al., Trends Cogn. Sci., 2016. [2] Kurvers et al., R. Soc. Open Sci., 2015.

2 - Deep Contolled Learning for Inventory Control

Tarkan Temizoz

Inventory control is a critical problem faced by various industries to optimize their profits and customer satisfaction. Traditional heuristics and linear programming approaches may be insufficient, however, to address the complexity of stochastic inventory control problems. Therefore, there is a growing need for more advanced methods, such as deep reinforcement learning (DRL), to tackle these problems. In this paper, we propose a novel DRL algorithm, named deep controlled learning (DCL), specifically designed to handle highly stochastic Markov decision processes (MDPs) in inventory control. The DCL algorithm is a classification-based approximate policy iteration, combining a well-known bandit algorithm with common random numbers (CRN), to address the high stochasticity and variance typically observed in inventory control problems. Moreover, DCL can use modern

hardware capabilities to achieve efficient parallelization, allowing simulation to be distributed across many computing clusters and threads. These modifications and the use of powerful neural networks for policy representation make DCL a suitable candidate for addressing many problems from inventory systems. To evaluate the performance of DCL, we conducted experiments on three inventory problems - lost sales inventory control, perishable inventory systems, and inventory systems with random lead times. Our results demonstrate superior DCL performance against the state-of-the-art heuristics in all instances tested, achieving an optimality gap of at most 0.1% and outperforming the benchmarks by order of magnitude. Moreover, DCL uses the same hyperparameter set across all experiments, showing a robust performance without hyperparameter tuning. Our bandit algorithm, equipped with CRN, decreases the simulation time by up to 100 times. The proposed algorithmic improvements made in the context of classification-based policy iteration, particularly in the efficient simulation mechanism, are very promising for many highly stochastic MDPs. This is the first general-purpose DRL algorithm to demonstrate remarkable performance in three inventory problems, without remodeling or hyperparameter tuning. Our approach is unique; it can potentially be a proof-of-concept and be adopted by practitioners due to its superior performance.

3 - Data science for digital transformation: application and insights towards Industry 5.0

Julián E. Tornillo, *Guadalupe Pascal*, *Federico Walas Mateo*, *Andrés Redchuk*

The business world is a complex field having undergone profound changes in the last decades. In particular, between 2010 and 2015 a worldwide trend toward the integration and interconnection of technologies, such as the Internet of Things (IoT), Big Data, 3D printing, and artificial intelligence, has developed to shape cyber-physical systems increasing industrial productivity and contributing to the development of companies in a dynamic and highly competitive environment. In this context, a strong impact is generated in products and services offered to the market, as well as on processes, the environment, and people, and constitutes the paradigm of the fourth industrial revolution, commonly called Industry 4.0. This paradigm is under review, since it does not place the socioeconomic and environmental impact of digital transformation at the center of the discussion, giving rise to the paradigm of Industry 5.0 or smart industry.

All the enabling technologies of the smart industry are intensive in using and exploiting data; in this way, data collection, depuration, treatment, analysis, and visualization play fundamental roles in industrial development. In this sense, one of the concepts most widely adopted and disseminated globally is data science based on its robustness from a scientific perspective and its potential to encompass all activities related to data processing, whatever the field of application.

This work studies the role of data science in adopting the Industrial Internet of Things (IIoT), Machine Learning, and big data analytics to improve industrial processes based on an Industry 5.0 model. We present a conceptual framework of the main problems related to digital transformation models and a model for implementing artificial intelligence in Industry 5.0, considering the human factor.

4 - One Analytical Framework of Societal Risk Transfer along the Event Evolution

Xijin Tang, *Zhihua Yan*

A variety of analytics have been proposed for a large group of tasks concerning analyzing information carried or disseminated via social media, and the analytical results have been widely used for various purposes. Besides sentiments being widely measured, societal risks need more attention, especially for various levels of societal governance.

This paper introduces an analytical framework to capture societal risks and their transfers, along the evolution of the concerned events addressed by social media streams; it includes three major tasks to fulfill. First, it generates the storyline to depict the event evolution, constructing one dynamic network. At each time stamp, a word co-occurrence network is constructed, while the Louvain algorithm is applied to acquire word clusters for identification of events (nodes in the dynamic network). We employ the event migration metric to build the link between events; the main evolutionary paths of events are identified, and the structures of event evolution, such as event formation, event merging and event split, are also exposed.

Second, it identifies the societal risks of each event (node) in the dynamic network, achieved via traditional machine learning. We have one corpus on societal risks including 7 risk categories - national security, economy and finance, public morals, daily life, societal stability, government management, and resources and environments. Each node (event) in the dynamic network is identified with one label (either one of the 7 societal risks or risk-free), then the risk transfer can be tracked, analyzing each main path of event evolution. Event risks vary at different stages of the whole event lifecycle.

Third, it measures the risk of each event; when combined with the transfer probability of the event, the probability of risk transfer is also defined.

We provide a case to illustrate a dynamic network of evolving structure, with the risk labeled events and transfer probabilities based on a Helmet Incident in Weibo in 2019. With this analytical framework, we may further predict future possible events by deep learning models and their risk, so as to provide effective support for decision-makers.

Reliability

Cluster: Applied Probability and Statistics
Invited session
Chair: *Tamara Fernandez*

1 - Exact reliability optimization for series-parallel graphs using convex envelope

Javiera Barrera, *Eduardo Moreno*, *Gonzalo Munoz*

Given its wide spectrum of applications, the classical problem of all-terminal network reliability evaluation remains a highly relevant problem in network design. The associated optimization problem—to find a network with the best possible reliability under multiple constraints—presents an even more complex challenge, addressed in the scientific literature, but usually under strong assumptions over failures probabilities and/or the network topology. In this work, we propose a novel reliability optimization framework for network design with failures probabilities, independent but not necessarily identical. We leverage the linear-time evaluation procedure for network reliability in the series-parallel graphs of Satyanarayana and Wood (1985) to formulate the reliability optimization problem as a mixed-integer nonlinear optimization problem. To solve this nonconvex problem, we use classical convex envelopes of bilinear functions, introduce custom cutting planes, and propose a new family of convex envelopes for expressions appearing in the evaluation of network reliability. Furthermore, we exploit the refinements produced by spatial branch-and-bound to locally strengthen our convex relaxations. Using our framework, one can efficiently obtain optimal solutions in challenging instances of this problem.

2 - Reliability of telecommunication networks, considering dependence on power supply in case of seismic failures

Dora Jimenez, *Javiera Barrera*, *Hector Cancela*

The reliability of telecommunication networks has become relevant as they have acquired a leading role in daily activities; they are part of critical infrastructures. Since earthquakes are one of the least predictable extreme events and, at the same time, have a high level of impact on the operability of networks, we propose a seismic risk analysis to estimate the operability of the network after these events. This study uses the Probabilistic Seismic Hazard Analysis method to estimate the network element status after an earthquake. We study the reliability of a telecommunications network, dependent on the power grid supply, and evaluate how its operability is affected by earthquakes causing infrastructure to fail or component unavailability, due to lack of power. We propose a network dependency model, simple and abstract enough to have a reasonable computational cost, while able to capture critical component infrastructure robustness and terrain characteristics. When evaluating proposals for the design of telecommunication networks, it

is not enough to consider its own infrastructure; performance and dependence on other networks, such as the electricity grid allowing it to operate, must also be taken into account. For this analysis, we use connectivity reliability metrics.

3 - Asymptotic systemic failure times of mixed coherent systems
Guido Lagos

In this work, we show a limit result for the probability of a system being in an operational state (i.e., working), as the size of the system grows to infinity. More specifically, we consider a sequence of mixed coherent systems whose components are homogeneous and non-repairable, with failure times of its components governed by a Lévy-frailty Marshall-Olkin distribution — a distribution allowing for simultaneous failures. Under mild conditions, the system failure time converges in distribution to a first-passage time of a Lévy subordinator process. To illustrate, we examine a parametrical family of systems, where the time of systemic failure converges to an exponential distribution. This is the first result to tackle the asymptotic behavior of system failure time, as the number of components of the system grows.

4 - A Kernel Method for Testing Factorial Designs in Survival Analysis
Tamara Fernandez

In this talk, I will present a new method for hypothesis testing in the context of factorial designs for right-censored data; our method combines well-known methodology in Survival Analysis and Machine Learning: the weighted log-rank test and kernel methods. We provide two methods - one for rejecting the global null hypothesis and another to identify the specific hypotheses in the contrast matrix being rejected. Additionally, we provide theoretical results giving support to our testing procedures, and we evaluate the performance of our methods in several simulated and real life data examples, showing our methods are competitive and very robust. Joint work: Marc ditzhaus (Technische Universität Dortmund, Germany) and Nicolas Rivera (Universidad de Valparaíso, Chile).

Applied Probability in Quality and Energy

Cluster: Applied Probability and Statistics
Invited session
Chair: *Young H. Chun*

1 - Comparison of power flow models in a queuing framework
Mark Christianen, *Maria Vlasiou*, *Bert Zwart*

The electric grid is facing major challenges, mainly caused by accelerating energy transition and active adoption of renewable generation; this leads to network capacity shortages for both generation and demand in electricity grids needing to be addressed and controlled. Managing the daily operation of the grid requires accurate modeling of power flows, satisfying all physical and operational constraints. We consider the Distflow and the Linearized Distflow models of the power flow in the grid and highlight differences between the two models, for example, in terms of stability, when they are used in a queuing framework. Furthermore, we perform an in-depth asymptotic analysis of a specific equation emerging as an approximation of voltages under the Distflow model.

2 - The repetitive Cpk sampling plan
Antonio Costa

The index Cpk quantifies a process's productivity within upper and lower specified limits (USL/LSL). In the last two decades, the sample estimator SCpk of the capability index Cpk has also been used to decide a lot's acceptability; if the SCpk value of a sample of size n, randomly taken from the lot, is lower/larger than a threshold, then the lot is rejected/accepted. The sampling plan based on the SCpk value is known as the Cpk sampling plan and in recent publications, it has been combined with the repetitive sampling scheme. In short, with the repetitive sampling scheme, the Cpk sampling plan might be applied m times, and, consequently, the lot has m chances to be accepted. If the Cpk sampling plan is applied m times and the lot is not accepted, then it is finally rejected. In all of the recent publications, the focus has been the correct optimization where the alpha risk is really respected. These researchers did not pay attention to the fact the average number of inspected items per lot (ANI) the repetitive Cpk sampling plan (where m>1) requires, to decide the lot's acceptability, is larger than the sample size n of the standard Cpk sampling plan (where m=1), and in consequence the repetitive sampling strategy is not recommended. Currently, we are investigating other sampling strategies, where the ANI is lower than the sample size n. An interesting sampling strategy consists of combining the information of the inspected samples; for instance, the double sampling plan by attribute works with d1 and d1+d2, where d1 is the number of defectives in the first sample, and d2 is the number of defectives in the second sample. If d1 =Re1) the lot is accepted (rejected); otherwise, a second sample is inspected, and the lot is accepted when d1+d2

3 - Bayesian Inspection Plan for Defective Items in the Presence of Inspection Errors
Young H. Chun

Consider a manufacturing process producing certain items, components, or products; each produced item is either defective (i.e., nonconforming) or non-defective (i.e., conforming to desired specifications). All items are screened to detect and eliminate any defective items, but the screening procedure is error-prone, with an unknow error rate. In the presence of inspection errors, some defective items may pass the screening procedure and subsequently be sold to the market. Thus, a particularly important task in quality management is to accurately estimate the proportion of defective items undiscovered during the screening procedure.

In this paper, we consider the problem of estimating (i) the unknown error rate of a screening procedure and (ii) the number of defective items still remaining in the lot. For the estimation of two unknown variables, we propose a Bayesian model incorporating prior knowledge and inspection results. Using Gibbs sampling in Bayesian analysis, we combine the prior information on the two unknown variables with the sample information and successfully derive the posterior distribution of the unknown detection probability and the number of defective items. We can easily find all the necessary information, such as point and interval estimates of the unknown variables, from the posterior probability distributions.

With an illustrative example, the same inspection model can be applied to the airport security screening procedure, an important topic in aviation security. Each passenger or a checked-in bag is labeled as either "defective" or "non-defective". The error rate of the security check point is unknown, and some of the "defective" passengers or baggage may pass the screening procedure. Using the Bayesian inspection model, we can accurately estimate the unknown error rate of the security check point and the number of passengers carrying prohibited items.

Applied Probability in Finance and Project Management

Cluster: Applied Probability and Statistics
Invited session
Chair: *Hachmi Ben Ameur*

1 - The connectedness of cryptocurrencies
Barbara Będowska-Sójka, *Piotr Wójcik*

The cryptocurrency market is evolving rapidly; Bitcoin, the first decentralized digital currency, is considered to be the main representative of coins, but a number of competing cryptocurrencies have emerged on the market. Cryptocurrencies play an important role in financial markets, as digital instruments existing outside of central banks' control and authority. This market has experienced several rises, reaching peaks in January 2018, May 2021 and November 2021, followed by several declines. These instruments are highly volatile, and their volatility tends to spill over into the entire market. Therefore, the connectedness of the system is important for market systematic risk.

This article explores the connectedness in the cryptocurrency market, examining the spillovers in volatility for the 100 most capitalized currencies, constantly traded between 2017 and 2022. Risk on the cryptocurrency market can be perceived from several perspectives, but we focus on the systemic risk for the whole market - this is crucial for risk management. We examine spillovers both in the static approach for the full sample and the dynamic approach in the moving window. LASSO method is applied in the estimation of the huge multidimensional system, and social network tools are applied to visualise the volatility dependencies between cryptocurrencies. In the dynamic approach, we focus on system-wide connectedness over time to indicate periods of higher risk.

2 - Dynamic shift scheduling with lead times and uncertain project durations
Lieke van der Heide, *Bram de Jonge*, *Onur Kilic*, *Dirk Pieter van Donk*

Large-scale infrastructure projects, such as road maintenance or renewals, are subject to a magnitude of uncertainties during their execution; projects might progress faster than anticipated, due to favorable weather, or delay, if unexpected complications are encountered. Additional work hours, such as overtime or weekend shifts, are commonly used to reduce delays. These costly interventions require careful planning, especially challenging in the face of uncertainties in project durations. Moreover, lead times (i.e., scheduling shifts ahead of their execution) are common in practice and further increase the difficulty of planning. The current study is motivated by this observation; it focuses on the dynamic shift scheduling problem with lead times to minimize the expected cost of completing a project before its deadline. Previous studies have identified various sources of uncertainties in large-scale construction projects and highlighted the importance of accurate duration forecasts, as well as effective workforce planning. In this context, the decision-making problems associated with workforce planning are typically statically addressed. That is, all uncertainties are assumed to be known in advance, and workforce planning is fixed at the outset, so expected costs are minimized, while ensuring with a predetermined probability the project is completed before its deadline. In contrast, our study adopts a dynamic approach, incorporating evolving uncertainties emerging as the project progresses. To this end, we use the concept of the Martingale model of forecast evolution, a comprehensive probabilistic model capturing how forecasts evolve over time, enabling us to formulate the dynamic shift scheduling problem with lead times as a stochastic dynamic program. Our modeling approach is highly versatile; it can accommodate various practical features, such as multiple project phases with different workloads and pay-offs, and distinct reward and penalty schemes based on the completion time. The resulting dynamic program suffers from the curse of dimensionality due to lead times; hence, it cannot be solved to optimality in reasonable computational times when the lead time is high. Therefore, we propose straightforward threshold policies to determine when to schedule additional shifts. These simple policies can be very effective in various real-life scenarios.

3 - On the Notion of Ambiguity and the Optimal Portfolio Allocation: Illustrative Examples and Empirical Evidence
Hachmi Ben Ameur, *Jean-Luc Prigent*, *Zied Ftiti*, *Wael Louhichi*

The effect of ambiguity on financial markets is still a matter of debate. As in almost every decision in life, we are confronted with ambiguity, namely uncertainty about the true probabilities. Nevertheless, this dimension of uncertainty is often ignored, even though ambiguity is widely present in financial markets, and its presence can have substantial effects. A typical example of extreme ambiguity is a financial crisis, when considerable uncertainty emerges and investors' behaviors are largely affected. Thus, it is essential to understand the effect of ambiguity on financial markets. This paper analyzes the optimality of financial portfolio allocations in the ambiguity framework. First, we introduce two fundamental statistical tools to measure ambiguity on financial data, namely the Wasserstein metric and the Kullback-Leibler divergence; they measure how close probability distributions are to a given expected probability distribution. These two criteria allow, in particular, to measure ambiguity during financial crisis; then, we consider the standard dynamic allocation on a benchmark risky asset with random parameters. Using results of porfolio allocation of Wachter (2002), we show explicitly how these two ambiguity measures impact directly the optimal allocation. Second, we provide a general result about the optimal positioning problem under ambiguity, when the investor exhibits ambiguity aversion in the Anscombe-Aumann framework, using the Maccheroni et al. (2006) approach, including Gilboa and Schmeidler's (1989) multiple priors preferences and Hansen and Sargent's (2001) multiplier preferences. We detail the CRRA case with an ambiguity index based on relative entropy. To determine dynamic ambiguity sets, we compute specific quantiles of both the drift and the volatility; for this, we use various sliding windows. All previous theorectical results are empirically illustrated using S&P500 data from January 2010 to December 2021, having important practical applications in structured portfolio management. Indeed, it is important to take account of uncertainty about the true values of financial parameters when determining the best portfolio profile.

Applied Probability and Stochastic Models

Cluster: Applied Probability and Statistics
Invited session
Chair: *Isaac Meilijson*

1 - Using Network Evolution Laws to Combat Malicious Internet Networks through Deliberate Misrepresentations
Mark Korenblit, *Eugene Levner*

In recent years, artificial intelligence has extensively researched models and algorithms for weakening and destroying malicious complex internet networks. These algorithms are designed to identify critical links and nodes in a dynamic network; removing them should lead to maximum destruction or impairment of the network's functionality. We propose introducing short-term information distortions in key sites, resulting in an incorrect network evolution, equivalent to weakening or destroying the malicious network. Specifically, we investigate the effects of artificial decentralization and fragmentation in the network. To simulate these phenomena, we utilize and enhance a network model (commonly referred to as a "one-max constant-probability network"), based on nonuniform random recursive trees.

2 - Probabilistic Analysis of the Inter-Departure Process from a Multi-Thresholded Queue with Poisson Input
Jie Chen

Inter-departure process from queues, in general, has not been extensively investigated. Legacy method to analyze the inter-departure process applies to a non-policy queue kindred, concluding the departure rate is the same as the arrival rate on statistical average. For application-wise engineering design on a purposeful queuing system, queues with policies have been proposed, analyzed, applied, simulated, verified and implemented, with a majority contributing to the performance evaluation of the system, instead of the inter-departure process analysis. In 2015, researchers in Poland moved forward to provide this analysis for N-policy queue; the directional research has halted since then. Inter-departure process analysis of a queuing system is of utmost importance in communication network engineering. Conventionally, queuing theory has focused on a comprehensive coverage of the performance evaluation of a whole network. On one hand, this canonical study was generic and has not progressed forward with the flux of time. On the other hand, in many research cases, network minors might be

of more realistic investigative value because the internet is not seamlessly a fit whole integral unity; by network minors, I might refer to just a single unity of node device.

In this work, a token-ring system, with three devices arbitrated by a scheduler for off-stream packet departure, has been studied. Each device serves as a portable terminal having Multi-Thresholded queuing control implemented in the abstract MAC layer. The scheduler handles the off-streams from these devices in a TDMA (time division multiple access) manner; the token to be arbitrated is a dedicated time-slot.

The inter-departure time on statistical average is the same as the input rate. Furthermore, the inter-departure process distribution follows a formula of two windowed exponential functions with both amplitudes and exponential indexes relevant to the system configurations. By applying this inter-departure process distribution, average waiting time upon being scheduled can be attained per packet on average, and, henceforth, the overall waiting time per packet within the token-ring system is derived.

3 - Pandemic-motivated queueing with negative network effects
Isaac Meilijson

In a M/M/c/n service facility, n is designed to restrict the number of - and total time spent with - other customers waiting for service; these are pandemic-motivated novel criteria, where the usual waiting loss due to earlier arrivals is complemented with the exposure loss due to later arrivals. Threshold balking strategies are identified as Nash equilibria. This study was initiated by fruitful interaction with colleagues at the Department of Industrial Engineering, University of Chile, on voting precinct design to prevent excessive exposure. The model will be outlined. References [1] Hassin, R., Meilijson, I. and Perlman, Y. (2021). Queueing with Negative Network Effects. Submitted for publication. [2] Meilijson, I. (2020). Voting in the era of Covid-19: an urn model with Bose-Einstein statistics. [3] Meilijson, I., Perlman, Y. (2021). The joint distribution of value and local time of simple random walk and reflected simple random walk. arXiv:2109.15076 [math.PR] [4] Mondschein, S., Olivares, M., Ordonez, F., Schwartz, D., Weintraub, A., Aguayo, C., Canessa, G., Torres, I. (2020). Service design to balance waiting time and infection risk: An application for elections during the COVID-19 pandemic. SSRN.1

Complex Topics in Combinatorial Optimization

Cluster: Combinatorial Optimization
Invited session
Chair: *Silvano Martello*
Chair: *Paolo Toth*
Chair: *Matheus Corrêa*

1 - Algorithmic Tools for Congressional Districting: Fairness via Analytics
David B. Shmoys

The American winner-take-all congressional district system empowers politicians to engineer electoral outcomes by manipulating district boundaries. To date, computational solutions mostly focus on drawing unbiased maps by ignoring political and demographic input and, instead, simply optimizing for compactness and other related metrics. This is a flawed approach, however, because compactness and fairness are orthogonal qualities; to achieve a meaningful notion of fairness, one needs to model political and demographic considerations, using historical data.

We will discuss two papers exploring and developing this perspective. In the first (joint with Wes Gurnee), we present a scalable approach to explicitly optimize for arbitrary piecewise-linear definitions of fairness; this employs a stochastic hierarchical decomposition approach to produce an exponential number of distinct district plans optimizable via a standard set partitioning integer programming formulation. This enables the largest-ever ensemble study of congressional districts, providing insights into the range of possible expected outcomes and the implications of this range on potential definitions of fairness. In the second paper (joint with Nikhil Garg, Wes Gurnee, and David Rothschild), we study the design of multi-member districts (MMDs) where each district elects multiple representatives, potentially through a non-winner-takes-all voting rule (as currently proposed in H.R. 4000). We carry out large-scale analyses for the U.S. House of Representatives under MMDs with different social choice functions, under algorithmically-generated maps optimized for either partisan benefit or proportionality. With three-member districts using Single Transferable Vote, fairness-minded independent commissions can achieve proportional outcomes in every state (up to rounding); this would significantly curtail the power of advantage-seeking partisans to gerrymander. This work opens up a rich research agenda at the intersection of social choice and computational redistricting.

2 - Quantum Computing based Combinatorial Optimization: Applications toward Critical Infrastructure Management
Gabriel San Martin, *Enrique Lopez Droguett*

Solving optimization problems over discrete domains is fundamental in managing critical infrastructure. Combinatorial optimization has been extensively used to enhance the infrastructure's resilience against natural and anthropogenic hazards. Tasks, such as maintenance scheduling and emergency response planning, require finding optimal actions to improve the system's performance during disruptions. These problems are subject to the well-known "curse of dimensionality," however, where the solution size grows in a combinatorial manner with the number of decision variables in the system. Within the context of critical infrastructures, this is an important consideration given the increasing size and complexity of engineering systems. The ill-conditioned relationship between decision variable space and the size of the overall makes a traditional exhaustive search approach infeasible for most practical applications. While for a subset of optimization instances, one can find exact solutions in a polynomial time, many relevant problems are NP-hard, and, therefore, they are limited to be solved using approximate techniques. Current state-of-the-art approaches for NP-hard problems are mostly built upon meta-heuristic techniques, such as simulated annealing and genetic algorithms. With the recent surge in the availability of quantum computing hardware and the subsequent increase in interest in the field, quantum-based optimization techniques developed over the past decade have resurfaced within the research community. Among these techniques, a promising alternative harnessing the more general gate-based quantum architecture is the Quantum Approximate Optimization Algorithm (QAOA). Current research on this technique is limited to abstract examples, however, usually tackling graph partition problems of varying complexity, without anchoring them to a particular application. To fill this research gap, in this work, we present two applications of QAOA toward critical infrastructure management, specifically in the areas of structural health monitoring and network protection. From these two applications, we draw relevant conclusions regarding the future opportunities of the technology, and, most importantly, the challenges quantum computing-based optimization will need to tackle to become a feasible option for combinatorial optimization in the near future.

3 - On von Neumann's cellular automata on bi and unidimensional grids
Nei Yoshihiro Soma

Cellular Automata (CA) are machines possessing a discrete model of computation. They consist on a collection of 'cells' disposable in a regular and homogenous grid. These machines appeared in a work of John von Neumann and Stanislaw Ulam in an epoch that the computer had yet to be invented. After John Conway's Game of Life in the 1970's the interested for its study blossomed. The research on CA's gained further momentum with the extensive studies of Stephen Wolfram since the publication of his "Cellular automata as models of complexity" that appeared in Nature (and front-cover). The objective of

the current research study is to offer innovative perspectives on a long-standing unresolved problem first introduced by von Neumann, which pertains to the identification of a general condition for irreversibility of Sigma+-automata, a specific class of two-dimensional cellular automata on square grids. To identify irreversibility in Sigma+-automata, the study adopts the conventional approach of computing the determinant of the adjacency matrices associated with the transition function in a grid graph. The research introduces novel and distinct methods for establishing the determinant of these matrices and presents an optimal algorithm for deriving Sutner's Pi polynomials. Despite the recent advancements and evidence related to von Neumann's problem, the original bidimensional case remains elusive, underscoring the need for continued exploration of the problem.

Dedication: This paper is dedicated to the loving memory of José Prado de Melo (1948–2020), one of the two authors of this study. It is also dedicated to the memory of Fábio Carneiro Mokarzel (1951–2021) and Waldecir João Perrella (1949–2023), who played an essential role in shaping the ideas and approaches presented in this work. The author honors their memory and expresses gratitude for their invaluable contributions to this research.

4 - Reversal, Addition and Complement of Arcs in Digraphs: Formulations and Exact Solution Algorithms
Matheus Corrêa, *Abilio Lucena*

Consider a digraph where operations of addition, complement and reversal of arcs are allowed; distinct costs apply to every different operation; and, for the applications we consider, only one predefined operation is allowed. The objective is to obtain a digraph satisfying certain connectivity requirements at minimum total cost.

Complexity results for the problems we investigate are found in [1]; with a single exception, they are NP-hard and ask for structures where one may eventually superimpose additional layers, to model particular transportation or telecommunication networks. Quite frequently, the connectivity level one requires from the resulting digraphs would reflect the resiliency, flexibility or operational efficiency requirements intended for the physical networks.

Mathematical formulations and exact algorithms are proposed for nine different problems, split into the following two groups: (a) direct extensions of standard multi-flow formulations to the problems we address, and (b) formulations using properly defined cutset inequalities, reflecting the arc operation allowed to be carried out.

For cutset based formulations, algorithms are refined to attain significant speed-ups in the separation of cutset inequalities. More specifically, benefiting from the computational advantages offered by min cut separation over integral points, we apply integer rounding as a heuristic procedure. Accordingly, cutset inequalities are initially separated over integer rounded points, and violated ones are double-checked (for violation) over the corresponding original fractional points.

In our computational experiments, algorithms for multi-flow formulations generally confirmed what was expected from them - good quality dual bounds and strong CPU time dependency on input graph density. Algorithms for cutset formulations also presented no surprise; they run much faster than their multi-flow counterparts, for test instances of medium- and high-density. Nevertheless, the performance of the latter branch-and-cut algorithm is very much dependent on how much flexibility CPLEX and Gurobi allow in the use of these inequalities.

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Combinatorial Optimization Problems Under Uncertainty

Cluster: Combinatorial Optimization
Invited session
Chair: *Anand Subramanian*

Chair: *Teobaldo Bulhões*

1 - A strong compact formulation for the robust knapsack problem with its application to a lifting heuristic for robust cover inequalities
Youngjoo Roh, *Junyoung Kim*, *Kyungsik Lee*

In this study, we consider the robust knapsack problem introduced by Bertsimas and Sim [Operations Research 52(1) pp.35-53, 2004]. Based on the decomposition property of the feasible solution set, we present a compact formulation using the disjunctive programming approach for the problem. Through theoretical analyses, we show the proposed formulation provides tighter linear programming (LP) relaxation bounds compared with existing formulations.

Then, we propose a heuristic procedure for lifting valid inequalities for the robust knapsack problem. Specifically, we devise a lifting heuristic for the robust cover inequality using the LP-relaxation of the proposed formulation. The performance of our lifting heuristic is promising compared to existing lifting methods for robust cover inequalities.

2 - Polynomial time algorithms for network connection problems with interval data
Xudong Hu

In this talk, we will present an approach for dealing with network connection problems, including the shortest path problem and the minimum spanning tree problem, in uncertain environment. The cost on a link/node in a given network falls into an interval instead of a value. Different from the robust model adopting the scenario approach, we introduce two risk models for these problems: minimization of risk sum and minimization of maximum sum. We propose polynomial-time algorithms for solving these problems and conducted computational experiments on algorithms proposed. Our theoretical and computational results show the flexibility of this new approach for decision-makers at different levels of aversion to risk, as well as satisfactory performance of standard CPLEX solver on our model.

3 - A Two-Stage Solution Approach for Electric Vehicle Routing Problem with Uncertain Waiting Times
Merve Keskin, *Nursen Aydin*

In this study, we focus on the electric vehicle routing problem with time windows and stochastic waiting times at recharging stations. This problem is an extension of the classical electric vehicle routing problem with time windows, where the electric vehicles face uncertain waiting times before the recharging service starts, due to limited charging capacity at stations. Unforeseen waiting times at the stations may cause disruption in logistic operations; to address this problem, we develop a two-stage solution approach using Adaptive Large Neighborhood Search and Dynamic Programming. We conduct numerical tests to assess the proposed solution methodology. We also investigate the effect of uncertain waiting times on routing and charging decisions.

4 - A matheuristic approach for a class of vehicle routing problems under time and demand uncertainty
Anand Subramanian, *Carlos Neves*, *Pedro Munari*

This work addresses decision-making under uncertainty in the context of vehicle routing; in broad terms, these problems consist of determining routes for efficiently delivering products to a set of customers by using a fleet of vehicles. They typically involve constraints, such as time windows restricting arrival times at customers and vehicle capacities limiting the quantity of products a vehicle may carry. Often, fleets are also heterogeneous (i.e., vehicles have different travel and fixed costs). Yet another challenge is imposed when we consider uncertainty regarding problem data may highly impact not only the quality, but also the feasibility of solutions.

Devising ways to incorporate uncertainties into existing methods is of extreme importance; hence, we address a class of VRPs under uncertain demands and travel times, considering multiple attributes, such as heterogeneous fleet, multiple depots, and time windows. We assume customer demands and travel times are random variables belonging to a budgeted uncertainty set and approach the problems under the robust optimization paradigm. To solve them, we implement a multi-start

matheuristic combining the iterated local search framework with an exact set partitioning (SP) procedure. The method works by constructing solutions possibly violating customer time windows and vehicle capacities - penalized according to the total amount of violation. Well-known local search operators, carefully adapted to efficiently compute violations in the worst-case scenario, are then used to improve the current solution, and resulting routes are stored in a route pool. The best-known solution is repeatedly perturbed and improved, until a stopping criterion is met. Finally, we attempt to find the optimal combination of routes stored in the pool by solving the SP model, using a mixed integer programming solver.

We conduct computational experiments over several sets of benchmark instances for many particular cases, such as VRPTW, HFVRP, and the classical CVRP. As also done in related works, we perform slight modifications (e.g. increase vehicle capacity or generate uncertainty sets) in each instance, to account for uncertainties and properly assess performance in robust counterparts. Overall, results are promising, as our method achieves best-known solutions in most cases, as well as improves many of the open instances.

Combinatorial Optimization in Logistics, Supply Chains, and Quantum Computing Applications

Cluster: Combinatorial Optimization
Invited session
Chair: *Fred Glover*
Chair: *Gary Kochenberger*

1 - Quadratic Unconstrained Binary Optimization (QUBO) Approach for Supply Chain Applications

Haitao Li, *Gary Kochenberger*, *Fred Glover*

A plethora of optimization applications in supply chains provide an excellent arena for the quadratic unconstrainted binary optimization (QUBO) approach, with the opportunity of using the emerging quantum computing technology. In this talk, we first provide an overview of a variety of combinatorial optimization problems for supply chain decision-making at the strategic, tactical, and operational levels. We then review the reformulation techniques for QUBO, including the general transformation method and the use of known penalty functions. We'll show multiple ways to implement and solve QUBO models, including using the QUBO and/or global optimization solvers in commercially available software, such as Gurobi and GAMS, and applications of various metaheuristics, such as tabu search (TS) and genetic algorithm (GA). In the third part of the presentation, we select several well-known problems and show how they can be transformed and solved by the QUBO approach, including: (i) the facility location problem (FLP) optimizing the strategic design of a supply chain network; (ii) resource planning (RP) at the tactical level optimizing the assignment and utilization of resources; and (iii) a machine scheduling problem optimizing the sequence of jobs to be processed by machine(s) with limited availability.

2 - Resource-constrained multi-stage machining and assembly scheduling with sequential and batch processes

Yu Du, *Yang Wang*

This paper introduces a new scheduling problem, considering resource constraints and multi-stage with sequential and batch processes. The workshop has some orders to make, and each order contains several different products - each composed of multiple semi-products and requiring some assembly. The semi-products are produced by a sequence of machining processes, having two modes: sequential processing and batch processing. Resources are categorized into high and low levels, including machines, personnel and equipment. Due to the complexity, we split orders, products, and semi-products into processes for machining and assembly to transform this problem into a network. For solving the problem, we propose a fast heuristic, combining a parallel schedule generation scheme (P-SGS) with a minimum slack time (MIN-SLK) priority rule. The algorithm divides the scheduling into a series of scheduling cycles. In each scheduling cycle, we first determine the start time of the cycle and generate a temporary schedule for unscheduled processes without considering resource constraints. Then, we apply the MIN-SLK priority rule to sort the candidate processes list and select the process with the highest priority subject to the resource constraints. When all processes are scheduled, the scheduling ends. For 120 randomly generated instances considering different resource capabilities, different order quantities, and time-decentralized and centralized orders, the proposed algorithm obtains a good makespan in a short time. In addition, we also analyze the resource utilization of various resources.

3 - Innovative approaches to optimal production scheduling in highly complex, real-world settings

Marco Better

Manufacturing seats for the automobile industry is a highly unique and specialized process; obtaining good production schedules is critical to the efficiency of the operation. ERP modules and off-the-shelf scheduling solutions cannot achieve the level of customization required to represent the complexity of the operation and its numerous business objectives, rules, and constraints.

A leading global supplier of automotive seating systems at the forefront of business innovation presented us with an urgent need to improve the scheduling of production at its foam parts manufacturing facilities. This client's plants, operating unique, racetrack-style production lines, are very complex, employing between 20 and 60 carriers on each production line, multiple molds per carrier, and 150 to 300+ parts produced monthly for a wide array of customers. Scheduling was being conducted manually, via large excel workbooks, leading to long hours of work for the schedulers, slow response time to disruptions on the shop floor, and inefficient planning to meet changes in customer demand.

We discuss a custom approach to optimize production schedules of foam parts manufacturing for automobile seating. The solution combines mathematical optimization approaches with artificial intelligence techniques and a digital twin simulation model to deliver an end-to-end scheduling solution, informing the production department, as well as procurement, packaging, and shipping. We report on the results for a pilot site where the solution was successfully implemented.

Plans are in progress to deploy the solution in 11 additional sites across North America, Europe, and Asia.

4 - Applied Quadratic Unconstrained Binary Optimization (QUBO) Formulations of Common Machine Learning Algorithms

Anna Hughes, *Gary Kochenberger*, *Fred Glover*

Machine learning has become almost ubiquitous in recent years, with broad applications in scientific research, entertainment and diagnostics; it relies on training a mathematical model on some input data, making the model architecture and parameters robust enough to do the following: (1) determine patterns in the data, (2) make predictions about new data, or (3) generate convincing synthetic data. Optimization plays a pivotal role in machine learning, improving model performance across iterations, while training the model itself to optimize hyperparameters used to construct the model. One optimization model, quadratic unconstrained binary optimization (QUBO), involves minimizing or maximizing some cost function, composed of binary-valued vectors and an upper triangular matrix of real numbers. Some common machine learning models, such as support vector machines, linear regression, and feature selection, can be formulated as QUBO problems. We present implementations of these QUBO machine learning models on real-world data across industries and disciplines. We compare our results, using QUBO solvers, to solutions found using common Python machine learning libraries. Finally, we discuss the practicality, advantages and limitations of employing QUBO formulations in machine learning routines.

Vehicle Routing

Cluster: Combinatorial Optimization
Invited session
Chair: *Gustavo Gatica*

1 - A heuristic method for the close enough traveling salesman problem
Ernesto G. Birgin, *Paula C. R. Ertel*

The traveling salesman problem is one of the most studied combinatorial optimization problems. Given n cities and their pairs of distances, one seeks to find a tour of minimum distance passing through all cities. In the Close Enough TSP variant, it is unnecessary to pass exactly through each city, but through one neighborhood of each city. This problem can be modeled as a continuous optimization problem with integer variables. In this paper, we present a heuristic method to find solutions of the Close Enough TSP, including a constructive heuristic, a local search based on the 2-opt movement and a continuous optimization method of the coordinate block search; for a given permutation, it tries to find a point to be visited in the neighborhood of each city, to minimize the tour length for the given permutation. Numerical experiments illustrate the performance of the proposed method.

2 - A multi-phase methodology for solving distribution problems with limited supply at the depots
Pedro Piñeyro, *Javier de Prado*, *Sandro Moscatelli*, *Libertad Tansini*, *Omar Viera*

We address an extension of the multi-depot vehicle routing problem (MDVRP), where the supply capacity of the depots is limited. The objective is to determine a set of routes starting and ending at each depot, minimizing the total distance travelled and subject to the supply capacity of each depot and the capacities of the vehicles. We refer to this problem as the Capacitated Multi-Depot Vehicle Routing Problem (CMDVRP). Distribution problems, like the CMDVRP, can be found in recent real-life applications, such as emergency facilities location-routing and city logistics problems. The CMDVRP is an NP-hard problem, since it can be considered an extension of the (MDVRP), in turn an extension of the classical Vehicle Routing Problem (VRP). To solve the CMDVRP, we propose a multi-phase methodology based on the "cluster first, route second" approach. The initial phase consists of the assignment of customers to depots, and the final phase produces the routing of the VRPs related to all depots. Between these two phases, there is an intermediate phase of reassigning customers to depots, with the aim of obtaining a high-quality solution in the final routing phase. Detection and reassignment of customers are based on a combination of misplaced-customer criterion and routing algorithms. The complexity of the algorithms used in each phase can be chosen by the decision-makers of the distribution problem, according to their needs and possibilities. In previous research, we studied the performance of the methodology using well-known routing algorithms and comparing the results obtained against a commercial solver, for small-size instances of the CMDVRP. In addition, we analysed the impact of including the intermediate phase of exploration in the methodology by means of a comparative study over ten large instances with different geographical characteristics. Considering the promising results obtained previously, we present here a more detailed version of the methodology, considering additional characteristics of the problem for the assignment and exploration phases. With this new version, we can improve the results obtained previously and solve MDVRP instances from the literature, in a competitive way. Finally, the benefits obtained from adding randomness to select the misplaced customers in the exploration phase will be shown.

3 - Vehicle routing problem with backhauls, time windows and stochastic demand
Gustavo Gatica, *Daniela Quila*, *Daniel Morillo Torres*, *Rodrigo Linfati*, *Jairo Coronado-Hernandez*

A generalization of the vehicle routing problem with backhauls and time windows (VRPBTW) is proposed, with the possible reduction of vehicles and a penalty cost. In addition, it involves a homogeneous vehicle fleet and a single central depot, to enhance certain aspects of the present study. The VRPBTW problem combines temporal and spatial aspects; undoubtedly, this represents a computationally challenging problem. If the variant with uncertain demands is added, it becomes academically interesting; a model is presented to solve the VRPBTW, with time constraints and stochastic demand (SDVRPBTW). Customers are divided into two subsets, delivery and pickup. Each vehicle leaves the depot to deliver commodities to Linehauls customers, but the quantity to be delivered is uncertain. After delivery, commodities are picked up from as many customers as possible (to utilize the vehicle capacity) and returned to the depot. The objective is to minimize the total distance, the number of vehicles to complete the route and the amount of missing demand, due to the variation of demand in each scenario. The problem without uncertainty, posed in the literature as a deterministic routing problem, has known demands. Naturally, a problem with uncertain demand is compared by taking the previously obtained solution with the model without uncertainty. This solution is evaluated in different scenarios with demand changes, to demonstrate, by taking into account the random component, better solutions can be obtained, compared to not considering the uncertainty in the demand. Finding a feasible solution for VRPBTW with a fixed number of vehicles is an NP-Hard problem. Applications of SDVRPBTW arise in both the public and private sectors, such as waste collection scheduling. The problem is addressed by means of a single-stage implementation of a mixed integer linear programming model. Subsequently, different scenarios are generated by simulating the randomness of the problem; random samples are solved using the sample average approximation (SAA) technique, and the candidate solutions are evaluated in a Monte Carlo simulation. The model is implemented with AMPL and solved with CPLEX 12.8.0.0. Its effectiveness is evaluated based on artificial stochastic data adapted from the literature, for small- and medium-sized generated instances (up to 30 nodes).

4 - Exact Separation of Rounded Capacity Inequalities for the Capacitated Vehicle Routing Problem
Konstantin Pavlikov, *Niels Christian Petersen*

The family of Rounded Capacity (RC) inequalities is one of the most important sets of valid inequalities for the Capacitated Vehicle Routing Problem (CVRP). This study considers the problem of separation of violated RC inequalities and develops an exact procedure employing mixed integer linear programming - very efficient for small- and medium-sized problem instances. For larger-scale problem instances, an iterative decomposition approach for exact separation of RC inequalities is developed, combining column and row generation and allowing the introduction of variables only when needed. A computational study demonstrates scalability of the proposed separation routines and provides exact RC-based lower bounds for some of the publicly available unsolved CVRP instances.

Mathematical Models and Metaheuristics for Combinatorial Optimization Problems

Cluster: Combinatorial Optimization
Invited session
Chair: *Paolo Toth*

1 - Metaheuristic Algorithm Based on Tabu Search for Consistent Vehicle Routing Problem
Rodrigo Linfati, *Lucas Barros-Lebanek*, *Esteban Santana-Contreras*, *John Willmer Escobar*

The Vehicle Routing Problem (VRP) is a well-known problem in operations research seeking to minimize the total distance traveled by a fleet of vehicles in serving a set of customers with known demands. Customer satisfaction is often neglected in the VRP, however; to address this, the Consistent Vehicle Routing Problem (ConVRP) was introduced, where the consistency of service is taken into account by either the time of service or the vehicle offering the service. In this

work, a new variant of the ConVRP is proposed, and a mathematical model and a metaheuristic algorithm based on tabu search are presented to solve it. The proposed mathematical model was developed using the AMPL programming language and solved using the commercial solvers CPLEX and Gurobi, while the metaheuristic algorithm was developed in Julia language. To evaluate the efficiency of them, experiments were conducted on structured instances by varying customer distribution (uniform or clustered), depot location, and arrival time to the customer. The experimental results demonstrate the proposed metaheuristic algorithm based on tabu search is highly efficient in producing feasible solutions of high quality. The algorithm outperforms commercial solvers for the mathematical model in terms of computation times and is effective in solving ConVRP instances with varying parameters. The experimental results demonstrate the effectiveness and efficiency of the proposed algorithm, beneficial for real-world applications of vehicle routing problems. In conclusion, the proposed algorithm provides an efficient and effective method for solving ConVRP, considering the consistency of service and offering feasible solutions of high quality in considerably less computation time than commercial solvers for the mathematical model.

2 - Optimizing Forest Harvest Planning Using Mathematical Model and Two-Phase Evolutionary Computation Algorithms

Carlos Rey, *Simón Sandoval*, *Guillermo Cabrera*, *Diego Seco*, *Zheng Li*, *Pierluigi Cerulo*

Forest harvest planning is a complex problem having been studied for several decades in operations research. One technique used for timber extraction is skylines, transporting wood from the surface to a field where it is subsequently transported to other production centers. Minimizing the extraction time of wood and the installation time of these skylines is fundamental to these planning problems. In this work, we present a binary integer mathematical model for planning the installation and removal of trees using skylines. Additionally, we propose novel two-phase algorithmic approaches based on evolutionary computation generating schedules for large-scale problems. Our approach differs from previous work in the field, and we demonstrate its effectiveness by testing it on different real instances. Our algorithm obtains high-quality solutions in reasonable computing times, achieving an average improvement of 8% over another method.

3 - A two-level Hybrid Metaheuristic to Solve the Quota Travelling Salesman Problem with Passengers, Incomplete Ride and Collection Time Optimization

Reinier Fernandez Lopez, *Carlos Contreras-Bolton*, *Rosa Medina*, *Lorena Pradenas*

The Quota Traveling Salesman Problem with Passengers, Incomplete Ride and Collection Time Optimization (QTSP-PIC) is a variant of the Quota Traveling Salesman Problem (QTSP) (Awerbuch et al., 1998; Ilavarasi & Joseph, 2014; Singamsetty et al., 2021), proposed by Silva et al. (2020). The QTSP-PIC models applications where a professional provides services in different locations and offers his vehicle to a mobility system. The problem involves finding a Hamiltonian cycle over a subset of vertices minimizing the cost of the trip and satisfying the quota constraints. In the QTSP-PIC, the seller is the vehicle's driver and can reduce travel costs by sharing the cost with passengers. There are budget constraints and maximum travel time for each person requesting to travel. Each passenger can be transported to the desired destination or an alternative one, since rides are pre-arranged. One of the relevant applications of this problem is to design tourist routes; a tourist must choose the best attractions to visit, and he uses a shared ride system to reach his destination minimizing costs and time (Moosavi Heris et al., 2022; Tlili & Krichen, 2021). Although state-of-the-art algorithms can find good solutions to existing instances, finding good quality solutions in large instances, however, requires large computing times. Therefore, a two-level hybrid algorithm working with the Greedy Randomized Adaptive Procedure (GRASP) and Simulated Annealing (SA) is proposed in this work (TLH-GRASP-SA). Our proposed algorithm operates at two levels over a solution representation, including a set of vertices representing a route, a set representing the origin of the passengers, and a set representing the passenger's destination. The first level of TLH-GRASP-SA applies a GRASP focusing on generating a route with a subset of the vertices to minimize travel costs. Thus, the route is generated by building an initial solution applying a random greedy heuristic and refining the solution through a local search in the hope of finding an improvement. Then, in the second level, SA efficiently assigns the passengers to be picked up, considering the origin and destination of each one and complying with the maximum capacity number of people to transport. Finally, TLH-GRASP-SA is tested on three data sets showing promise and competitive results concerning other algorithms.

4 - Systematic Conservation Planning with Multiple MIP Models for Addressing Spatially Complex Conservation Problems

Eduardo Álvarez-Miranda, *José Salgado-Rojas*, *Virgilio Hermoso*

Systematic conservation planning (SCP) is an essential approach to address increasing biodiversity loss and habitat degradation in the face of anthropogenic pressures and climate change. Spatial complexity in conservation problems often requires advanced techniques to prioritize areas for protection and management, while considering ecological, socio-economic, and political factors. In this manuscript, we propose several Mixed Integer Programming (MIP) models as innovative and efficient tools for tackling spatially complex conservation problems in SCP.

The main contribution of this study is the development and comparison of multiple MIP models integrating spatial and ecological connectivity, species distribution, and other critical factors into the conservation planning process. The MIP models proposed include (i) a basic MIP model for reserve site selection, (ii) a MIP model with spatial connectivity constraints, and (iii) a MIP model incorporating multi-species distribution and habitat quality. These models are designed to address various spatial complexities in conservation problems, such as habitat fragmentation, coordination of actions among realms, and competing land-use demands.

Knapsack and Packing Problems

Cluster: Combinatorial Optimization
Invited session
Chair: *Stefano Novellani*

1 - An integer linear programming formulation for the cutting stock problem with due date

Kelly Cristina Poldi, *Daniel Schulmeister*

We address the cutting problem with due date, referred to in the literature as the Cutting Stock and Scheduling Problem (CSSP). In practical situations, demanded items must be delivered on a stipulated date, so other services, such as painting, drilling and gluing, can be carried out and the final product can be obtained without delay. We combined the objective of minimizing raw material waste and a term penalizing possible delays in the cutting stage; these delays occur when an order is not completed within the agreed period, possibly due to either insufficient capacity or availability of raw material. We propose an integer linear programming formulation for the two-dimensional CSSP; the cutting patterns used are guillotine, non-exact two-stage. A column generation approach was applied to solve some randomly generated instances, and some computational results will be presented.

2 - A lifting heuristic for probabilistic cover inequalities based on the non-convex continuous relaxation for the chance-constrained binary knapsack problem

Junyoung Kim, *Kyungsik Lee*

We propose an efficient lifting heuristic for probabilistic cover inequalities for the chance-constrained binary knapsack problem (CKP), where the weight of each item is a normally distributed random variable independent of the others. We first introduce a non-convex continuous relaxation of the CKP and show the relaxation provides tighter

upper-bounds compared to the existing continuous relaxations. In general, non-convex optimization problems are computationally hard to solve; however, we show the proposed non-convex relaxation can be solved in polynomial-time. Then, we devise a heuristic procedure for lifting probabilistic cover inequalities, using the exact polynomial-time algorithm for the non-convex relaxation. The proposed lifting heuristic outperforms the existing methods in terms of computational efficiency, while the effectiveness of the resulting lifted probabilistic cover inequalities remains competitive compared to the existing lifting procedures.

3 - The k-Best Solutions of the 0-1 Knapsack Problem Algorithms and Applications
Stefano Novellani, *Marco Antonio Boschetti*

The problem of generating the k-best solutions to combinatorial optimization problems is of great interest and has been addressed by many authors, since the early 1970s (see, e.g. Lawler (1972) and Wolsey (1973)). We propose some new algorithms for computing the k-best solutions for the 0-1 Knapsack Problem (KP); they can be very useful, in particular, for developing effective column generation approaches. We first define a basic dynamic programming algorithm, and then we propose an enhanced version improving the performance and allowing for the generation of columns, without specifying their number in advance, as well as the inclusion of additional constraints. We briefly introduce the classical dynamic programming procedure for the KP, and we describe a basic dynamic programming procedure for generating the k-best solutions. Then, we describe the well-known backward recursion for the KP, only generating the optimal solution, and propose the new backward recursion to generate the k-best solutions. The latter algorithm generates only the necessary states and allocates memory dynamically, as needed. These algorithms are also extended to solve the bounded and unbounded versions of the KP. To demonstrate the benefits of the proposed algorithms, we also describe an exact method for the bin packing problem and some of its variants, based on a column generation procedure generating multiple columns at a time. In the computational results, we analyze the performance of the proposed algorithms alone and when embedded in the exact method for the basic bin packing problem and some of its variants.

Lawler, E.L.: A procedure for computing the k best solutions to discrete optimization problems and its application to the shortest path problem. Management Science 18(7), 401-405 (1972) Wolsey, L.A.: Generalized dynamic programming methods in integer programming. Mathematical Programming 4, 222-232 (1973)

Discrete Modelling

Cluster: Combinatorial Optimization
Invited session
Chair: *Jan van Vuuren*

1 - An investigation into deep generative models for optimisation problem solution initialisation
Stephan Nel

In recent years, deep generative models have been shown to be highly effective in generating realistic data within a wide range of applications (such as image/text generation, data synthesis, and data augmentation). The application of deep generative models for solution initialisation is investigated in this paper within the context of unconstrained optimisation. More specifically, a data-driven approach is proposed utilising a deep generative model in the form of a variational autoencoder for generating high-quality initial solutions to unconstrained optimisation problems. The model is trained on a data set of high-quality solutions to the optimisation problem and then used to generate new solutions, similar to those in the data set. To evaluate the effectiveness of the proposed approach, experiments are conducted on a set of unconstrained benchmark optimisation problems. The approach is compared with several standard initialisation methods (such as random initialisation).

2 - A generic framework for modelling customer invoice payment predictions
Willem Moore

Apart from a select few retailers and small 'high street' shops, most companies offer credit sales to their customers, providing a financial service as well as their basic services or products. By offering clients attractive credit terms on sales, a company may increase its turnover, but granting credit also incurs the cost of money tied up in accounts receivable (AR), increased administration and a heightened probability of incurring bad debt. The management of credit sales, although eminently important to any business and often performed manually, may become time-consuming, expensive and inaccurate; an administrative workload becomes increasingly cumbersome as the number of credit sales increases. As a result, a new approach of proactively identifying invoices from AR accounts, likely paid late or not at all, has recently surfaced in the literature, to employ intervention strategies more effectively. Several computational techniques from the credit scoring literature and particularly techniques from the realms of survival analysis or machine learning appear embedded in this approach. This body of work suffers, however, due to the limited guidance provided during the data preparation aspect of the model development process and because survival analytic and machine learning techniques have not yet become ensembled. In this study, we propose a generic framework for modeling invoice payment predictions, to facilitate the process of preparing transaction data for analysis and to generate relevant features from past customer behavior, as well as selecting and ensembling suitable models for predicting the time to payment associated with invoices.

3 - Using Linear Reformulations to Explain Solvable Cases of the Quadratic Assignment Problem
Lucas Waddell

The quadratic assignment problem (QAP) is perhaps the most widely studied nonlinear combinatorial optimization problem, having a variety of applications, yet proving to be extremely challenging to solve. This difficulty has motivated researchers to identify special objective function structures permiting an optimal solution to be found efficiently. In this talk, we show how certain structures can be explained in terms of the continuous relaxation of a mixed 0-1 linear reformulation of the problem known as the level-1 reformulation-linearization-technique (RLT) form. Specifically, the objective function structures of these special instances all guarantee a binary optimal solution exists to the continuous relaxation of the RLT form. We demonstrate our methodology by considering known solvable cases, where the objective function coefficients have special chess-board and graded structures. We also consider other special instances called linearizable, meaning they can be rewritten as linear assignment problems preserving the objective function value at all feasible solutions. We identify a relationship between polyhedral theory and linearizability promoting a strikingly simple necessary and sufficient condition for identifying linearizable instances; an instance of the QAP is linearizable, if and only if the continuous relaxation of a weakened RLT form is bounded.

4 - A Fitness Landscape-integrated Metaheuristic Selection Framework for Optimisation Problems
Jan van Vuuren, *Nathan van der Westhuyzen*

In recent decades, there has been a remarkable increase in the number of metaheuristic optimisation methodologies proposed in the literature. Consequently, researchers and analysts face the challenging and time-consuming task of identifying an appropriate metaheuristic from the vast array of solution methodologies available. In this paper, we propose an algorithm selection framework suitable for a user-specified optimisation problem class, allowing for different variables, the presence or absence of constraints, and a specified objective function. Our approach facilitates the construction of a flexible algorithm portfolio, comprising multiple algorithms with a variety of functionality configurations. This consideration, paired with different hyperparameter configurations, mitigates the phenomenon of performance complementarity. The framework conforms to a two-phased approach (an offline collection phase of training data and an online selection recommendation phase) to produce rapid and accurate predictions. A bi-objective prediction approach is employed utilising fitness landscape analysis methods, together with general problem characteristics to extract meta-features for meta-learning prediction purposes. The prediction and selection capabilities of the framework are tested on a suite

of test instances of the k-tuple selection problem (k-tSP), a new optimisation problem class proposed in this paper. Numerical testing is based on two ranger model implementations (random forest variants) for predicting the solution quality indicator and computational expense measure, respectively. The algorithm portfolio consists of a single metaheuristic, the dominance-based multi-objective simulated annealing algorithm, in conjunction with various functionality options and hyper-parameter configurations. The results show that the proposed framework is capable of providing accurate predictions for selecting suitable metaheuristic configurations for solving k-tSP instances with near optimal performance.

Optimization Models and Exact Methods Applied to Vehicle Routing Problems

Cluster: Combinatorial Optimization
Invited session
Chair: *Alejandro Arenas*
Chair: *Gulnara Baldoquin*
Chair: *Juan Carlos Rivera*

1 - Effect of formulations over a Periodic Capacitated Vehicle Routing Problem with Multiple Depots, Heterogeneous Fleet, and hard Time-Windows
Alejandro Arenas, *Juan Carlos Rivera*, *Gulnara Baldoquin*

This study addresses the Periodic Vehicle Routing Problem (PVRP) with three other attributes: heterogeneous fleet, multiple depots, and time windows. Based on a real-life application, this problem routes a heterogeneous fleet of vehicles over 12 days to serve customers from various depots; due to operational conditions, customers must receive the company's products within a time window. For this study, the presented formulations are based on the tactical decisions required of a vending machine company in Medellín, Colombia. Currently, decisions are made by a trial-and-error method giving room for a more efficient solution using mixed-linear integer programming. Even though adding three attributes to the PVRP makes it harder to solve, it is required to have a solution close to a real-life scenario.

The literature on routing problems considering the four attributes is, at best, scarce. This research presents two equivalent models for a vehicle routing problem with the attributes above. The first formulation has a variable with four indexes; it is a flow and load-based formulation. The second formulation decomposes the four-index variable into a three-index flow variable and an assignment variable. This research also presents how these two formulations compare among the scarce literature available for PVRP with a heterogeneous fleet, multiple depots, and time windows.

Preliminary results on these characteristics of both formulations are presented (all using GUROBI):

• Effect of presolve command • GAP obtained • Impact of several valid inequalities

2 - An Integer Programming Model for Heterogeneous Team Orientation Problem with Split Delivery of Renewable Resources and Time Windows: Protest mitigation application
Juan Antonio Martinez Becerra, *Santiago Barriga Jama*, *Daniel Morillo Torres*, *Gustavo Gatica*

In recent years, mainly after 2021, protests in Colombia have had a significant relationship with disturbances of public order and damage to public and private property in the country. Just during the 2021 national strike, the number of deaths reached 76 people and monetary losses exceeded 11.9 billion Colombian pesos (US$ 2.5 million). In particular, Cali was one of the most affected cities by this historic milestone. The response of police institutions to the protests during the days of demonstrations was, in many cases, neither timely nor efficient, because the current operating mechanisms do not have a quantitative decision support system. Therefore, there is a need for a design allowing the allocation of limited police resources adequately. The present research proposes an integer-mixed linear programming model based on the well-known Team Orientation Problem with Time Windows (TOPTW). Given the conditions of the context addressed, however, the addition of more realistic features is considered: heterogeneous fleet management (diverse police resources), multiple source nodes, and renewable resource allocation. These resources involve considering the waiting times associated with the attention of each of the intervened areas to, subsequently, continue with the designed route with the initial resources available. On the other hand, the demand for resources can be completed in a shared manner by different vehicles, as long as full compliance is guaranteed. The objective of the proposed model is to maximize the coverage of the protest hotspots; for this purpose, a prioritization index of the nodes is presented considering the particular needs of each protest hotspot and its size. The validation of the proposal was carried out through computational experimentation by simulating 90 test cases based on real data. Scenarios with 4, 5 and 6 police stations (depots) and 10, 15 and 20 protest foci (nodes) were considered. As a result, in 70% of the cases, the model found the optimal solution attending 100% of the considered foci. For the remaining 30%, the best solution could not be found, but a feasible solution was found, because it reached the computational time limit; the latter were those of greater complexity and size.

3 - The Periodic Capacitated Clustering Problem
Marcos José Negreiros

We propose an extension of the capacitated clustering problem, called periodic capacitated clustering problem, where items with attributes of demand, coverage periodicity and others that characterize them, are given. It is desired to define the clusters and their medians that minimize the dissimilarity between items in the same group so they do not exceed the maximum capacity of the heterogeneous groups and the periodicity between coverages. This problem arises in wholesale sales, waste collection in health units, capacitated grid design and maneuver, and many other. We present a general formulation for the problem, including new periodic based constraints, which facilitate solving the problem by mixed integer binary solvers such as CPlex, Gurobi and XPress. The model is evaluated with periodic vehicle routing instances and new ones from specific real applications. We obtained quality upper bounds and optimal solutions for expressive subgroups of these instances.

Discrete, Continuous or Stochastic Optimization and Control in Networks, Transportation and Design

Cluster: Combinatorial Optimization
Invited session
Chair: *Gerhard-Wilhelm Weber*
Chair: *Thomas Weber*

1 - Exploring integer programming techniques for the hyper-rectangular clustering problem with axis-parallel clusters
Javier Marenco, *Diego Delle Donne*

Given a nonempty set of points in the space of an arbitrary (but fixed) dimension, the hyper-rectangular clustering problem with axis-parallel clusters consists of grouping the points into clusters, so each cluster is determined by a hyper-rectangle in the corresponding space. Up to a certain number of points may be discarded and not included in any cluster, and these points are declared to be outliers. Hyper-rectangular clustering has been proposed as a model for explainable clustering, since it is straightforward to describe the obtained clusters by the bounds defining each hyper-rectangle. In this context, if each coordinate corresponds to a relevant parameter in the application generating the given points, then clusters are specified by a lower and an upper bound on each parameter; this is easier to communicate than

a distance-based clustering. Previous works have taken advantage of this feature of axis-parallel hyper-rectangular clusterings. In this work, we assess how far standard mixed integer programming techniques can go at solving these problems with optimality. In a previous work, we presented a mixed integer programming formulation for this problem, and we explored a large family of valid inequalities, separable in polynomial time. In this work, we continue this study, by presenting a generalization of this family and by evaluating additional separation strategies. We also propose a column-generation-based heuristic for this problem, and we evaluate the practical contribution of this procedure.

2 - Valid inequalities for the robust multi-agent pathfinding problem
Seyoung Oh, *Kyungsik Lee*

The multi-agent pathfinding problem (MAPF) is a class of problems, involving finding collision-free routes for centrally controlled agents over a graph. Conventional MAPF research has mainly focused on finding solutions, where agents do not collide with each other while traveling, i.e., no vertex and arc conflicts. In these applications, as indoor logistics systems have gained attention, research has been actively conducted to find MAPF solutions satisfying more realistic constraints. One variant is the multi-agent pathfinding problem with time-spacing constraints (MAPF-TS), aiming to find more robust solutions in situations where agents might encounter delays, hastes, or communication delays while executing a given route plan. Since MAPF and MAPF-TS have mainly been studied in the AI community, so research on their polyhedral structure is relatively scarce. In this talk, we propose an integer programming formulation for MAPF-TS along with a number of classes of new valid inequalities, much smaller and tighter than the previously proposed formulation. New valid inequalities dominate all known valid inequalities of MAPF-TS and provide a hierarchy among them. Some of the proposed valid inequalities are proved to be facet-defining for a substructure of MAPF-TS. The new formulation is still large to solve by itself, however, using generic integer programming solvers. We propose a branch-price-and-cut algorithm for the problem and then compare the computational characteristics of formulations, such as LP bound, solution time, and gap. We also empirically compare the effectiveness of proposed valid inequalities.

3 - Planning the Daily Shift Assignment for the Medical and Paramedical Personnel at a Hospital
Luis Moreno, *Javier Diaz*

The present algorithm carries out planning for a predefined period of time (usually 4 or 5 weeks) of the shift assignment for medical and paramedical personnel of a hospital by means of a hybrid exact-heuristic algorithm. The problem is solved each day using a traditional shift assignment algorithm, filling a square matrix with shifts as rows and people as columns. To solve the problem for one day, the quite efficient Hungarian algorithm is used. The problem is sequentially solved heuristically for a set of days, where a multi-objective cost function is minimized, with 30 criteria, some of them nonlinear, added to fill each cell of the matrix. The matrix could be interpreted as an evaluative matrix of people discomfort (a minimization problem). As time progresses, the cost coefficients are altered to achieve equity during the planning period for all the criteria and for all people. A set of different averages are used and changed as time progresses. The assignment of costs to each criterion is subjective, depending on the importance the institution (hospital) wants to give each, where high values are used for unacceptable situations and low values for unwanted, although acceptable, criteria.

Optimization Approaches for Freight Distribution Problems

Cluster: Combinatorial Optimization
Invited session
Chair: *Claudia Archetti*

1 - A branch-and-price approach for last-mile deliveries with capacitated robot stations
Diego Delle Donne, *Yerlan Kuzbakov*, *Laurent Alfandari*

We define the capacitated routing-scheduling problem (CRSP) for a multimodal delivery system, where the first leg of the delivery is performed by a truck and the second leg by robots (or some other dedicated lightweight vehicle). The truck makes a tour starting from the depot and visiting some facilities from a set of candidates. We assume there is only one truck, hence there is a single tour connecting the depot and (some of the) the facilities. The second leg, performed by robots, starts from the facilities and ends at the doorsteps of the customer. Each robot can take one request at a time, so it has to return to the starting facility after serving a customer. The capacity to serve customers of each facility is limited and depends on the size of the demands of the customers, but no limit on the number of required robots at a facility is imposed. Each customer has a scheduled time of delivery and has to be served from a single facility. If the robot serving a customer arrives after this time, the difference between the time of the delivery and the scheduled time is computed as the delay for the customer. The CRSP asks to select a tour for the truck and a feasible assignment of customers to facilities so the total delay of delivery is minimized. The problem is NP-hard.

Existing literature tackles a version of this problem, not considering capacity limits for the facilities. We propose a compact and an extended integer programming formulation for CRSP. We further refine the extended formulation by adding valid inequalities, and we propose a column generation-based method to solve its linear relaxation. We then develop a branch-and-price algorithm for this formulation and propose two different methods for the branching step. In addition, we propose methods for heuristically pruning the branching tree, with the goal of finding good feasible solutions even if the algorithm reaches a time limit before finishing. We perform a theoretical study on the linear relaxation of the two proposed formulations and show the extended formulation usually provides better lower bounds (and never worse) than the compact formulation. Finally, we perform a computational experimentation to assess the practical contribution of the proposed methods to solve CRSP.

2 - Approximation of the Double Traveling Salesman Problem with Multiple Stacks
Laurent Alfandari, *Sophie Toulouse*

The Double Travelling Salesman Problem with Multiple Stacks (DTSP-MS) involves the collection and delivery of n commodities in two distinct cities, where the pickup and the delivery tours are related by LIFO constraints. During the pickup tour, commodities are loaded into a container of k stacks with capacity c; during the delivery tour, commodities loaded on the same stack during the pick-up are unloaded in the reverse order. The objective is to minimize the sum of distances of both pick-up and delivery tours. The problem is known to be NP-hard. We first review the complexity of two critical subproblems: deciding whether a given pair of pickup and delivery tours is feasible and, given a loading plan, finding an optimal pair of pickup and delivery tours - both polynomial under some conditions on k and c. We then prove a 3k/2 approximation for the metric minimization problem, where distances satisfy the triangle inequality. Other approximation results are provided for various versions of the problem, as well as approximation-preserving reductions from the classic TSP. Finally, we focus on the special case with k=2 stacks; we present a matching-based heuristic for this case when the distances are symmetric and analyze its worst-case performance. This heuristic provides a 1/2 approximation ratio for the maximization problem.

3 - A pricing and routing bilevel problem for last-mile delivery
Claudia Archetti, *Martina Cerulli*, *Elena Fernandez*, *Ivana Ljubic*

The Profitable Tour Problem (PTP), belonging to the class of Vehicle Routing Problems with profits, has a vehicle, starting from a central depot, visiting a subset of available customers and collecting a specific revenue, whenever a customer is visited; the objective being the maximization of net profit, i.e., the total collected revenue minus the total route cost. Most of the literature in this field considers only one

decision-maker; in several real-world routing applications and, in particular, the last-mile delivery, there are several involved agents, however, with conflicting goals. If the decisions are made in a hierarchical order, this problem can be modeled with bilevel programming, with the PTP at the lower level. In this paper, we consider a company, acting as a "leader" and offering disjoint subsets of a given set of items to a set of independent drivers. At the lower level, each driver solves a PTP, communicating to the company the items they agree to serve; both the company and the drivers aim at maximizing their net profit, calculated differently in the two levels. We further propose two bilevel formulations modeling this interaction, allowing the leader not only to anticipate the best followers' response, but also to find the optimal pricing scheme for each carrier. The value function reformulations of the bilevel models are considered and further reformulated by projecting out some of the lower-level variables; we find exact solutions to these models using a branch-and-cut approach, leveraging an alternative reformulation of the lower-level problems.

Topics in Combinatorial Optimization

Cluster: Combinatorial Optimization
Invited session
Chair: *Juan José Salazar González*

1 - Manufacture of flower bouquets using Mathematical Optimization
Karen Acosta, *Andres Miniguano-Trujillo*, *Diego Recalde*, *Juan Pablo Dueñas*

The objective of this project is to maximize the perceived benefit of fulfilling customer orders by determining the optimal allocation of flower stems of different ages in finished products. To this end, flexibility rules are established on the elements that make up the bouquets, i.e., the different types of flowers with their respective color. In addition, when working with a perishable product, it is necessary to give priority to the use of stems that are close to expiring. With respect to demand, we know the number of boxes of each product requested by a customer, the original assembly pattern (original recipe) of each product, the number of bouquets in each box, and the number of stems for each bouquet. As for the offer, the quantity of stems classified by flower, color and days of life is given. The bouquet maker has the option of interchanging the colors used in a bouquet or substituting the flower type with respect to the original recipe, which implies a great variety of assembly patterns under a given set of rules. The constraints of the model determine the interaction between the availability of flowers in the bouquet producer and the specific orders of each customer. For this reason, relationships are established between the demanded bouquet boxes and the flower stems that comprise them, respecting the recipes established for each product. The problem can be formulated as a generalization of the problems of inventory management and material cutting.

In order to determine the best set of recipes for assembling all orders, respecting the change rules, a column generation approach is proposed. In this case two pricing models are needed to capture the rules, i.e., two column generation algorithms are needed. The first one is related to color crossing rules and the second one associated to substitution rules. The models and algorithms were implemented using Gurobi's Python API. For computational testing, a simulated database based on market information was used. The results show the orders filled, the number of boxes allocated, with their respective assembly patterns and the unfulfilled demand. In addition, a summary of stems used from each source and leftover stems is presented.

2 - Wayki: a web-based experimentation platform to support research on hard optimization problems
Roberto Asín, *Julio Godoy*, *Rosa Medina*, *Federico Meza*, *Pedro Pinacho*

Research on difficult optimization problems has advanced significantly since its early days. However, many challenges remain unsolved and new ones continue to emerge. An active research community perseveres in tackling these problems. Nonetheless, several issues hamper faster progress. Despite numerous publications, information sharing is inefficient. For many optimization problems, it is impossible to find suitable test cases, code, logs of obtained results, and performance data (e.g. time/memory usage) of different algorithms under the same computing environment. This, combined with pressure in academia to publish, leads to articles lacking proper experimental evaluation and irreproducible findings. Besides, in practical applications where computationally hard optimization problems arise, one of the most expected characteristics of the solution methods relate to the anytime behavior of the search procedure. Such behavior is not commonly studied and or reported in the literature.

To address these issues, we built Wayki (http://www.wayki.net/): an online experimentation platform for research on hard optimization problems. Wayki enables researchers to propose new challenges, for which a formulation, input and output formats, initial set of benchmarks and solution checker should be provided. It allows researchers to report the anytime results of their solvers by uploading solution files associated to execution times when they were generated while running on personal hardware. With all these data (benchmarks and performance of the solvers), the platform provides downloading, visualizing, and ranking functionalities. The platform is built around the idea of generating a research community around the challenges, enhancing information sharing, and encouraging collaboration. Besides the functionalities explained above, the community can propose new benchmark sets, report bounds for specific instances and report new research related to the challenge.

Currently, Wayki can host challenges focusing on solution time and quality regardless of hardware specifications. For Wayki to support and advance the community more scientifically, it should also enable certifying running times under a common hardware infrastructure. Wayki's team is further developing the platform and seeking collaboration toward this goal.

3 - A heuristic approach for selecting objects to observe in Astronomy
Juan José Salazar González

This talk concerns a new optimization problem arising in the management of a multi-object spectrometer with a configurable slit unit. The field of view of the spectrograph is divided into contiguous and parallel spatial bands, each one associated with two opposite sliding metal bars that can be positioned to observe one astronomical object. Thus, several objects can be analyzed simultaneously within a configuration of the bars called a mask. Due to high demand from astronomers, pointing the field of view of the spectrograph to the sky, rotating it, and selecting the objects to conform a mask is a crucial optimization problem for the efficient use of the spectrometer. This talk describes this problem, presents a Mixed Integer Linear Programming formulation for the case where the rotation angle is fixed, presents a non-convex formulation for the case where the rotation angle is unfixed, describes a heuristic approach to the general problem, and discusses computational results on real-world and randomly-generated instances.

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Combinatorial Optimization

Cluster: Combinatorial Optimization
Invited session
Chair: *Monique Guignard-Spielberg*

1 - Models for the 2D cutting stock problem in the honeycomb cardboard industry
Antonio Alonso-Ayuso, *Paula Terán Viadero*, *F. Javier Martin-Campo*

We present a novel mathematical optimization model for the 2-D Guillotine Cutting Stock Problem for the honeycomb cardboard industry. The honeycomb panels, made of paper with a sandwich structure of two paper layers and a paper net inside (the honeycomb structure), are used for transportation, replacing expanded polystyrene and wood, since it is economical, green, light, and resistant. The problem is motivated by collaboration with a medium-sized Spanish company in the honeycomb cardboard sector, whose objective for the future medium-term is to automatize operations to gain efficiency and effectiveness. The company can produce the stock (cardboard panels) at the same time it is cut into smaller rectangular pieces requested by customers. This fact introduces a variant in the cutting stock problem: the stock can be considered of variable size, i.e., the company must decide panel dimensions (width and length). Therefore, the company must decide: (1) how many cardboard panels to produce, (2) their dimensions, and (3) how to cut them to reduce leftover material. A Mixed Integer Linear Optimization (MILO) model was developed and validated using real data from the company, yielding results drastically reducing the amount of material produced and the amount of leftover material, thereby reducing operating time and economic costs.

2 - Models for the Euclidean Steiner tree problem in d-space (d>=3)
Nelson Maculan, *Renan Pinto*, *Hacène Ouzia*

Several models for the Euclidean Steiner tree problem in d-space (d>=3) will be presented, among them a new second-order conic optimization model. Also, strategies for eliminating isomorphic trees will be presented. Finally, computational results highlighting the efficiency of these models will be discussed.

3 - Some MIP algorithms may be strengthened by adding intermediate improving steps
Monique Guignard-Spielberg

Whether solution methods aim at solving problems optimally or at providing good feasible solutions within a guaranteed percentage error from the optimum, it may be possible that a closer look at each required intermediate step would show a potential "local" modification or addition that would improve the starting point for the next step. Depending on the situation, it might require strengthening an intermediate computational step, or adding a intermediate step that one's knowledge of the problem guarantees to be legitimate and possibly improving. Examples of such an approach will be presented.

Last Mile Delivery Optimization

Cluster: Combinatorial Optimization
Invited session
Chair: *Alfredo Candia-Véjar*

1 - Hybrid algorithms for real-time delivery systems in the gig economy
Karla Hoffman, *Carolyn Mooney*

This talk describes the use of optimization to assist in real-time decision-making, where solutions must be available almost instantaneously. We highlight the success of these methods in the routing and scheduling of deliveries in gig-economy applications, and we present the problem of assigning drivers to service requests and presenting the drivers with an efficient routing of all request locations. The decision framework for these assignment problems often has competing objectives (e.g., minimizing cost to the company, providing profitable assignments to drivers, and assuring customers receive their orders in a timely fashion). The process may include predicting whether a driver will accept a given assignment and the notification to both customer and supplier (e.g., the restaurant providing the food to be delivered). If the drivers are not hired on a schedule, then the driver might refuse an offer, and it might, therefore, take multiple "offers" to alternative drivers before the assignment is finalized. The entire process - of allocating assignments to drivers, notifying customers of expected delivery time and alerting suppliers to new demands - must be done in under a minute.

2 - An exact cutting plane method for the Euclidean max-sum diversity problem
Sandy Spiers

This research answers an open question recently posed in the literature - to find a fast exact method for solving the max-sum diversity problem, a nonconcave quadratic binary maximization problem. For Euclidean max-sum diversity problems (EMSDP), the distance matrix defining the quadratic term is always conditionally negative definite. This interesting property ensures the cutting plane method is exact for EMSDP, even in the absence of concavity. The cutting plane method, primarily designed for concave maximisation problems, converges to the optimal solution of EMDSP. The method was evaluated on several standard benchmark test sets, where it was shown to outperform other exact solution methods for EMSDP, and can solve two-coordinate problems of up to eighty-five thousand variables.

3 - On models and algorithms for the Pickup to Delivery Drone Routing problem
Alfredo Candia-Véjar, *Javier Gómez Lagos*, *Benjamín Rojas*

In the literature, a distribution logistics problem has recently been defined, consisting of routing a fleet of drones picking up products from a set of facilities to satisfy the demand of a set of customers - named Pickup to Delivery Drone Routing Problem (PDDRP); it specifies each customer can order one package of products, served by only one drone. Additionally, there is a drone depot, where the drones are initially located. The problem, in its original variant, assumes each facility has a full inventory; each drone visits only one facility to serve one customer. In this work, we present a generalization of the problem defined above, named Delivery Drone Routing Problem with Limited Inventory (DDRPI), where the facilities do not have a complete inventory. A drone must visit more than one facility to complete a customer's order, and, thus, a subproblem, for finding a path between the last customer visited and the following, has to be solved. We formulate an integer linear programming model - very difficult to solve due to the additional drone path problem through the facilities. A standard solver could obtain feasible solutions for small problem instances. Given the high computational complexity of the DDRPI, to find near-optimal solutions when exact approaches cannot achieve optimal solutions or small gaps, different solving schemes are used. A hybrid metaheuristic approach, including Greedy Randomized Adaptive Search Procedure metaheuristic and Variable Neighborhood Descent algorithms, is designed. The hybrid approach can find good solutions in a short time, when larger instance sizes need to be solved. Also, two valid inequalities were formulated to support the performance of the exact algorithms. We present different solution schemes mixing the metaheuristics approaches with the exact approach using MIP starting techniques. The algorithmic approaches implemented for solving the problem allow for obtaining optimal solutions for all the small instances. For larger instances, the exact algorithm degrades fast in its performance, however, so the metaheuristic approach is used to obtain good, feasible solutions in reasonable times. With the exact approach using valid inequalities, improved results were obtained.

Design and Evaluation of Approximations

Cluster: Combinatorial Optimization
Invited session
Chair: *Bo Chen*

1 - Joint replenishment meets scheduling
Péter Györgyi, *Tamas Kis*, *Timea Tamasi*, *József Békési*

A combination of two classic problems of operations research is considered - the joint replenishment problem and single machine scheduling with release dates. In this problem, there is a single machine and one or more items. We also have a set of jobs, and each job has a release date, a positive processing time, and a required subset of items. A job can be processed on the machine at time point t if all the required items were replenished between the release date of the job and time point t. Furthermore, the machine can process at most one job at a time. One has to decide about both the replenishments and the schedule on the machine; the objective is to minimize the sum of the replenishment cost and the scheduling cost. The former depends on the number of replenishments; more precisely, the cost of ordering a subset of items simultaneously is the sum of a joint ordering cost and an additional item ordering cost for each item in the subset. The latter is a standard scheduling criteria, like the total weighted completion time or the maximum flow time.

First, we survey the complexity results for the offline problem, where the complete input is known in advance. Then, we present some online and semi-online algorithm. We also derive several lower bounds for the best competitive ratio of any deterministic online algorithm under various assumptions. In the online variant of the problem, the jobs arrive over time, and the input becomes known gradually. The solution is built step-by-step, but we cannot interrupt an already scheduled job before its completion time. In the semi-online variants, we have some limited information about the jobs, e.g. there is an upper bound on the time period between the consecutive release dates of the jobs or exactly one job is released at every time point and only the number of jobs is unknown at the beginning.

This research has been supported by the TKP2021-NKTA-01 NRDIO grant on 'Research on cooperative production and logistics systems to support a competitive and sustainable economy'.

2 - Fairness Criteria for Allocating Indivisible Chores: Connections and Efficiencies
Bo Chen, *Ankang Sun*, *Xuan Vinh Doan*

We study several fairness notions in allocating indivisible chores (i.e., items with non-positive utilities) to agents, who have additive and submodular cost functions. The fairness criteria are envy-free up to any item (EFX), envy-free up to one item (EF1), maximin share (MMS), and pairwise maximin share (PMMS), proposed as relaxations of envy-freeness. For allocations under each fairness criterion, we establish their approximation guarantee for other fairness criteria. Under the additive setting, our results show strong connections between these fairness criteria and, at the same time, reveal intrinsic differences between allocations of goods (i.e., items with positive utilities) and chores. Strong relationships cannot be inherited by the sub-modular setting, however, where PMMS and MMS are no longer relaxations of envy-freeness, and, even worse, few non-trivial guarantees exist. Furthermore, we investigate efficiency loss under these fairness constraints and establish their prices of fairness.

Urban Transportation Problems

Cluster: Combinatorial Optimization
Invited session
Chair: *Antonio Mauttone*

1 - A multioperator genetic algorithm for the traveling salesman problem with job-times
Pablo Gutierrez, *Lorena Pradenas*, *Carlos Contreras-Bolton*

This paper addresses the traveling salesman problem with job-times (TSPJ); it considers two sets of equal size, a set of tasks and a set of vertices, where a traveler must visit each vertex exactly once, return to the starting vertex, and perform a unique task at each vertex. Each task is assigned to only one vertex, and each task is completed with a job-time depending on each vertex; thus, the objective is to minimize the time of the last task performed. Among its applications are equipment maintenance, highly automated manufacturing, agricultural harvesting, and disaster recovery. Due to its NP-hardness, however, existing algorithms do not optimally solve the TSPJ larger instances. Therefore, we propose an approach based on a multioperator genetic algorithm, utilizing three crossover operators and six mutation operators. Four of the mutation operators focus on diversification, while two are designed to aid intensification. The results are evaluated on four sets of instances ranging in size from 17 to 1000 vertices: tsplib, small, medium, and large. Our approach outperforms the state-of-the-art algorithms on the four instance sets, due to the synergistic effect of the multioperators of crossover and mutation, along with effective parameter tuning.

2 - A multi-layer network design model for planning bicycle infrastructure
Antonio Mauttone, *Gabriel Bayá*, *Franco Robledo*

We address the problem of designing a set of bicycle lanes over a given street network to fulfill a given origin-destination demand. Different infrastructure technologies are available to be deployed over each street section. The more expensive the technology in terms of construction cost, the better from the point of view of user travel cost. Given an available total construction budget, we find a feasible allocation of technologies to each street section, so as to minimize the total user travel cost. We assume bicycle users travel from origin to destination following the least costly path, including sections of different infrastructure technologies, even those where no infrastructure is built. Moreover, we penalize the cost of the path, whenever there is a switch to a worse technology along it ("discontinuity"). We cast this problem into a fixed-charge multi-commodity network design model, formulated over a multi-layer network representing different available technologies. The proposed methodology is tested with data from Montevideo, the main city of Uruguay. We consider an abstraction of the street network, derived from a zonal division of the city. Origin-destination data is inferred from detailed records of public transportation usage. The first set of computational experiments studies the sensitivity of results to variations in both available budget and discontinuity penalization. Results are analyzed in terms of (i) distribution of budget, length, and user flow among different technologies, and (ii) total network length, user cost, distance traveled, and discontinuities experienced. In the second set of experiments, we analyze particular solutions of the optimization model for the test case, in terms of the distribution of the demand experiencing different degrees of deviation from the ideal solution (the one where all the demand travels over the best technology) and different numbers of discontinuities. Moreover, we provide graphical output of the solutions, showing the technology built and the user flow over each street section. Finally, we provide managerial insights regarding the allocation of budget, according to different values of discontinuity penalization and its impact over the user travel cost, distance traveled, and discontinuities experienced.

3 - A stochastic MILP approach for cross-docking platforms design and management
M. Araceli Garin, *Laureano Fernando Escudero*, *Aitziber Unzueta*

The pure Cross-dock Door Design Problem (CDDP) consists of deciding on the number of strip and stack doors and their reference capacity for receiving product pallets through inbound doors from the origin nodes (i.e., the suppliers), consolidating products in a collection of destination mixed pallets and, finally, delivering them through outbound doors to the destination nodes. The uncertainty lies on two points: First, on the sets of origin and destination nodes and, then, on the number of product pallets from each origin node to each destination one to transverse the cross-dock for a given time horizon; and, Second, on the door capacity disruption due to different reasons, such as sabotage or misuse. The uncertainty is realized in a finite set of scenarios; it represents the occurrence of the CDDP elements in the time horizon. The problem can be represented by a two-stage binary quadratic model, where first stage decisions are related to the design of the cross-dock infrastructure, and second stage ones are related to the inbound and outbound commodities flow assignment to the strip and stack doors under each scenario. This is the first time a two-stage stochastic model is presented, whose goal is to minimize the expected cross-dock infrastructure building cost plus the expected cost of the

standard and outsourcing assignments of the nodes to the doors in the scenarios, subject to the related net capacity constraints. Moreover, given the special structure of the problem and the high computational complexity of the corresponding binary quadratic model, a Linearized mixed Integer Programming Problem (LIP), mathematically equivalent to the former, is introduced. The intrinsic difficulty of solving even LIPs in situations of huge model dimensions in realistic applications, however, makes it impractical to search for an optimal solution. So, a Lagrangean Decomposition (LD) approach will be considered, by dualizing the first-stage variables splitting constraints and by decomposing it into independent scenario-related sub-modes solvable by decoupling them, taking benefit of the Integer Linearization Property of the model, if necessary. Based on the LD solution, a lazy heuristic scheme is introduced to obtain good feasible solutions with a reasonable computational effort. A computational study will be carried out to test the goodness of the proposed scheme.

Scheduling Problems

Cluster: Combinatorial Optimization
Invited session
Chair: *Horacio Yanasse*

1 - A B&P procedure for a Concurrent Open Shop Problem
Emiliano Lancini, *Michele Barbato*, *Diego Delle Donne*

In this work, we study a variant of the Open Shop Scheduling Problem. We are given a time horizon and a set of jobs, each composed of several tasks with unitary duration. Each task must be processed on a specific machine. Each machine can process at most one task at a time. The tasks of a given job can be processed in any order, and possibly two or more tasks of a same job can be processed at the same time. The problem consists in finding a schedule of the tasks on the machines, within the time horizon, minimizing the average number of time slots used by each job. We call this problem the Concurrent Open Shop Coloring Problem (COSC). To tackle this problem, we present a new edge-coloring model. Let B = (M, P ; E) be a bipartite graph, with parts P and M, and let k be an integer value. The resolution of the COSC requires to assign a color form 1 to k to each of the edges of B, so for every vertex w in P, all edges incident to w are assigned to distinct colors. This coloration has as objective the minimization of the average number of colors assigned to edges incident to each of the vertices of M.

In this work, we prove the problem is hard to tackle, and we give an extended formulation for the problem.

We present a branch-and-price procedure for COSC. To solve the linear relaxation of the model, the pricing problem consists in a variant of the star-packing problem. Given values associated with the edges of B, the pricing problem consists in finding a set of vertex-disjoint stars rooted in M where the sum of the values of the edges minus the number of stars in the set is smaller than a given value γ issue from the dual values of the formulation. We develop a heuristic algorithm to quickly solve the pricing problems and we use a MIP formulation to solve the pricing in an exact manner, whenever the proposed heuristic fails to find a solution. In addition, we developed a branching scheme following a Ryan-Foster branching rule. From a pair of edges of E, we create two subproblems: in one of these, the two edges are forced to receive the same color, while, in the other, they are forced to receive different colors. This procedure completely explores the space of integer solutions. We present the computational results of our procedure on a set of artificial instances.

2 - Selecting and scheduling research projects in Antarctica considering environmental effects
Mauricio Vega-Hidalgo, *Lorena Pradenas*, *Víctor Parada*

Research in Antarctica is fundamental to understanding phenomena related to biodiversity, geology, and astrophysics; this territory is the coldest and driest continent on the planet, making it a challenging place to conduct studies. In addition, extreme climatic conditions, lack of infrastructure, isolation, logistical costs, and environmental and legal restrictions make research in Antarctica very expensive. Despite these difficulties, scientists continue to research Antarctica because of its importance for understanding climate change and other natural phenomena. This study will address the problem of selecting and scheduling research projects at multiple Antarctic stations. Each project has a time frame and may precede another project. A subset of pre-selected projects must be scheduled during the current season. There are various resources, where a limited number of units of each are available; some of these cannot be used at specific stations and periods. Each project requires certain resources for its execution. Each unit may be fixed at a station or transported from one station to another within a certain number of days. In addition, each unit has a daily usage cost considering consumption (e.g. food or fuel), a monetary penalty for emissions generated (e.g. waste or gases), and a fixed cost of use. The objective is to maximize the total benefit of the selection and scheduling, considering the difference between the revenue generated by each project and the cost of using each resource. An integer programming model was proposed to represent the problem. The model's performance was tested in CPLEX with 480 test instances classified into 60 classes. In almost 13% of the cases, the optimal solution was found before 3600 seconds, suggesting a high complexity of the problem. Therefore, an ILS method implemented in Python was proposed to find near-optimal solutions in a reasonable time. The results show improvements in 25% of the test instances.

3 - Improved lower bound for a job sequencing and minimization of tool switches problem
Horacio Yanasse

In this work, we present two lower bounds for a job sequencing and minimization of tool switches problem (JSMTSP), based on the corresponding minimization of open stacks (MOSP) graph. The JSMTSP we are considering presents the following characteristics: a single machine; jobs and the tools they require are previously defined; the machine has a limited magazine capacity; each tool occupies a single position in the tool magazine of the machine; the tool can occupy any position of the magazine; a tool switch takes a constant time independently of the particular tool; and the machine changes only one tool at a time. The first lower bound proposed is based on the lower bound of the associated MOSP; the second lower bound proposed is based on the largest complete subgraph obtained from the MOSP graph.

Models and Algorithms for Routing and Scheduling Problems

Cluster: Combinatorial Optimization
Invited session
Chair: *Juan José Miranda Bront*

1 - Routing of electrical vehicles over steep streets
Emilio García, *Luis Torres*, *Sandra Gutierrez*, *Diego Recalde*, *Fernanda Salazar*, *Ramiro Torres*

The local government of Quito is interested in creating a low-emission zone in the Historic Centre of the city. A key issue within this initiative concerns the transition to low-carbon transportation modes for last-mile logistics in the involved area, such as electric cargo bikes and light electric vehicles (LEVs). Within this context, we investigate integer programming models for optimizing the routes of the vehicle fleet. Due to the area's topography, this application motivates the study of a variant of the electric vehicle routing problem (EVRP) taking into account both the vehicle load and the slope of the streets for battery consumption and travel times. This talk presents preliminary results concerning the modeling approach and possible solution schemes for this problem.

2 - Decremental State-Space Relaxations for the Basic Traveling Salesman Problem with a Drone
Francisco Soulignac, *Marcos Blufstein*, *Gonzalo Lera Romero*

Truck-and-drone routing problems have become an important topic of research in the last decade, due to their applications for last-mile deliveries. Despite the large number of publications in this area, the most efficient exact algorithms designed thus far struggle to solve the benchmark instances with 39 or more customers within one hour. This fact is true even for one of the simplest variants, involving one truck and one drone whose routes must synchronize at customers' locations: the Basic Traveling Salesman Problem with a Drone (TSP-D). In this work, we devise a new algorithm for the TSP-D able to solve benchmark instances with up to 59 customers, and it scales up to 99 customers when the drone is much faster than the truck.

Our method builds upon and enhances a recent dynamic programming (DP) algorithm by Roberti and Ruthmair (Exact Methods for the Traveling Salesman Problem with Drone. Transportation Science 55(2):315-335.), able to solve every benchmark instance with up to 29 customers when it is applied to solve the pricing problems in a branch-and-price algorithm. Regarding the DP method, we propose an alternative relaxation of the TSP-D via ng-routes yielding higher lower bounds without much impact on computational efficiency. Also, we devise new, stronger, dominance rules for discarding partial routes, and we design a bidirectional search method. When used to solve pricing problems in the branch-and-price algorithm by Roberti and Ruthmair, our DP method is able to solve every instance with up to 39 customers.

To further improve the running time, we replace the branch-and-price scheme by a tailored decremental state-space relaxation (DSSR) strategy, mixing column generation with variable fixing. First, column generation is executed to obtain an initial lower bound; then, an iterative variable fixing procedure is applied to increase this lower bound. Both the column generation and the variable fixing methods apply our new DP method. As DP is not fast enough for the larger pricing problems, the column generation method is adapted with another DSSR strategy applying variable fixing to simplify each pricing problem.

3 - Rescheduling the NBA regular season via Integer Programming
Nicolas Garcia Aramouni, *Juan José Miranda Bront*

The COVID-19 pandemic generated disruptions across multiple sectors; in particular, in the sports industry as many leagues had to readapt their competitions as a consequence of lock-downs, travel restrictions and other implemented safety measures. Even when activities started to resume, match suspensions continued throughout the different leagues. Dealing effectively with these unexpected events is extremely relevant regarding both sports and economic aspects of the competitions. In this paper, we propose a framework building upon Integer Programming models to systematically reschedule suspended games and generate a contingency fixture accounting for relevant operational constraints. For this purpose, we consider and compare two reactive strategies: a constrained approach, where disrupted games are rescheduled into feasible dates without modifying the original fixture, and a flexible framework, allowed to introduce a controlled number of small perturbations to the original fixture to improve the solution. Using the 2020-21 NBA season as a benchmark, we compare different scheduling approaches under different objective functions and discuss different characteristics of the solutions obtained. The approach produces good quality schedules, and the framework has potential to be applied in practice.

Graph Problems

Cluster: Combinatorial Optimization
Invited session
Chair: *Gustavo Angulo*

1 - A Branch & Cut Algorithm for a New Coloring Problem
Sebastián Taboh, *Isabel Méndez-Díaz*, *Paula Zabala*

The vertex coloring problem consists of assigning a color to each vertex of a graph so no two adjacent vertices are assigned the same color, using the minimum number of colors. This problem has been widely studied. In this work, we present a problem we call "Connected Components Coloring Problem" (CCCP), a variation of the vertex coloring problem and neither defined nor handled before. After demonstrating various properties, we formalize its definition with different mathematical programming models and develop a branch & cut algorithm for this problem. Our first step is obtaining lower bounds and upper bounds for our problem, allowing us to eliminate variables from the original model, accomplished both by proving various properties, some relating this problem to others, and by devising heuristics. The objective of some of these heuristics is to find solutions for CCCP, also provided as initial solutions to the branch & cut algorithm. We add several valid inequalities and propose diverse primal heuristics to further improve the performance of our algorithm. To assess its performance regarding the quality of the solutions found and the execution time, we generate an instance set and carry out experimentation. The conclusions drawn allow us to comprehend the parts of the algorithm to improve and to conceive of new ways of tackling our problem.

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2 - A novel three-level matheuristic for the Capacitated Minimum Spanning Tree Problem with Time Windows
Pablo Reyes-Polanco, *Lorena Pradenas*, *Carlos Contreras-Bolton*

The minimum spanning tree problems have been widely studied in the literature due to their relevance in various fields, such as telecommunications, transportation, water supply networks, electricity networks, airport planning, and military logistics. This work addresses an extension of the minimum spanning tree problem - the capacitated minimum spanning tree problem with time windows (CMSTPTW) - taking into account capacity constraints for the subtrees and time windows. CMSTPTW belongs to the NP-hard family; thus, it continues to be a computational challenge to find good-quality solutions efficiently. This work proposes a novel three-level matheuristic (3LM) approach combining Prim's algorithm, an iterated local search (ILS), and a mixed-integer linear programming model (MILP), solved with a general-purpose solver. The first stage involves generating an initial solution using Prim's algorithm adapted to CMSTPTW. Having generated the initial solution, the second stage consists of solving the MILP from the generated initial solution using a general-purpose solver, considering a given time limit. In the last stage, the 3LM approach employs an ILS with multiple perturbations and local search operators to further refine the solution. Moreover, the ILS uses two additional strategies: a set of elite solutions to preserve the best solutions throughout the algorithm's execution and to navigate the infeasible solutions space; these complement each other to increase the algorithm's variability and enhance the quality of the final solution. The proposed algorithm's performance is evaluated on an existing set of instances and in two new additional sets of larger instances. The 3LM approach outperforms state-of-the-art algorithms and the general-purpose solver, in terms of solution quality within a given time limit.

3 - Generalized formulations for the traveling salesman problem
Gustavo Angulo, *Diego Moran*

The traveling salesman problem is a widely studied classical combinatorial problem, with several integer linear formulations. In this work, we consider the Miller-Tucker-Zemlin (MTZ) formulation. First, the choice of some parameters of this formulation is arbitrary and, therefore, there is a family of formulations, with MTZ a particular case. We analyze this family; in general, the formulations involved are not comparable to each other, and there is no one dominating the rest. Then, we study the intersection of this family, equivalent to the well-known Circuit Inequalities formulation. Finally, we extend this approach to the Desrochers-Laporte and Single-Commodity Flow formulations, obtaining similar results.

Inclusion Problems (Monotone, Semi-monotone, Non-monotone) and Splitting Methods

Cluster: Continuous Optimization
Invited session
Chair: *Dimitri Papadimitriou*
Chair: *Cong Bang Vu*

1 - Nonlinearly preconditioned forward-backward splitting methods and applications
Dimitri Papadimitriou, *Cong Bang Vu*

In this paper, we prove the weak convergence of the iterates generated by the nonlinearly preconditioned forward-backward splitting method for the sum of a maximally hypermonotone operator A and a hypercocoercive operator B, under several suitable conditions. We provide several choices of the non-linear preconditioners for solving nonlinearly composed inclusions. In particular, the backward-forward splitting method is recovered by the nonlinearly preconditioned forward-backward splitting method, with a special choice of the non-linear preconditioner.

2 - On the SCD semismooth* Newton method for solving generalized equations
Helmut Gfrerer, *Jiri Outrata*

We present a novel Newton-type method for solving inclusions, e.g., the first-order optimality condition in nonsmooth programming, that zero belongs to the subdifferential of the objective. The proposed method relies on a new concept of generalized differentiation for set-valued mappings, the so-called Subspace Containing Derivatives (SCD), which is rather simple to compute. Together with the semismooth* property, we can derive a superlinearly convergent algorithm. Numerical experiments are also presented.

Advances in Continuous Optimization Theory (Column Generation, Regularity and Constraint Qualification, Generalized Lagrangian Theory, Decomposition vs. Parallelization, etc.) and Applications

Cluster: Continuous Optimization
Invited session
Chair: *Dimitri Papadimitriou*

1 - Estimation of Manning coefficients with derivative-free methods
Fabio Fortunato Filho, *José Mario Martínez*, *Rodolfo Begiato*

A very common mathematical model used to describe the behavior of a channel is called the Saint-Venant equations, a one-dimensional simplification of the Navier-Stokes equations; the numerical solution of these equations is based on explicit and/or implicit methods, consisting of discretizing the channel in a finite number of points and using the data collected. Although many data relevant to hydraulic modeling can be easily collected, such as depth and flow rate, the Manning roughness coefficient is an important variable, difficult to obtain. This coefficient is responsible for considering the effect of channel roughness on flow resistance, taking into account channel geometry. A commonly used technique to estimate the Manning coefficient is solving the problem of minimizing the sum of squares of the residuals between the curve generated by the equations and the collected data. To solve this problem, only using input (Manning coefficient) and output (sum of squared residuals) information, it is necessary to use optimization methods independent of derivatives. Furthermore, as the size of the problem tends to be large, it is necessary to adopt approaches reducing the size of the problem, making it easier to solve. Based on this, it was decided to solve the Saint-Venant equations with an explicit method of finite differences with diffusion and to minimize the problem with two different software - the BOBYQA derivative-free optimization software and a software created by me of the Nelder-Mead method, together with the interpolation-based space reduction method, to estimate the Manning coefficient from depth data at a point of the East Fork River. With this application, it was possible to describe and to estimate river depth data with significantly small errors.

2 - Computational aspects of column generation for nonlinear and conic optimization: classical and linearized schemes
Renaud Chicoisne

Solving large scale nonlinear optimization problems requires either significant computing resources or the development of specialized algorithms. For Linear Programming (LP) problems, decomposition methods can take advantage of problem structure, gradually constructing the full problem by generating variables or constraints. We first present a direct adaptation of the Column Generation (CG) methodology for nonlinear optimization problems; when optimizing over a structured set X, plus a moderate number of complicating constraints, we solve a succession of 1) restricted master problems on a smaller set $S \subset X$, and 2) pricing problems/Lagrangean relaxations wrt the complicating constraints. The former provides feasible solutions and feeds dual information to the latter. In turn, the pricing problem identifies a variable of interest, then taken into account into an updated subset $S' \subset X$.

Our approach is valid whenever the master problem has zero Lagrangean duality gap wrt to the complicating constraints and, not only when S is the convex hull of the generated variables as in CG for LPs, but also with a variety of subsets, such as the conic hull, the linear span, and a special variable aggregation set. We discuss how the structure of S and its update mechanism influence the number of iterations required to reach near-optimality and the difficulty of solving the restricted master problems, and present linearized schemes alleviating the computational burden of solving the pricing problem.

We test our methods on synthetic portfolio optimization instances with up to 5 million variables, including nonlinear objective functions and second order cone constraints. Some CGs with linearized pricing are 2-3 times faster than solving the complete problem directly and can provide solutions within 1% of optimality in 6 hours for the larger instances, while solving the complete problem runs out of memory.

3 - A successive centralized circumcentered-reflection method for the convex feasibility problem
Di Liu, *Alfredo Iusem*

We present a successive centralization process for the circumcentered-reflection scheme, with several control sequences for solving the convex feasibility problem in Euclidean space. Assuming a standard error bound holds, we prove the linear convergence of the method with the most violated constraint control sequence. Moreover, under additional smoothness assumptions on the target sets, we establish the superlinear convergence. Numerical experiments confirm the efficiency of our method.

Optimal Control Theory and Applications

Cluster: Continuous Optimization
Invited session
Chair: *Andrea Seidl*

1 - Institutional Change, Education and Population Growth: Lessons from Dynamic Modelling
Andreas Novak, *Gustav Feichtinger*, *Franz Wirl*

The contribution of this paper is to be one of the first papers linking population growth, education and institutional change within a dynamic optimization framework. The basic premise is, following interesting papers of Boucekkine with different coauthors dealing with the Arab Spring, elites manage first the ruling and then the transition to a 'democratic' government. We are less optimistic concerning the economic efficiency of domestic resource use and, more important, extend this framework by accounting for (endogenous) population growth. These extensions render the survival of any elite much less feasible than already in models without population growth. Only a (cynical) elite worrying about the size of the population allows for a longrun and interior outcome. Therefore, the rulers and the elite have to account for a second phase where they lose control over a country's (financial) resources. If the elite lacks sufficient stakes in the second phase, it will 'take the money and run', i.e., no investment, at least close to the (endogenous) terminal time.

2 - Climate change and optimal design of international environmental policies: an approach through optimal control and game theory
Fausto Gozzi

Over the last decade, climate change has become a research focus across several disciplines, but few papers consider the problems of designing international environmental policies in the framework of dynamic optimal control/game theory. The current papers on the subject critically rely on strong linearity assumptions. Our paper studies the problem in a more general nonlinear context, while, at the same time, retaining tractability. Although our modeling approach can be applied more generally, in this paper, we will employ this framework to derive several new insights on climate-related issues and policy.

3 - Economic Competition and Pollution Dynamics under Costly Production Adjustments
Konstantin Kogan, *Fouad El Ouardighi*

Competing firms' behavior toward pollution control deserves particular attention, as it can involve myopic behaviors that disregard the future impact of firms' current polluting emissions and, thus, accelerate the switch of pollution sinks into a pollution source. Another potentially harmful factor in the presence of environmental irreversibility lies with production adjustment costs that can slow down the ability of firms to reduce their polluting emissions in a timely manner. In the context of a Cournot market structure, we consider competing firms that incur both production adjustment costs and polluting emissions taxes. We analyze how the firms' behavior –based on the distinction between myopic and farsighted pollution control policy– and production adjustment costs affect the firms' competitiveness and long run environmental sustainability in the presence of a possible switch of natural pollution sinks into a pollution source. We show that horizontal competition is not environmentally sustainable with myopic pollution control policies, if the maximum threshold of pollution absorption is already crossed, because the later face history-dependency that cannot be neutralized.

4 - Production Versus Pollution: Indifference Thresholds on the Pareto Front
Andrea Seidl, *Richard Hartl*, *Peter Kort*

We consider the optimal control problem of a firm deciding about investing in capital stock needed for production; on the one hand, the firm wants to maximize revenues, and, on the other, it wants to minimize emissions caused by production. To handle the conflicting objectives, we apply the epsilon-constraint method; a boundary value and continuation approach is used to numerically calculate the Pareto front for various initial state values. We determine an indifference threshold curve, separating areas on the Pareto front, where various long-run steady states are approached, and we discuss differences and similarities to conventional Skiba points and the impact of key parameters on the solution paths and on the Pareto front.

Continuous Optimization Theory and Applications

Cluster: Continuous Optimization
Invited session
Chair: *Luis Zuluaga*
Chair: *Olga Kuryatnikova*

1 - Polyhedral Structure of Penalty Coefficients in QUBO Reformulations of Combinatorial Optimization Problems
Luis Zuluaga

In recent years, the study of Quadratic Unconstrained Binary Optimization (QUBO) problems has regained importance because it provides a unified framework to model and to solve many combinatorial optimization (CO) problems using several quantum computing algorithms (such as QAOA, VQE, and quantum annealing algorithms). In this talk, we will present a polyhedral characterization of the penalty coefficients arising when penalization methods are used to obtain QUBO reformulations of constrained CO problems. As a result, we can readily recover previous QUBO reformulations characterizations in the literature. More importantly, for inequality-constrained CO problems, our approach shows a QUBO reformulation of the problem can be obtained without the need to use additional binary slack variables - of high relevance in quantum computing, given the limitations on the number of qubits of current and near-term quantum computing devices.

2 - A robust interior point method for quadratic programming
Danilo Oliveira, *Maria Gonzalez-Lima*, *Aurelio Oliveira*

The linear systems arising when using primal-dual interior point methods have been the focus of many researchers for several decades. Many approaches decompose the original linear system into smaller ones, adding ill-condition and affecting the exactness of the solution. Oliveira, Gonzalez-Lima, and Oliveira (COAP, 2013) introduced a way to solve the systems arising in Linear Programming by forming the so-called Stable system, so the solution of the optimization problem is very precise and the computational cost competes with classical approaches. In this talk, we present an algorithm (an extension of the Stable system to Quadratic Programming), and we also show preliminary numerical results. For the results, we implemented our proposed approach within the PCx environment, a state-of-the-art, freely available code written in C, designed for solving linear programming problems using the predictor-corrector interior point method.

3 - Multi-periodic hybrid limit cycles and near steady-state stabilization in pollution control problems
Anton Bondarev, *Anna Tur*

In this paper, we contribute to recent studies of periodic optimal solutions emerging in hybrid control systems with time-driven switches. We extend the recent result on optimality of hybrid limit cycles from one time-dependent switch to an arbitrary number of switches (e. g. when multiple parameters of the model undergo non-smooth variations in different time instants and with different periodicity).

Depending on the length of period for a parameter's variation, the optimal dynamics may consist either of periodic fluctuations or of a combination, including fluctuations and near steady-state dynamics. In the first case, the dynamics obtained are qualitatively similar to Gromov et al. (2022), where only one parameter undergoes periodic (seasonal) non-smooth variation. In the latter, the optimal trajectory preserves periodicity, but it demonstrates segments of near steady-state behavior, depending on the length of periods when parameters stay constant.

In this way, by setting different lengths of seasonal variations to different parameters of the model, we can obtain a wide class of possible

seasonal dynamics for environmental problems, including regular fluctuations without convergence to any steady state value, fluctuations between several near steady-state solutions and a combination of the two. In this last case, we can demonstrate optimal trajectories, including both regular periodic transitional behavior and near steady-state behavior.

We discuss further potential development in this emerging field, as well as environmental policy implications of it.

The work of A. Tur was funded by RFBR and DFG, project number 21-51-12007.

Polynomial Optimization and Applications

Cluster: Continuous Optimization
Invited session
Chair: *Bissan Ghaddar*
Chair: *Julio González-Díaz*

1 - A polynomial optimization model for energy-efficient operation of industrial plants
Ángel M. González-Rueda, *Alfredo Bermúdez*, *Mohsen Shabani*, *Christian Ávarez-Pelaez*

Following the European Union's recommendations, there is great interest in generating more efficient and cleaner energy markets. In this work, a mathematical optimization model has been developed to analyze the energy efficiency of industrial plants. The model allows for the planning of the installation of new green-energy generation units (such as photovoltaic panels, wind turbines, geothermal energy and biogas). Furthermore, it must ensure the security of the energy supply, while respecting operational and environmental constraints, such as reducing greenhouse gas emissions (like CO2). To achieve this, both physical models (based on differential equations) and data-based models are used, involving the formulation of a mixed-integer polynomial optimization problem.

2 - On obtaining the convex hull of quadratic inequalities via aggregations
Gonzalo Munoz

A classical approach for obtaining valid inequalities for a set involves the analysis of relaxations constructed using aggregations of the inequalities describing the set. When the set is described by linear inequalities, thanks to the Farkas lemma, every valid inequality can be obtained using aggregations. When the inequalities describing the set are two quadratics, Yildiran (2009) showed the convex hull of the set is given by at most two aggregated inequalities. In this work, we study the case of a set described by three or more quadratic inequalities. Under technical assumptions, the convex hull of a set described by three quadratic inequalities can be obtained via aggregated inequalities. By counterexamples, the result does not hold, if either the technical conditions are relaxed or if we consider four or more inequalities.

3 - Domain reduction techniques in spatial branching
Ignacio Gómez-Casares, *Julio González-Díaz*, *Brais González Rodríguez*, *Pablo Rodríguez-Fernández*

One of the main ways of improving the performance of a branch-and-bound scheme is the reduction of the tree size. Bound-tightening techniques are usually applied in the context of MILP problems, and, here, we extend several of those techniques to the context of a non-linear branch-and-bound algorithm. We also include new ways of doing bound-tightening through the use of SDP and SOCP constraints. In addition to bound-tightening, the selection of the branching point at each node in the tree also has a big impact on the overall size of the tree. We analyze the performance of several ways of choosing the branching point in a non-linear tree. Finally, we use a portfolio selection approach using machine learning and choose the best configuration for a particular problem.

Composite Optimization with Applications

Cluster: Continuous Optimization
Invited session
Chair: *Xiaoqi Yang*

1 - A regularized Newton method for l_q-norm composite optimization problems
Xiaoqi Yang

In this talk, we will discuss the composite optimization problem with a twice continuously differentiable loss function and an l_q-norm regularized term. For this class of nonconvex and nonsmooth composite problems, we will review some existing first-order and second-order algorithms and propose a hybrid of proximal gradient method and subspace regularized Newton method. The whole iterate sequence produced by the algorithm is proved to have a finite length and converge to an L-type stationary point under a mild curve-ratio condition and the Kurdyka-Lojasiewicz property of the cost function, converging linearly if further a Kurdyka-Lojasiewicz property of exponent 1/2 holds. Moreover, a superlinear convergence rate for the iterate sequence is also achieved under an additional local error bound condition. Our convergence results do not require the isolatedness and strict local minimality properties of the L-stationary point. Numerical comparisons with some existing algorithms for the l_q-norm regularized linear and logistic regressions on real data indicate our algorithm not only requires much less computing time, but also yields comparable, or even better, for sparsities and objective function values.

2 - A primal-dual MM method for large-scale linear programming
Xinwei Liu, *Yu-Hong Dai*

We present a primal-dual majorization-minimization (MM) method for solving large-scale linear programming. A smooth and strictly convex barrier augmented Lagrangian for dual linear programming is first introduced. Then the MM approach minimizes the augmented Lagrangian. Our method only depends on a factorization of the constant matrix, independent of iterations, and does not need any computation on step sizes - thus, particularly appropriate for large-scale linear programming. The global convergence is analyzed, without previously requiring either the primal or dual linear programming to be feasible. Under regular conditions, the method is globally linearly convergent, and a new iteration complexity result is obtained.

3 - Model-driven and data-driven inverse problems
Yanfei Wang

In recent years, we have used various geophysical methods to study the structure, lithology, physical properties and imaging of underground media from different viewpoints. In terms of model-driven inverse problems, the correlation between multiple physical parameters is used as a priori information, and spatial structure coupling characteristics are incorporated. With appropriate geological assumptions, by studying appropriate optimization inversion algorithms, inversion precision and interpretation are improved. In terms of data-driven inverse problems, since geophysical data is generally "big data" in the 5V sense, artificial intelligence analysis methods (e.g. deep learning) can be further introduced to improve the inversion accuracy and interpretation of geophysical inverse problems.

Optimization Algorithms: Some Recent Advances

Cluster: Continuous Optimization
Invited session
Chair: *Laurent Condat*

1 - Communication-efficient distributed optimization algorithms
Laurent Condat, *Peter Richtarik*

In the big data era, the explosion in size and complexity of data arises in parallel to a shift towards distributed computations. In distributed optimization and machine learning, specific issues arise, such as decentralized data storage and privacy concerns. Thus, the parallel workers alternate between computations and communication of the right amount of information back and forth with a distant server. Communication, costly and slow, is the main bottleneck in this setting. Therefore, it is of primary importance to devise novel algorithmic strategies for distributed optimization, with proved convergence guarantees and reduced computation and communication complexities. A first strategy is to communicate less frequently at every iteration, making use of so-called local steps. A second strategy is to compress the communicated vectors. In this talk, I will present several recent contributions we made on this topic in our "Optimization and Machine Learning" group.

2 - Theoretical and numerical comparison of algorithms for smooth convex optimization
Luis Briceño-Arias, *Nelly Pustelnik*

In this talk, we provide a theoretical and numerical comparison of classical first-order splitting methods for solving smooth convex optimization problems. Theoretically, we compare convergence rates of gradient descent, forward-backward, Peaceman-Rachford, and Douglas-Rachford algorithms for minimizing the sum of two smooth convex functions when one is strongly convex. In several instances, we obtain improved rates with respect to the literature by exploiting the structure of our problems. Moreover, we indicate the algorithm having the lowest convergence rate, depending on the strong convexity parameter and the Lipschitz constant of the gradient. From a numerical point of view, we verify our theoretical results by implementing and comparing previous algorithms in well-established signal and image inverse problems involving sparsity. We replace the widely used $\ell 1$ norm with the Huber loss, and we observe fully proximal-based strategies have numerical and theoretical advantages, with respect to methods using gradient steps.

3 - Extensions and Applications of Three-Operator Splitting
Alp Yurtsever, *Alex Gu*, *Varun Mangalick*, *Suvrit Sra*

Three-operator splitting (TOS) [Davis & Yin, 2017] can minimize the sum of three functions when each term comprising the objective is convex and has an efficient gradient oracle or proximal operator. These requirements may fail in many data science and machine learning applications: (i) instead of full gradients, only stochastic gradients may be available; (ii) there might be a nonsmooth term with a simple subgradient oracle, but a complex prox operator; and (iii) there might be a nonconvex term. Motivated by these concerns, we analyze four valuable extensions of TOS. The first two permit using subgradients and stochastic gradients. The third extension endows TOS with adaptive step-sizes. For the important setting of optimizing a convex loss over the intersection of convex sets, AdapTOS attains universal convergence rates, i.e., the rate adapts to the unknown smoothness degree of the objective. Finally, the fourth extension permits a smooth nonconvex term in the problem template. In contrast with existing work on nonconvex TOS, our guarantees do not require additional smoothness assumptions on the other two terms; hence, they cover instances of particular interest where the nondifferentiable terms are indicator functions. Finally, we illustrate the effectiveness of the proposed extensions of TOS in various numerical experiments.

Recent Advances in Nonlinear Optimization and Its Applications I

Cluster: Continuous Optimization
Invited session
Chair: *Cong Sun*

Chair: *Yu-Hong Dai*

1 - New gradient methods for smooth unconstrained optimization problems
Cong Sun

In this talk, a new gradient method for an unconstrained optimization problem is proposed, where the stepsizes are updated in a cyclic way and the Cauchy step is approximated by the quadratic interpolation. Combined with the adaptive non-monotone line search technique, we prove the global convergence of this method. Moreover, the algorithms have sublinear convergence rates for general convex functions and R-linear convergence rates for strongly convex problems. The numerical results show our proposed algorithm outperforms the benchmark methods.

2 - Optimization with Least Constraint Violation
Yu-Hong Dai

Study about theory and algorithms for nonlinear programming usually assumes the feasibility of the problem, but many important practical nonlinear programming problems have feasible regions unknown to be nonempty. This leads to a class of problems called optimization with least constraint violation. First, the optimization problem with least constraint violation is proved to be a Lipschitz equality constrained optimization problem, and an elegant necessary optimality condition, named as L-stationary condition, is established. Properties of the classical penalty method for this Lipschitz minimization problem are developed, and the proximal gradient method for the penalized problem is studied. Secondly, the optimization problem with least constraint violation is reformulated as a mathematical program with complementarity constraints (MPCC) problem, and a local minimizer of the MPCC problem is proved to an M-stationary point. The smoothing Fischer-Burmeister function method is constructed and analyzed for solving the related MPCC problem. Thirdly, the solvability of the dual of the optimization problem with least constraint violation is investigated. The optimality conditions for the problem with least constraint violation are established in terms of the augmented Lagrangian. The augmented Lagrangian method can find an approximate solution to the optimization problem with least constraint violation and has linear rate of convergence under an error bound condition. Finally, the constrained convex optimization problem with the least constraint violation is considered and analyzed under a general measure function. Several other related works on the optimization problem with least constraint violation will also be mentioned.

3 - An Actor-Critic Objective Penalty Function Method for Trajectory Tracking of Automatic Vehicles
Fusheng Bai, *Bo Wang*, *Ke Zhang*

Minimizing trajectory tracking errors in autonomous driving is a challenging optimal control problem. In this talk, we propose a Model Predictive Control (MPC) based Reinforcement Learning (RL) method where the objective penalty function method is employed to handle the constraints to tackle the problem. First, the trajectory tracking problem is modeled as a constrained nonlinear optimization problem, then we employ the objective penalty function method under the frame of deep reforcement learning to solve the problem. The convergence of the present method is established under certain conditions. The effectiveness of the method is shown in simulated lane-change scenarios.

DEA 1

Cluster: Data Envelopment Analysis and its Applications
Invited session
Chair: *José Dulá*

1 - Stochastic and Dynamic Efficiency Analysis: An approach based on Chance-Constrained Data Envelopment Analysis and Optimal Control Theory
Paulo Nocera Alves Junior, *Ali Emrouznejad*, *Wilfredo Yushimito*, *Carlos Monardes*, *Isotilia Costa Melo*

This research studies Stochastic and Dynamic Efficiency Analysis models, based on Data Envelopment Analysis (DEA) and Optimal Control Theory (OCT), relating inputs, outputs, and intermediate variables dynamically in an optimal way, considering the new total costs approach, the uncertainties, and stochastic components of the problem. The only models in the literature similar to what is proposed in this project do not consider the characteristics from the recent models as the intermediate measures, the total costs efficiency (solving the problem of unitary costs), besides specific characteristics of Inventory Control Systems. These characteristics can be incorporated into the development of this model. This research project starts with a systematic literature review to address the models and evolution of Dynamic and Stochastic Dynamic DEA models, Optimal Control Theory (OCT), the use of Intermediate Measures in Efficiency Analysis, and Efficiency Analysis of Inventory Control Systems. The findings can be incorporated into the development of a model. The expected results of this research will be a Stochastic DDEA-OCT model to be applied to control systems of Decision-Making Units (DMUs). This model will be an important contribution to the efficiency analysis of control systems, e.g. to control efficiently without shortage of essential products, as is the case of inventory control systems with a relationship among variables (the output is demand; the input is production; and the intermediate variable is inventory as a relationship between demand and production). As an example, this model could be applied to the retail sector, considering its production-inventory systems and data from accounting variables, then comparing observed costs to the optimal cost obtained from the Chance-Constrained DEA-OCT model, resulting in total cost efficiency.

2 - Benchmarking in Data Envelopment Analysis: Balanced efforts to achieve realistic targets
Hernan Guevel, *Nuria Ramón*, *Juan Aparicio*

Benchmarking consists of evaluating and analyzing the processes, products, services or other aspects of companies to draw a comparison and to take this information as a reference point to guide future strategic decision-making. The intention is to learn from the experience of other units in the sector to improve the performance of the evaluated unit. Various support tools for developing management and decision-making in organizations are used, including statistical and econometric approaches and Operational Research methods. Data Envelopment Analysis (DEA) has proven to be a useful tool for the benchmarking of Decision Making Units (DMUs) involved in a production process. In fact, benchmarking in DEA has been applied in multiple fields. The identification of best practices allows the establishment of targets and, with them, the design of improvement plans in susceptible areas. In the benchmarking process, it is important to bear in mind the following considerations: 1) the identification of best practices must be done taking into account the circumstances and characteristics of the organizations being evaluated, 2) these best practices must reflect efficient behaviors and 3) the established targets must be achievable and, as far as possible, require control over the effort necessary for their achievement. In the total absence of information, the most realistic and conservative solution would be the one where the effort necessary to achieve optimal operating levels is as balanced as possible in all dimensions, without neglecting the overall necessary effort. In this regard, we propose three different approaches (Minimum Range Model, Distance to the Minimum Squared Model and Distance to the Mean Squared Model), with the aim of reaching an impartial distribution of efforts to achieve optimal operating levels without neglecting the overall effort required. Therefore, we offer different alternatives for planning improvements directed toward DEA efficient targets, where the decision-maker can choose the one best suiting their circumstances. Moreover, and as something new in the benchmarking DEA context, we will study the properties satisfying the targets generated by the different models proposed. Finally, an empirical example used in the literature illustrates the new methodologies, comparing with closest targets, proposed by Aparicio, Ruiz & Sirvent (2007) and the MRAM measure (Aparicio, Monge & Ramón, 2021)

3 - Operation counts for analyzing and comparing fast DEA procedures
José Dulá, *Gregory Koronakos*, *Dimitris Despotis*

Algorithms and computations are important aspects of Data Envelopment Analysis (DEA). Current practices, when introducing a new computational procedure for DEA, consist of describing the approach and comparing its performance to current procedures based on execution times. The predominant operation in DEA is solving linear programs; therefore, an operation count for DEA procedures can be limited to counting the number and size of LPs solved. Operation counts provide a common ground for analyzing and comparing DEA procedures; they are independent of hardware, LP solvers, and platform. We discuss the use of machine-independent operation count to analyze and compare DEA procedures. We make the case for the use of operation counts in DEA procedures claiming substantial speedups as part of the analysis and comparison with competing approaches.

DEA 2

Cluster: Data Envelopment Analysis and its Applications
Invited session
Chair: *Dieter Saelens*

1 - Rethinking the Education and Training 2030 goals: setting targets for European countries adjusted to goals
Dovilė Stumbrienė, *José L. Ruiz*, *Inmaculada Sirvent*

European Commission has set common goals under the strategic framework to address challenges in education and training for all Member States by 2030. Member States were invited to consider how, and to what extent, they can achieve these goals. Previous research showed a gap between actual performance, however, and the goals defined in the strategic framework "Education and Training 2020". For this reason, we suggest rethinking the goals to ensure more sustainable trajectories of improvement at the country level.

To address this issue, we propose a Benefit-of-the-Doubt approach through a benchmarking model incorporating information on the goals set. Thus, we seek to find targets on the frontier of an attainable set, formed by the best performing countries. The model proposed is a bi-objective problem imposing two objectives of closeness, namely between actual performances and targets (effort) and between targets and goals (adjustment). Therefore, this model allows us to find country-specific targets - attainable, representing best practices, and closing the gap with the goals as much as possible - and to consider the policy of improvements pursued with the setting of the goals.

A series of targets can be generated by varying the importance attached to each of the two objectives; these can be used to identify alternative directions of improvement for managers to consider. Eventually, the proposed approach aims to design a plan of action for each European country, to improve performance based on defined goals of declared indicators in the strategic framework.

We employed the proposed approach with the most recent data currently available in Eurostat and OECD databases for 30 European countries to illustrate its applicability.

Acknowledgment: This project has received funding from the Research Council of Lithuania (LMTLT), agreement No S-PD-22-87.

2 - Energy Efficiency Evaluation of Wastewater Treatment Plants: A Methodological Proposal for its Benchmarking
Maria Molinos-Senante

To evaluate the energy performance of wastewater treatment plants (WWTPs), reliable, robust and holistic methods are needed; the data envelopment analysis (DEA) method, allocating a flexible set of weights to input and output variables, has previously been used to benchmark the energy efficiency (EE). This methodological approach

suffers from discriminatory power, however, making it difficult to rank WWTPs and to compare their performances, because the EE scores are estimated under nonhomogeneous conditions. To overcome these limitations and to better understand the water-energy nexus, in this study the EE of a sample of WWTPs was evaluated by allocating common weights to variables for all WWTPs in a DEA model (DEA-CSW). Evaluated WWTPs were shown to have a poor energy performance, with an average EE score of 0.372; WWTPs could save 62.8% of their current energy use. Potential energy savings were estimated to be 118,206,789 kWh/year, equivalent to 29,552 tons of CO2eq/year. Based on a DEA-CSW approach, only one WWTP was identified as energy efficient; therefore, it is the best performer among the assessed WWTPs. Significant differences in the weights allocated to energy and pollutants removed from wastewater were reported by the DEA-CSW and DEA, allocating flexible weights. Hence, under the latter methodological approach, some relevant variables, from the functionality perspective of WWTPs, were ignored in the EE assessment. This study demonstrates the relevance of using suitable methods to benchmark the energy performance of WWTPs to avoid misleading conclusions and, therefore, avoiding misguided regulatory decisions.

3 - Assessing performance of Belgian household financial portfolios

Dieter Saelens, *Laurens Cherchye*, *Bram De Rock*

The lowering of interest rates by the ECB during the past decade has forced households in search of investment return to shift portfolio holdings into riskier investments. In an environment of declining interest rates, a thorough understanding of the evolution of households' participation in risky asset markets becomes essential, to monitor risks related to household financial vulnerability. This raises the questions, to what extent changes in portfolio allocations reflect efficient decision-making (as measured by maximizing investment returns for a given risk level) and whether this ability may vary across socio-economic groups. Within the finance literature, there is growing interest in better understanding financial decision-making by retail investors, using aspects from efficiency analysis. We develop a DEA model for performance measurement integrating Sharpe ratios. Instead of benchmarking against the predicted outcomes of a normative CAPM model, DEA estimates an endogenous performance score measured relative to the best performing households. We allow for variation in riskfree returns to account for heterogeneity in savings account rates and implement a subsampling procedure to overcome sensitivity to outlier observations. Using Malmquist indices, we study efficiency change over time. We examine portfolios of Belgian households, using data from the first 3 waves of the HFCS survey, containing information on household balance sheets across a wide range of asset classes; this allows for the study of complete portfolio performance, with the literature offering little guidance. In addition, the HFCS survey provides detailed information on demographic characteristics, as well as income and wealth levels. We find household participation in risky asset markets declines over time and is higher for households with a male, older, employed or more educated head and wealthier households. We report significant cross-sectional variation in household portfolio efficiency, with a small fraction of households performing efficiently. Quantifying inefficiencies in monetary terms, we find suboptimal investment strategies cost the median household in the sample between 0.5% and 3.1% of annual gross income in foregone investment returns. Highly-educated and wealthier households obtain higher efficiency scores, as do households with a female head. Finally, we find preliminary evidence of households improving performance over time.

4 - Network DEA approach for eSports performance assessment

Shih-Heng Yu, *Ming Chen*

E-Sports has become one of the most rapidly growing sectors in the world; despite this trend, little research has been conducted into benchmarking and performance evaluation in an e-Sports context. This paper presents a network data envelopment analysis (DEA) model with two-stage parallel-series structure to assess game performance in a multiplayer online battle arena (MOBA). E-Sports team managers can use the model to better understand how their players and teams perform in comparison to others. This study contributes to planning targeted training and to improved tactics for e-Sports teams.

Decision Support Tools for Astronomical Observatory Management

Cluster: Data Science Meets Optimization
Invited session
Chair: *Rodrigo A. Carrasco*

1 - Connecting predictive and prescriptive analytics in industrial-scale-telescope systems for maintenance

Anthony D. Cho, *Rodrigo A. Carrasco*, *Gonzalo Ruz*

Recently, industrial-scale telescopes have been growing rapidly, due to technological advances, making these systems increasingly sophisticated, with a greater number of electronic and mechanical parts, carefully calibrated and interconnected, to provide the best performance and quality. Since the systems are prone to failures, due to aging or factory defect of the components, this could lead to instances of system failure, caused by damaged parts composed of several components, requiring replacement or repair. Therefore, maintenance planning has become more intricate.

To address this problem, different maintenance strategies have been developed, from the perspective of replacing parts by expert suggestions, to estimating the remaining useful life (RUL) of components based on a physical model. These methods have improved system downtime, but still present some cases of unexpected failures, due to inherent errors in RUL estimation; therefore, the quantification of uncertainty of the estimation plays an important role in decision-making, and incorporating this information into a stochastic optimization model is not an easy task.

In this research, we have designed a method to estimate RUL distribution based on run-to-failure signals segmentation and Long Short-Term Memory (LSTM) neural network when a fault is present in a component. The estimated distribution of each component is used as input for the decision-making model, incorporating them via chance constraints, helping control the number of failed components and considering the distance between them, to reduce sparsity and to minimize maintenance costs. The capacity to solve maintenance scheduling problems is relatively large, compared to experimental results described in most of the literature, in reasonable computational time.

2 - A decision support tool for programming the cycle of astronomical observation at the ALMA observatory

Camila Marcuello, *Rodrigo A. Carrasco*

As observatories worldwide have grown in scope, so has their operational complexity. One of the central problems they face today is planning the observations throughout the observation cycle (generally one year), allowing for maximizing the value generated to the scientific community by these instruments of high cost and potential. Because it is a recent problem, there is a lack of long-term planning tools allowing observatories, such as the ALMA radio telescope, to plan their cycle accordingly. No solutions exist in the literature with tools usable in the context of these instruments. Due to these problems, our work develops a decision support tool helping the ALMA carry out strategic planning - delivering an optimal solution in a reasonable time. Our solution will assign the observations throughout the cycle using different metrics to be defined, evaluated, and analyzed. The work supports the process of generating value by reducing the hours used in planning and improving the efficiency and use of the telescope. To achieve the desired results, a model based on the formulation of the 'Generalized Assignment Problem' is built, with necessary modifications to fit the problem better.

3 - Improving Exoplanet Observations through Mathematical Optimization

Constanza Lorca, *Rodrigo A. Carrasco*

Several approaches have been used to tackle the observation scheduling problem in astronomy observatories. Many observatories still schedule observations manually or using greedy algorithms, however, not capturing the complete picture and making it difficult to predict the impact certain decisions will have in the future. When making daily decisions analyzing multiple exoplanet candidates, their stellar parameters, and if they align with the scientist's research focus, the task of choosing the ones to observe manually in a limited timeframe can be time-consuming, providing suboptimal results. Furthermore, each new observation improves the knowledge of the candidate's stellar parameters, adding new information needing to be accounted for in future schedules. This work proposes a combinatorial optimization model, derived from the Vehicle Routing Problem (VRP), adjusted to the exoplanet transits observations scheduling problem. We provide an approach maximizing observational efficiency, aligning the resulting schedule with the observatory's objectives and prioritizing observation constraints in the discovery of exoplanets.

4 - Scheduling astronomical data processing combining predictive and prescriptive analytics
Alfredo Manuel De Rodt Sanchez, *Rodrigo A. Carrasco*, *Luis Aburto*

In the Atacama Large Millimeter/submillimeter Array (ALMA) Observatory the demand for observation services is expected to increase, while the amount of servers to process each observation is limited. Besides, inefficiencies in the scheduling system (SS) and non-finished jobs (observations needing to be processed more than one time, because they fail in the last step of the process) reduce observatory productivity and timely completion of observations. The current scheduling practice at the observatory assumes all observations are equally likely to fail in any step of the process. This paper proposes a prescriptive analytics framework to improve the performance of an SS with respect to job completion (measured using average job waiting time and number of jobs unable to be processed in the first intent) and resource utilization (measured using average resource idle time, overflow time and overtime). In the proposed framework, observation-related data from various sources are used to develop predictive models identifying the mean processing time and its confidence intervals, to then take the predicted distribution and generate a scheduling system.

Inductive Optimization and Methods to Incoporate Data Properties

Cluster: Data Science Meets Optimization
Invited session
Chair: *Dimitri Papadimitriou*
Chair: *Claudio Sole*

1 - Two-Dimensional Rearrangement of Atoms with Defect-Free Formation
Chulin Likasiri, *Radom Pongvuthithum*

We are interested in the problem of atom rearrangement, where p randomly generated atoms in n×n initial array are moved to a dense m×m target array and m is significantly less than n. Some restrictions for atom rearrangement include the following: 1) they should not collide; 2) their paths should not overlap; 3) they should not be in nearly trespassing paths; and 4) there is a time limit for the atoms to be moved. To solve this problem, we construct it as an assignment problem with specific cost functions to assign atom movement following the indicated restrictions. The problem consists of n4 variables and 2n2 constraints, or as low as pm2 variables and 2p constraints in a modified version of the problem. For an acceptable size of array (100×100 initial array half-filled with atoms and 70×70=4900 target sites), the number of variables exceed 24 million variables and 10 thousand constraints. Although this problem is still solvable (albeit at the limit of solvability), given the ability of today's computers, it has not passed the time limit restriction. This work offers a tailored-made algorithm to solve the problem over an extremely shorter execution time. Our algorithm partitions the problem into a collective of much smaller sub-problems, enlarging the size of the problem we can solve. Even though we have to solve a number of sub-problems, we can still solve the original problem in a shorter time.

2 - Control Charts for Statistical Process Control - A Literature Overview
Anika Johlke

Control charts are a widely used tool for statistical process control and have been continuously researched and applied for several decades. If the underlying assumptions are guaranteed, traditional charts, such as the Shewhart, EWMA or CUSUM chart, are a reasonable choice for monitoring production or service processes. With the increasing availability of data and the need for more complex monitoring processes, however, these charts have evolved, resulting in broad and diverse field of research. This literature overview aims to categorize the different characteristics of control charts, including general and specific control charts, different data, multivariate and distribution-free charts, and the economic approach for designing a control chart. Especially, a categorization scheme for different performance metrics is provided. The overview offers a brief summary of all categories, outlines representative articles, introduces the most influential authors in the field, and suggests several areas for future research. Unlike recent literature reviews, we do not focus on a specific property of control charts, but rather provide a comprehensive overview. Research on this topic has not ceased at all; in fact, it has increased in the past two years, emphasizing the continued importance of control charts.

3 - On the estimation of the Generalized Stochastic Preference choice model to capture irrational customer behaviors
Claudio Sole, *Sanjay Dominik Jena*, *Andrea Lodi*

The random utility maximization model is by far the most adopted framework to estimate consumer choice behavior. Behavioral economics has provided strong empirical evidence of irrational choice behaviors, such as halo effects, however, incompatible with this framework; models belonging to the random utility maximization family may not accurately capture this irrational behavior. More general choice models, overcoming these limitations, have been proposed, but their flexibility comes at the price of increased risk of overfitting; estimating the models remains a challenge. In this work, we propose an estimation method for the recently proposed generalized stochastic preference choice model, subsuming the family of random utility maximization models and capable of capturing halo effects. Specifically, we show how to use partially-ranked preferences to efficiently model rational and irrational customer choices from transaction data. Accounting for irrational preferences can boost predictive accuracy by 12.5% on average, when tested on a real-world dataset from a large chain of grocery and drug stores.

Machine Learning,Data Analysis and Combinatorial Optimization

Cluster: Data Science Meets Optimization
Invited session
Chair: *Jorik Jooken*

1 - Instance space analysis for the 0-1 knapsack problem using rich and expensive features
Jorik Jooken, *Pieter Leyman*, *Patrick De Causmaecker*

The 0-1 knapsack problem, a classical combinatorial optimization problem, studied for several decades, has very efficient algorithms to solve many large problem instances to optimality in a couple of seconds. As a consequence of this success, researchers have also shown a lot of interest in finding problem instances hard to solve to optimality and in characterizing what makes them hard. Among other things, the Instance Space Analysis methodology allows one to visualize problem

instances in a two-dimensional space and to determine regions where the hard problem instances occur, based on a description of the problem instances as feature vectors. Typically, these features are cheap to compute, making them attractive for predictive purposes. In this work, we propose a new set of 14 computationally expensive features, based on previous work by the authors. We propose polynomial and pseudopolynomial time algorithms to calculate the features and show their use for hardness analysis, as they contain more hardness-related information than previous features from the literature. We use the instance space analysis methodology to show hard instances occur in a dense cluster and to make connections between the distribution of several features and problem instance hardness. Moreover, we show the features can be cheaply approximated for prediction purposes at the cost of a less accurate prediction.

2 - A Graphical Approach to Text Summarization based on Text Mining and Mathematical Programming Methods
Li-Ching Ma

With the popularization of the Internet, social networks, and information technology, the amount of data from various sources has exploded, often leading to information overload. Because most of the data or online content is in unstructured text format, it greatly increases the difficulty and time of processing. Therefore, there is an increasing demand for text summaries to help users rapidly interpret text information in the fast-growing information age. Text summarization technology refers to extracting the most important information from the original text and generating a simplified version of it. In recent years, text summarization technology has been widely used to analyze online customer reviews, to reduce the time spent viewing customer reviews in detail. This study aims to develop a graphical approach for text summarization, based on text mining and mathematical programming methods. A text mining process is performed to identify high-frequency terms and build a term-by-frequency matrix. Starting from the idea of data warehouse schema, this study designs a star diagram and a snowflake diagram to visualize the relationship between nouns and adjectives. Mathematical programming optimization models were proposed to display nouns and adjectives on a two-dimensional plane. This research provides a simple and readable way to summarize a large amount of text contents on a single graph. Users can greatly reduce the time spent browsing a large number of documents or reviews one by one.

3 - A Machine Learning augmented Simheuristic for Stochastic VRP with Surrogate Modelling
Hassana Abdullahi, *Ramazan Esmeli*, *Angel A. Juan*, *Djamila Ouelhadj*

Hybrid simulation-optimisation (sim-opt) methods and, in particular, simheuristics have been proposed to solve stochastic optimisation problems, but they can be computationally expensive and time-consuming, especially with large-scale and complex problems. In this study, we propose a two-fold machine learning approach to improve the efficiency of sim-opt methods. The proposed approach comprises two processes, as follows: (i) development of classification models to filter out unpromising deterministic solutions worthy of simulation; and (ii) definition of a surrogate model to predict the simulation's outcome, thus reducing the need for computationally expensive simulations. The proposed methodology begins with data collection; historical simulation input parameters, settings, and output results are gathered, then preprocessed to ensure compatibility with machine learning algorithms. The classification models are trained using suitable algorithms and used to filter out deterministic solutions deemed unpromising ("not worthy of simulation budget"), allowing resources to be focused on more viable solutions. The surrogate model, on the other hand, is trained on linear regression models, aiming to accurately predict the simulation's outcome based on input parameters, significantly reducing computational times and enabling faster decision-making. The performance of both models is assessed through a rigorous evaluation using validation and testing datasets. Also, this method will be evaluated using the mean absolute error and a comparison of the cost metrics. In conclusion, the proposed machine learning-based filtering and surrogate modeling approach significantly improves the efficiency of simheuristic methods. By intelligently filtering out unpromising solutions and leveraging surrogate models to predict outcomes, we can achieve substantial time and resource savings, without sacrificing prediction accuracy. This study contributes to the growing body of research on the intersection of machine learning, simulation and optimisation, highlighting the potential benefits of integrating these technologies in various industries and applications.

4 - Scheduling Limited Initiation Cues (SLIC): A Novel Combinatorial Scheduling Formulation for Adaptive Machine Learning and Cybersecurity Applications
Nouri (Nourhan) Sakr, *Ojas Parekh*, *Cynthia Phillips*, *Clifford Stein*

Inspired by adaptive machine learning theory and moving target defense games, we develop a combinatorial scheduling framework to optimize on resources of a given system. We introduce a novel scheduling problem where each of a set of parallel machines has a specific set of jobs that must be executed on that one machine in a specific order. We must select a limited set of global start times. Upon completing a job, a machine must wait to the next global start time to begin its next job. We wish to maximize the total work completed before a given global deadline. This problem comes from a stochastic-programming version of a probabilistic game that models moving-target defense in cybersecurity. This game also has an interpretation in adaptive machine learning. We motivate and define the scheduling problem and give the first hardness results, algorithms for special cases, and initial approximation results.

Discrete Optimization

Cluster: Discrete Optimization
Invited session
Chair: *Carlos Testuri*

1 - On outer approximation method for nonconvex binary optimization
Hoa Bui

The current state-of-the-art algorithms for solving nonlinear binary optimization problems have two challenges: they are mostly restricted to convex/concave settings and they struggle with large problems. We revisit the outer approximation method, a widely used solution methodology for convex/concave discrete optimization, to a more general nonconvex framework; this involves deriving a new convergence condition allowing for generalized concave cases, such as quasiconcavity and pseudoconcavity, and rigorous convergence analysis quantifying the number of points removed by each cutting plane. We exploit these results to devise a new strategy to accelerate the convergence of the algorithms. We apply the results in certain classes of non-concave binary quadratic programming problems, including cardinality Boolean quadratic programming problems. The new approach outperforms the traditional methods and can handle some instances of up to a thousand variables.

2 - Cyclic workforce rostering in the public sector, an application
Sandra Gutierrez, *Fernanda Salazar*

This study addresses a cyclic workforce rostering problem presented by the Ecuadorian State Prosecutor's Office; the objective is to design a rostering system ensuring fair distribution of shifts among workers and teams, while meeting specific requirements. The workday consists of three shifts, and each shift must be covered by a team composed of three individuals with unique qualifications: a prosecutor, a secretary, and an assistant. For Late-at-night and Overnight shifts, a secretary or an assistant can be omitted, but a prosecutor must always be present in each team. On weekdays, a fixed team of personnel rotates to cover shifts. On weekends, a different set of workers must alternate to complete a team, however, while ensuring coverage of multiple offices located in different geographic areas. To solve this problem, we propose an integer linear programming model and solution methods. Our approach ensures each team/worker is assigned an equitable number of shifts during the planning horizon.

3 - Solving a problem of enrolling students in shifts of courses with quotas, considering preferences and shift overlap
Carlos Testuri, *Pedro Piñeyro*, *Libertad Tansini*

We address variants of a problem of assigning students to course shifts, maximizing student preferences for shifts while accounting for shifts overlap and capacity. This problem arises in the context of "Universidad de la República", the largest state and public university in Uruguay with over 150 thousands students, 85% of the country's university students. The university has several schools or faculties, such as medicine, law, engineering, psychology and chemistry. In many careers of these schools, some course shifts are deserted and most of them are overcrowded with excess demand on available resources for various reasons - infrastructure and budget constraints and student preferences for certain shifts or teachers. Currently, the assignment of students to course shifts is quota-based, established as the maximum number of students assigned to a certain shift. The enrolment is done on a first-come, first-served basis through an online computer system on the web. This procedure, in addition to causing service peaks on the system and, therefore, its failure, is not equitable in terms of access, is not transparent, and takes a lot of time and generates frustration among students. To avoid these unwanted effects, a new assignment procedure is being developed for law and psychology schools, where students register for a course indicating their shift preferences prior to assignment. This new assignment procedure maximizes student preferences, taking into account schedule overlap, among other specific variants determined by priority criteria of the schools. While the law school gives higher priority for certain course schedules to students who live far away or work, the psychology school gives priority to students based on their academic progress. Problem variants of these schools has been modeled by discrete optimization and formulated using an algebraic language. The formulation has been coded with AMPL and solved with GUROBI. The proposed procedure allows students equitable access to enrollment and to a transparent and efficient resolution of the assignment to the shifts of their preference.

New Trends in Operations Management

Cluster: Game Theory and Operations Management
Invited session
Chair: *Rene Caldentey*

1 - Demand Estimation Under Uncertain Consideration Sets
Gustavo Vulcano

Consider-then-Choose (CTC) models have gained significant popularity recently within operations; in practice, however, we do not observe consideration sets, making it difficult to estimate these models. When firms only collect transaction data, do CTC models offer any predictive advantage over the classic choice models? In this work, we study a general class of CTC models and propose techniques to estimate these models efficiently and compare them against the classic approach, ignoring consideration sets. CTC models outperform classic models, when there is noise in the offer set information and the noise is asymmetric across the training and test offer sets, but otherwise offer no particular predictive advantage . We demonstrate the benefits of using CTC models in real-world retail and online platform settings.

2 - Information Design and Sharing in Supply Chains
Rene Caldentey

We study the interplay between inventory replenishment policies and information sharing in the context of a two-tier supply chain with a single supplier and a single retailer serving an iid Gaussian market demand. We investigate how the retailer's inventory policy impacts the supply chain's cumulative expected long-term average inventory costs C in two extreme information sharing cases: (a) full information sharing and (b) no information sharing. To find the retailer's inventory policy minimizing C, we formulate an infinite-dimensional optimization problem whose decision variables are the MA(infinity) coefficients characterizing a stationary ordering policy. Under full information sharing, the optimization problem admits a simple solution and the optimal policy is given by an MA(1) process. On the other hand, to solve the optimization problem under no information sharing, we reformulate the optimization from its time domain formulation to an equivalent z-transform formulation where the decision variables correspond to elements of the Hardy space H2. This alternative representation allows us to use a number of results from H2 theory to compute the optimal value of C and characterize a sequence of epsilon-optimal inventory policies under some mild technical conditions. By comparing the optimal solution under full information sharing and no information sharing, we derive a number of important practical takeaways. For instance, we show there is value in information sharing, if and only if the retailer's optimal policy under full information sharing is not invertible with respect to the sequence of demand shocks. Furthermore, we derive a fundamental mathematical identity revealing the value of information sharing by exploiting the canonical Smirnov-Beurling inner-outer factorization of the retailer's orders when viewed as an element of H2. The value of information sharing can grow unboundedly when the cumulative supply chain costs are dominated by the supplier's inventory costs.

3 - Optimal Work-Rest Cycles
Thomas Weber

For a system whose state declines exponentially when 'active' and increases exponentially otherwise, we determine optimal work-rest cycles. The optimal switching policy maximizes the average cycle benefit, where the benefit at any given time is proportional to the system state during an active period and zero otherwise. Any given lower bound for the length of a rest period determines a unique limit cycle, where the state converges, irrespective of its initial value. The average benefit becomes maximal when the length of the resting period converges to zero and the system reaches a steady state of 'flow' with a nontrivial work-rest split. For that case, we provide a relatively robust parameter estimate, valid in the absence of any knowledge about the system's time constants.

4 - Contractual coordination under co-opetition strategies embedding complementary resources
Bo Feng, *Jixin Zhao*

This paper investigates an emerging business model in electric vehicle (EV) operations. The model is established upon a yet unexplored co-opetitive paradigm, where a pair of complementary resources are taken within a co-opetition process. We investigate how to bring about the model's maximum efficacy using reciprocal cooperation contracts and ingenious pricing strategies. We develop game theoretical models under a co-opetitive and a benchmark competitive mode to capture the participants' strategic interactions and optimal decisions. Comparison of the equilibria suggests all the players are expected to benefit from co-opetition, if a quantity discount contract is carefully designed based on the market situation. Analysis of the equilibria also alludes to a need to incorporate an inter-decision trade-off, when the co-opetition process is embedded with complementary cooperating and competing elements. We also show and explain how the changes in relationship-specific and market-specific factors mutually moderate to affect the co-opetitors' pricing strategies. Co-opetitors can thus strategically adapt and respond to the concurrent changes in multifaceted factors. Our paper develops critical insights, utilized as strategic guidance for firms to pursue co-opetition in a changing business environment.

Topics on Operations Management

Cluster: Game Theory and Operations Management
Invited session
Chair: *Fernando Bernstein*

1 - Dynamic population tracking in large service systems
Fernando Bernstein

We develop asymptotically optimal policies to track queue lengths under different cost structures in a setting with inaccurate arrival and departure sensor data. We propose an idleness detection policy and explore the value of queue inspections. Our model is supported by queue length tracking at a large airport.

2 - An Analysis of Project Structure and its Impact on Project Completion Delays
Greg DeCroix, *Fernando Bernstein*

Consider a project (e.g. construction of a major commercial facility) where a general contractor is hired to manage multiple subcontractors to complete project activities; the general contractor may have to compensate the end customer for costs from any delays beyond an agreed completion time. While the general contractor pays these penalties, delays typically arise from a subset of the subcontractors, possibly earning additional revenue by diverting resources away from the project to an outside activity, slowing their work on the focal project. General contractors often write contracts allowing them to pass-on delay penalties to the appropriate subcontractors. If multiple subcontractors contribute to the overall delay, however, it is challenging to determine the appropriate allocation of penalties and, even more difficult, to predict how the subcontractors will respond (i.e., what delays they will choose) to the incentives created by the penalties.

For these projects, we consider allocation schemes based on Shapley or Owen values from cooperative game theory. Under this scheme, we study equilibrium delays chosen by individual subcontractors - and the resulting overall project delay - for specific project structures. We use these findings to observe general principles having implications for project design. For example, when activities occur in series, there is a first-mover advantage, where subcontractors, managing activities earlier in the series, choose longer delays (and earn higher net revenues), relative to those falling later in the series. Also, a larger number of activities leads to a greater project delay. On the other hand, subcontractors managing activities in parallel choose identical delays in equilibrium. This common delay is increasing in the number of parallel activities (and so is the overall project delay). We also derive equilibrium delays for more complex projects and note how the preceding general principles extend more generally. Finally, we analyze the impact on equilibrium delays if a single subcontractor manages multiple activities.

3 - Operational Risk Management: Optimal Inspection Policy
Yuqian Xu

Major banks around the world lost nearly $210 billion from operational risk events between 2011 and 2016 (Huber and Funaro 2018). To mitigate the severe consequences brought by operational risk, the Basel Regulatory Committee has required financial institutions worldwide to conduct inspections on operational risk. Motivated by the importance of operational risk and its current industry regulation, this paper proposes a continuous-time principal-agent model to examine a financial firm's (principal) optimal inspection policy and their employees' (agent) effort toward lowering the occurrences of risk events. First, we characterize the optimal inspection strategy under two commonly used policies in practice: random and periodic policies. This characterization reveals the conditions for two different modes of inspection (effort inducement and error correction), as well as nuanced interactions among inspection frequency, penalty charged on errors, and the wage paid to employees. Next, by comparing random and periodic policies, we find random policy outperforms periodic policy, if and only if the inspection cost is high. Furthermore, we propose a hybrid policy strictly dominating random policy and weakly dominating periodic policy, suggesting a proper reduction of the random element in the inspection policy can always improve its performance. Finally, we examine the first-best benchmark, supplemental mitigation strategies, and numerical studies to provide further insights and show the robustness of our main findings.

4 - Sustainable Sourcing of Agricultural Products: Fixed vs. Flexible Premiums
Can Zhang, *Vishal Agrawal*

Sustainability certifications have gained increasing popularity for the sourcing of agricultural products. To help smallholder farmers achieve a living income, an important lever these certifications use is a premium manufacturing firms pay to certified farmers, on top of the market price. A popular premium approach, implemented by several major certification programs, is the fixed premium, where farmers receive a fixed level of premium, independent of the market price. Although a fixed premium approach is simple, it has been criticized for not protecting farmers from low market prices. An alternative approach, flexible premium, has been widely advocated and considered by some of the most recent certifications; under this approach, farmers receive a higher level of premium when the market price is lower. In this paper, we analyze and compare the effectiveness of these two premium approaches. Our analysis offers several insights. First, although the flexible premium approach is intuitively appealing and has been widely advocated, it does not necessarily help improve the expected farmer income compared to fixed premium. Moreover, even when flexible premium improves farmer income, it may lead to a lower expected sustainable sourcing quantity and a lower expected firm profit. Nevertheless, flexible premium can lead to "win-win-win" outcomes for farmer income, sustainable sourcing quantity, and firm profit in supply-ample, demand-constrained settings. Finally, motivated by the increasing number of sustainability labels created by manufacturing firms, we study the choice of premiums under self-labeling and compare the equilibrium outcomes with those under NGO labeling. Although self-labeling leads to a lower expected premium level, it can lead to a higher expected sustainable sourcing quantity than NGO labeling.

Matching Game Theory with Supply Chain

Cluster: Game Theory and Operations Management
Invited session
Chair: *Ana Meca*
Chair: *Juan Vidal-Puga*

1 - The Blockchain Newsvendor: Value of Freshness Transparency and Smart Contracts
Jingsheng Song, *N. Bora Keskin*, *Chenghuai Li*

Motivated by the emerging practice of adopting blockchain technology in the fresh produce supply chain, we investigate how blockchain-enabled transparency on product freshness affects a grocery retailer's inventory decisions, profit, and food waste. We introduce a freshness-dependent consumer demand model in a newsvendor framework and derive closed-form expressions for the retailer's expected profit growth and food waste reduction after adopting blockchain. Using real-life data to calibrate our model, we estimate blockchain technology can bring USD 60 million extra profit while reducing 23 million lbs food waste for Walmart's strawberry business in the U.S. annually, making only about 4% of Walmart's fresh produce sales. Despite the enormous value for the retailer, blockchain adoption may hurt the supplier's expected profit. To incentivize the supplier, we design a family of threshold smart contracts, contingent on the freshness consensus and examine its win-win propositions. In addition, when the retailer can adjust the retail price based on freshness, the retailer will offer discount for a less fresh product, reducing food waste. When the supplier can change the wholesale price based on freshness, the supplier will also lower the price for a less fresh product, but cause more food waste. Finally, we generalize our findings to the cases of (i) noisy measurements in the IoT sensors feeding data into the blockchain, (ii) dual sourcing, and (iii) other practical issues, including the traditional retailer's rejection behavior and the retailer's "culling" process.

2 - Stability in shortest path problems
Juan Vidal-Puga, *Eric Bahel*, *Gómez-Rúa María*

We study three remarkable cost sharing rules in the context of shortest path problems, where agents have demands that can only be supplied by a source in a network. The demander rule requires each demander to pay the cost of their cheapest connection to the source. The supplier rule charges to each demander the cost of the second-cheapest connection and splits the excess payment equally between her access suppliers. The alexia rule averages out the lexicographic allocations, each of which allows suppliers to extract rent in some pre-specified order. We show all three rules are anonymous and demand-additive core selections. Moreover, with three or more agents, the demander rule is characterized by core selection and a specific version of cost additivity. Finally, convex combinations of the demander rule and the supplier rule are axiomatized using core selection, a second version of cost additivity and two additional axioms that ensure the fair compensation of intermediaries.

3 - Integration of sales and operations: a dynamic mixed-integer programming game
Claudio Telha, *Margarida Carvalho*

We define a family of mathematical models, capturing a few of the very fundamental aspects making operations and marketing decisions challenging; the goal is to perform a production optimization when sales are affected by competition with other firms.

The problems in the family are multi-period; we consider three game formulations depending on how the game is played in each period. In the dynamic version, firms can react to the past play of the competition at every period. In the myopic version, firms may react to past play, but they cannot recognize the long-term benefit current decisions may yield. And, in the static version, firms commit to a production plan at the beginning of the game. Each formulation (dynamic, static, and myopic) leads to a different notion of equilibrium; we describe how to compute the equilibrium of the dynamic game and the myopic game efficiently (polynomial in the number of periods of the game).

We performed a computational study on one specific problem in this family, building on the top of two single-product models - one is the Cournot oligopoly and the other is a simple model capturing the value of investing in technology to increase productivity in the long term. We merge these two models into a two-firm, multi-period production planning model, adding competition. We focus mostly on the Stackelberg version of the game, where one firm is the leader and can commit to a quantity first. Our goal was to evaluate the impact dynamic interactions may have on the leader and the follower; we provide several observations in this direction.

Applications of Game Theory in Operations Management

Cluster: Game Theory and Operations Management
Invited session
Chair: *Gonzalo Romero*
Chair: *Charles Thraves*

1 - Technological and Market Response to the Environmental Tax by a Competitive Industry
Anton Ovchinnikov, *Dmitry Krass*

We consider a response to environmental taxes by firms producing a commodity good with a polluting by-product; the firms are heterogeneous with respect to production efficiency and pollution control technology. Cournot competition is assumed, with two demand functions: iso-elastic and linear. In this setting, we consider a market response, where firms choose production quantities given their technology choices, and a technology response, where firms also choose among a discrete set of available technologies. We characterize the equilibria and examine using environmental taxes to incentivize "green" technology choices; results may qualitatively differ depending on the demand function assumed.

2 - Electric Vehicle Fleet and Charging Infrastructure Planning
Francisco Castro, *Siva Theja*, *Sushil Varma*

We analyze an optimal electric vehicle (EV) fleet and charging infrastructure capacity planning problem in a spatial setting. As customer requests arrive, the system operator must determine the minimum number of vehicles and chargers along with a matching and charging policy maximizing the service level. We provide a sharp characterization of the fleet size and the charging infrastructure requirements as the demand grows. While a system with negligible charging times needs a 2/3-staffing rule on top of the nominal capacity, an EV system has a fundamentally different scaling. Due to charging times, the nominal capacity of the system is increased, but this extra capacity allows for an optimal EV dispatching policy to result in an extra fleet requirement translating into a decreased staffing rule anywhere between 1/2 and 2/3, depending on the number of charging stations and the size of the EV battery packs. We propose the Power-of-d dispatching policy, achieving this performance by selecting the d closest vehicles to a trip request and choosing the one with the highest battery level, thus optimizing the trade-off between the pickup distance and balancing the state of charge across the fleet. Our study provides valuable guidelines for determining the optimal fleet and charging infrastructure capacity for an EV-based on-demand transportation system.

3 - Optimizing Pit Stop Strategies with Competition in a Zero-Sum Feedback Stackelberg Game
Charles Thraves

The current work presents an application of a zero-sum feedback Stackelberg game for optimizing pit stop strategies in Formula 1. The result of a race not only depends on a driver's performance, but also on pit stop decisions - necessary (among other things) to change used tires for new ones. Indeed, tires degrade with their usage as more laps are raced, and, therefore, lap times are affected. During a race in Formula 1, there are three tire compounds: soft, medium, and hard. Softer tires allow faster lap times, but do not last as many laps as the harder compound, because the former degrades faster than the latter.

An additional complexity of the problem we consider is the competition between drivers (such as overtaking) during a race, affecting their lap times; thus, drivers' decisions could account for their opponents' decisions. Most works in this area have addressed the problem as an optimization problem, either neglecting competition or accounting for it in simulations or past decisions, but not in a game theory sense.

We present a model where two drivers compete against each other during a race; each car decides on each lap whether to continue on track or to do a pit stop, to change tires to one of the three tire compounds available. Since the drivers' decisions affect each other, the problem is formulated as a zero-sum feedback Stackelberg game, where, in each lap, the driver leading the race decides first, followed by the decision of the driver who is second. The game is solved via Dynamic Programming. In addition, at the beginning of the race, both players solve a simultaneous game to decide the tire compound to start the race. The formulation introduced also allows for the inclusion of random events, such as yellow flags (when cars must slow their speed due to a race incident).

We show the existence of game equilibrium and provide an algorithm to find this; then, we solve instances of the problem, based on a real race. We perform numerical experiments comparing the performance of a miopic driver (who does not account for his opponents' decisions) versus a strategic one and show omitting the strategic behaviour of the opponent car leads to worse race results in almost all scenarios.

4 - Geometry of linear bilevel programming with uncertain lower-level costs
David Salas, *Gonzalo Munoz*, *Anton Svensson*

In this talk, we will revise linear bilevel programming problems, whose lower-level objective is given by a random cost vector with known distribution. The cost function is interpreted as the belief of the leader over the uncertain follower's decision process, following the Bayesian approach for bilevel games. Where the distribution is nonatomic, we pose the problem of the leader using vertex-supported beliefs. Under suitable assumptions, this formulation turns out to be piecewise affine

over the chamber complex of the feasible set of the high point relaxation. Two algorithmic approaches solve general problems enjoying this property. The first one is based on enumerating the vertices of the chamber complex. The second one is a Monte-Carlo approximation scheme with randomly drawn points of the domain located, with probability 1, in the interior of full-dimensional chambers; the problem (restricted to this chamber) can be reduced to a linear program.

Combinatorial Optimization & Game Theory

Cluster: Game Theory and Operations Management
Invited session
Chair: *Xujin Chen*

1 - Stochastic Shortest Path Interdiction
Natalia Trigo, *Denis Saure*, *Juan Borrero*

Motivated by recent work in sequential bilevel problems under uncertainty, in this work we study sequential shortest path interdiction in settings where arc costs form an iid sequence of random vector, drawn from a common distribution known by the evader, but initially unknown by the interdictor. We model this problem of sequential decision-making under parameter uncertainty using the multi-armed bandit framework. In a first contribution, we extend the techniques used to find a fundamental bound on policy performance for the classic bandit problem and adapt them to obtain an asymptotic performance lower bound in this setting. The regret, a measure of performance degradation due to the initial lack of information commonly used in the bandit literature, is proportional to order log(T), where T denotes the time horizon, and to a constant depending non-trivialy on the combinatorial structure of the underlying full-information interdiction problem. The constant is the solution to a lower bound problem optimally searching for sufficient information to guarantee the optimality of the full information solution, unobtainable in finite time by observing the evader's reaction to different interdiction actions. We use the insight gained by lower-bound results to develop efficient policies mimicking the combinatorial structure of the asymptotic result, and we obtain asymptotic optimality. We test the performance of the proposed policies in exhaustive numerical experiments, where we contrast their performance with relevant benchmarks arising from more naive approaches to the problem. Our results provide key insight on the difficulty of the setting and should serve to close the gap between practice and theory on sequential interdiction problems - typically ignoring the difficulty associated with learning parameters in real time.

2 - Condorcet Stable Set: Optimizing Decision-making in Facility Location
Xujin Chen, *Changjun Wamg*, *Chenhao Wang*

In a facility location problem, k facilities are to be built to serve spatially distributed customers, but who decides the locations to choose for building the facilities? Different approaches place the decision in the hands of different groups or individuals. In a central planning approach, the central authority enforces a (near) optimal solution according to some system objective. In a market approach, the facilities (i.e., facility managers) play a game for selecting their own locations and return a Nash equilibrium. In a democratic approach, the customers collectively make the decision. We propose a novel solution concept for the democratic approach, called Condorcet stability. A solution, i.e., a set of selected locations, is Condorcet Stable (CS) if no unselected candidate location is more popular than any selected one. Focusing on the setting with customers continuously distributed on a network, we first give a string of existence results on CS solutions. Most notably, when the number k of facilities is large enough, we provide a characterization of CS solutions, leading to an efficient algorithm for finding the solution. We measure the efficiency of CS solutions w.r.t. the minimum total cost of all customers, using the standard terms of Price of Anarchy and Price of Stability, both upper bound with small constants.

Compared with the market approach, our democratic approach is more likely to achieve a desirable solution of higher efficiency. Compared with the central planning approach, CS solutions are naturally more stable and fair for the customers, and their efficiency is very close to the optimum, even in the worst case. Therefore, the customers in the scheme of Condorcet stability are better decision-makers for balancing the efficiency, stability, fairness, and tractability of facility locations.

3 - The optimal play against the fictitious play learning algorithm in infinitely repeated games
Yifen Mu, *Hongcheng Dong*, *Xiaoguang Yang*

With the rapid development of artificial intelligence in recent years, games between the human(or a perfect player) and machine/AI would become more common and the related problems would be more important. In this work, we will investigate the infinitely repeated games between the human and machine/AI, where the machine/AI adopts the classical learning algorithm, Fictitious Play(FP), to update its action each time. We will study the globally optimal strategy of the human over the infinite time. This problem involves evolution analysis and optimal control for the dynamical game systems driven by the learning algorithm and a perfect opponent, insufficiently studied in the literature, especially from the point of theoretical analysis. For all the two-player-two-action games, we will prove and construct the optimal strategy of the human, turning out to be dependent on the order relations between the human's payoff values. Furthermore, under the optimal strategy, the outcome of the game system will enter a cycle if the machine's payoff parameter is rational, while the cyclic behavior would be broken if the machine's payoff parameter is irrational. Moreover, the period of the cycle or the limiting proportion of outcomes depends on the machine's payoff parameter, too. In all the games with different payoff structures, the Fictitious Play algorithm can be exploited to the utmost extent, implying the intrinsic drawbacks of the algorithm from this point. Results in this work are rigorous and might shed some light on the analysis for more general game models and more advanced learning algorithms.

Game Theory Models

Cluster: Game Theory and Operations Management
Invited session
Chair: *Vinay Ramani*
Chair: *Sara Rezaee Vessal*

1 - Weighted voting games with small quotas
Xavier Molinero, *Salvador Roura*, *Maria Serna*

A simple game is a tuple (N,W), where N is a finite set of players and W is a monotonic family of subsets of N called winning coalitions. A simple game is a weighted voting game if there exists a real quota q and a weight function from N to real numbers, so $S \in W$ if and only if the sum of the weights of S is greater than or equal to q. Each simple game can be expressed as the intersection (or union) of weighted voting games. This work studies properties and develops methods to generate weighted voting games with many players and small quotas, up to isomorphism. To do this, we fix a canonical representation for all isomorphic weighted voting games. In this vein, we characterise and analyse properties among simple games generated as intersections (unions) of the subfamilies of weighted voting games (with small quota), as well as to count and list all those games. This work also studies the probabilistic distribution followed by the weights of the canonical weighted voting games.

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2 - Accepting defective products: Implications for supplier incentives
Sara Rezaee Vessal, *Ali Shantia*

Suppliers might sometimes develop a new product with an inferior quality to the buyer's expectations; we model the possibility of conditional acceptance of these products by the buyer. Our goal is to track the effect of conditional acceptance on supplier incentives to exert product development efforts. We construct a non-cooperative sequential game with risk-neutral players and analyze their equilibrium strategies. Implementing the conditional acceptance policy indeed affects supplier incentives, if the product is relatively high value to the buyer. The effect direction depends on the cost of effort and project success probability.

3 - Facilitating Human Capital Quality Control in Service Industry: A Case Study on Urban Company using Automated Query Systems, Visual Tracker Enabled Dashboards and Spreads
Rashmi Singh, *Sambuddha Maitra*, *Pragya Bajpai*

When the COVID-19 pandemic subsided to some extent in Dec. 2020, E-service Management Company resumed its business as usual and reactivated its dormant supply-chain. The service-providers were faltering, however, in service protocols and SOPs; their behavior was deteriorating. Due to bad customer experiences in one job, customers were refraining from using the platform again for their monthly services; this was due to the large period of inactivity of the service-providers who had almost forgotten several familiar service protocols. Gradually, the quality metrics started decreasing. Tag bubbles from previously used NLP-based sentiment analysis were being generated for management team to review and plan trainings, but the sheer number of Andon cords led the analytics dashboard and Andon notification system to crash. Due to social distancing norms, it was impossible to organize and conduct retraining and motivation sessions. The in-app communication system, serving as the primary communication touch point, was now dysfunctional, due to the cloud platform and dashboard crash. The API systems providing sentiment analysis insights from customer reviews were of no use due to the huge volumes of Andon's generated; they also did not provide proper micro-level tracking mechanisms.

The problems can be summarized as follows: - Voluminous Training Andon Requests - No Scope of Individual Service-Provider Performance Tracking Post-Training - No Communication Systems Between Management and Supply-Base

The problems discussed above required strategic thinking to be solved. The objectives of this study are as follows: 1. Automated Query Systems will be integrated within spreadsheet apps to automatically derive quality data from databases; 2. Dashboards will be created to serve as individual level performance trackers and city or category overviews; and 3. Development of Spreadsheet-based communication tools connecting and sending messages via What's App to facilitate information transfer for scheduled trainings and relevant information.

The study develops a more personalized approach to quality control and is specially aimed at non-technical operations management teams to execute quality control strategy with maximum efficiency. It will help in easy data extraction, will enable individual- and city/category-level tracking of performance, and will bridge communication gaps between management and service providers.

Game Theory Applications

Cluster: Game Theory and Operations Management
Invited session
Chair: *Kaori Isawa*

1 - Empowering Consumers: The Impact of Consumer-Determined Delivery Fees on Online Food Delivery Platforms
Arvind Shroff, *Bhavin Shah*

Currently, the online platform decides the delivery fee to be charged to customers for orders placed through Online Food Delivery (OFD) platforms, like DoorDash, Zomato and UberEats; it is based on the order value and the distance traveled by the driver to complete the delivery. Pay-As-Asked (PAA) delivery pricing strategy is the name of this tactic. On the contrary, Pay-What-You-Want (PWYW) is an innovative pricing strategy many businesses use, giving customers the final say over the price they are willing to pay based on how valuable they perceive the service to be. To investigate how the adoption of pay-what-you-want (PWYW) for delivery fee pricing affects the financial viability of OFD platforms, we present an analytical model. By dividing consumers into three groups—free riders, fair-minded consumers, and generous consumers—we can identify their social preferences for things like fairness and reciprocity. This allows us to determine the conditions under which PWYW might be more profitable for the platform than the typical PAA delivery pricing strategy. To maximize platform profits, when implementing a PWYW delivery fee, OFD platform managers should work to reduce delivery costs as much as they can. Furthermore, platforms should impose a minimum delivery fee customers may use as a guideline when determining the fee they want to pay to prevent free riders from reducing profits under PWYW.

2 - A Stackelberg Game for Empty Container Sharing under a Carbon Tax Policy
Haoyu Wang, *Dongping Song*

In the container shipping industry, container sharing between different shipping carriers have been considered as an effective way to reduce the movements of empty containers. Meanwhile, due to rising concerns about climate change and global warming, governments propose to levy the carbon emission tax that may suppress the demands for container shipping. This research develops a Stackelberg game model to investigate how container sharing in the maritime industry may be affected by the carbon tax imposed by governments. In the game, as the leader, the government's decision is to maximise social benefit by setting up the best carbon tax rate; while, as the followers, shipping carriers aim to design a mechanism of sharing containers to achieve container supply chain coordination under the government's carbon tax rate. It has been found that the carbon tax can affect carriers' profits positively or negatively and thus it is the dominant factor affecting the system coordination. However, even if the government introduces a carbon tax rate, a revenue sharing contract still can make a container sharing supply chain coordinated as long as the parameter in the contract is appropriately set.

3 - Solving the Conflict of Opinions over the Preservation of Historic Architecture in Japan as an Ordinal Utility Game
Kaori Isawa, *Hiroko Watanabe*, *Yudai Honma*

The issue of architectural conservation in Japan is increasingly in the international spotlight. The BBC and DEZEEN, international news websites, recently reported on demolishing historic Japanese architecture, such as the Nakagin Capsule Tower and the Kagawa Prefectural Gymnasium. Surprisingly, "oldness" is cited as one of the reasons for the demolition of notable architecture in Japan. Since the dominance of new construction was bred during the postwar recovery, Japanese prefer urban clearance development because old construction means "low economic efficiency. It is natural for an owner of historic architecture to want to demolish it." We then focus on a conflict between owners and outsiders over the conservation of historic architecture in Japan and visualize possible outcomes by solving it as an ordinal utility game. Finally, we make the situations more realistic by considering "Social Value Orientation (SVO)", where each player prefers a balance between self and others. Specifically, an owner of historic architecture hopes for demolition, while a citizen, an expert, and a municipality, namely an outsider, hope for conservation. Furthermore, the players have one of the SVOs: Individualistic, Altruistic, Prosocial, and Equality (Equalistic/Egalitarian); thus solving a total of 16 pattern games. The range of equilibrium points increases as the number of owner options increases. Moreover, this tendency is pronounced when a player has a prosocial or egalitarian SVO. Thus, the arrival of the outsider has a mathematical validity to change the owner's decision. Architectural conservation will be unsuccessful, however, unless the

owner has an SVO, such as adjusting the balance of utility between self and others by respecting the utility of the outsider. In addition, we compare the results of the analysis and cases of conservation requests from the Architectural Institute of Japan (AIJ) and estimate the SVO of owners and AIJ by industry. Finally, based on the results, we introduce existing approaches in Japan as nudges, such as installing certification plaques in Kanazawa City and the Large-Scale Development Reviewed by Ordinance in Fuchu City.

4 - Competitive Markovian Pricing
Haokun Du

Problem definition: Dynamic pricing is often complicated by strategic customer behavior. One tactic utilized by retailers to counter strategic customer behavior is to adjust prices in an unforeseeable manner. This phenomenon has been studied in the Markovian pricing literature in single-retailer settings. In this paper, we extend the study to a competitive setting. Methodology/results: By analyzing a competitive Markovian-pricing model and comparing it with a non- competitive benchmark, we show that, in the Markovian pricing setting, competition may improve retailer profits and price synchronization may reduce retailer profits, both of which are contrary to conventional economic wisdom. Managerial implications: Our findings highlight unique properties of the Markovian pricing setting and provide strategic caveats against retailers na ¨ıvely applying conventional economic wisdom in this setting.

Market Design I

Cluster: Game Theory, Market Design, and Mathematical Economics
Invited session
Chair: *Gabriel Weintraub*
Chair: *Martin Bichler*

1 - Simulating and Evaluating a Joint International Kidney Exchange Program
Felipe Subiabre, *Itai Ashlagi*, *José Correa*

In a kidney exchange program (KEP), willing but incompatible patient-donor pairs associate to form exchange cycles. KEPs exist in different forms in several countries around the world, and are generally limited to the patient-donor pools of the country or a region within. In a joint international KEP, a set of countries team up to share their corresponding exchange pools.

The most important benefits to creating joint international KEPs are the enlargement of the pools, of particular importance for small countries, and an increase in diversity of their compositions, which can have a large impact in the prospect for each country's hard to match patient-donor pairs. On the other hand, implementing such a program creates considerable logistic costs.

We develop a simulator to evaluate a possible joint international KEP between countries under two main policies. The first one is sequential, prioritizing the formation of cycles at the local level first and then matching the remaining pairs, while the second one us considers fully joint exchange pools. By implementing optimization methods to solve weighted instances we can realistically penalize the formation cost of international cycles in both cases.

Our model can use historical data for each country's exchange pools to simulate instances of pool developments over time, with corresponding periodic matching runs under each policy.

As a proof of concept we show how, starting from partial data for the United States and Chile, we can simulate the dynamics of a not yet implemented KEP in the second country and compare its expected performance against a hypothetical joint KEP.

2 - Treasury Auction Format
Aleksandrs Smilgins, *Sasa Pekec*

The choice of auction format for government bond auctions varies by country, with uniform or discriminatory sealed-bid auctions with preapproved bidders (Primary Dealers) being the most prevalent. We compare bidding in Danish and Swedish government bond auctions, and how it relates to the auction pricing rule: Denmark uses uniform pricing, while Sweden uses discriminatory pricing.

3 - Sharing sequentially triggered losses: Automated conflict resolution through smart contracts
Jens Leth Hougaard

When actions by one agent force another to deviate from their agreements with a third, "victim" turns into "injurer" in the chain's subsequent steps. Should the chain's initiator be responsible only for the direct harm they cause, or also bear some of the indirect losses they trigger? Through an axiomatic approach, we characterize the class of fixed-fraction rules, striking a balance between incentives for accident prevention, on the one hand, and fairness in terms of how liabilities are assigned, on the other. Their simple designs make the rules ideal for practical implementation through smart contracts, enabling automated conflict resolution.

Market Design II

Cluster: Game Theory, Market Design, and Mathematical Economics
Invited session
Chair: *Gabriel Weintraub*
Chair: *Martin Bichler*

1 - Designing incentive mechanisms to reduce public spending: A Field Experiment in Government Procurement
Marcelo Olivares

We design a field experiment to study how information-based, implicit monitoring technologies affect performance in public services, while keeping organizational structure fixed. In collaboration with the Chilean Public Procurement Office, we randomly assigned monthly reports with systematic information about the purchasing performance of procurement officers and services to a sample of 2,600 procurement officers in 184 public services and randomly varied whether the individual performance was disclosed to managers (public) or not (private). After 5 months of treatment exposure, we find the reports generated significant reductions in overspending, but only when individual performance was observable for managers - extrinsic motivation is a necessary condition for performance information to generate a change in purchasing behavior of officers. We further find most of the treatment effect comes from organizations where values associated to efficiency were misaligned across managers and officers, suggesting organizational culture plays a key role in easing the impact of implicit monitoring technologies in preventing the misuse of public resources.

2 - Market Re-Design of Framework Agreements in Chile Reduces Government Procurement Spending
Gabriel Weintraub

Framework agreements (FAs) are procurement mechanisms used in private and public organizations where a central procurement agency selects an assortment of products, typically through auctions, and, then, affiliated organizations can purchase from the selected assortment as needs arise. In Chile's central procurement agency (ChileCompra), FAs accounted for 23% of the procurement expenditures during 2018-19. Descriptive analysis of purchase transaction data suggests some FAs exhibited low levels of competition in the auctions used to select the suppliers, however, potentially resulting in larger government expenditures. We collaborated with ChileCompra to redesign FAs to enhance competition, introducing two important changes: (i) standardize the product catalogue using natural language processing algorithms; and (ii) use this product standardization to induce more competition in

the selection of suppliers. These changes were implemented through an experimental design in the new Food FA to measure its impact, showing that inducing more intense competition in the auction stage reduced transaction prices by 8%. This pilot study ultimately led ChileCompra to implement a similar design in all of its FAs, and many of the improvements in the design of the FAs were included in the new regulation on government purchases. If extrapolated the savings from our pilot re-design to all of these FAs, the total savings would amount to around $64 million USD in 2022.

3 - Efficiency Bounds for Stable Matchings
Martin Valdevenito, *Juan Escobar*

A common method to allocate scarce resources is to apply the Deferred Acceptance (DA) algorithm proposed by Gale and Shapley (1962) and to obtain a stable matching; it need not be Pareto efficient, however. How efficient a stable matching is depends on the alignment of the preferences of both sides of the market. We provide efficiency bounds for a stable matching and apply our insights to priority design in school choice.

Game Theory

Cluster: Game Theory, Market Design, and Mathematical Economics
Invited session
Chair: *Ulrike Leopold-Wildburger*
Chair: *Gerhard-Wilhelm Weber*

1 - A sampling approach for the approximation of the Deegan-Packel index
Livino M. Armijos-Toro, *José María Alonso-Meijide*, *Manuel Alfredo Mosquera-Rodríguez*, *Alejandro Saavedra-Nieves*

The exact calculation of power indices with a large number of players represents a high computational complexity, since the number of coalitions evaluated in the game increases exponentially. Statistical sampling is used in those situations where accessing information from all individuals in the population under study is costly. We estimate the Deegan-Packel index in simple games based on sampling, and we present the application of this method in the estimation of the Deegan-Packel index for the Electoral College of the United States and the members of the Board of Governors of the International Monetary Fund in 2022.

2 - Two-stage hierarchical games and approximations
Lina Mallozzi

This paper concerns a multiple-player two-stage hierarchical game where the second stage consists of a finite Nash equilibrium problem. To ensure the second stage game admits solutions, its mixed extension is considered. Many situations are described by this model, such as security games. One of the players is the leader in a leader-follower problem, while opponents are involved in a simultaneous noncooperative game. The case one leader-one follower is known also as the Stackelberg problem. The leader makes the solution optimistic or pessimistic in choosing the best or the worst the leader can achieve when the followers choose the best reply. We concentrate on the strong (or optimistic) Stackelberg solution to solve the multiple-player two-stage hierarchical game. Existence results of solutions and approximated solutions for the strong hierarchical problem are illustrated. Moreover, by using the Shannon entropy, a regularization scheme for the two-stage game is introduced and some properties are presented, as the asymptotic subgame perfectness.

3 - A mathematical model of organizational capital
Januj Juneja

In this paper, we develop a stochastic model of employees' ability to turn human knowledge, skill, and ability into outcomes of return to organizational capital, based upon five measures of management decisions: (1) ratio of the firm's intangible assets to total conventional assets (δ), (2) rate knowledge is utilized by the firm (σ), (3) arrival and departure of knowledge from the firm (φ), (4) rate of knowledge turning into organizational capital (μ), and (5) rate of work completion (ν). Our model can help management integrate intangibility in its operations (for enhancing organizational capital), by assessing, monitoring and integrating intangibility; we include existing and acquired goodwill with existing and acquired intangible assets. Starting with the SEC reported Services segment of revenues, we enhance its value by other related revenues to arrive at knowledge output. Next, using many decision and outcomes variables, we assess the firm's intangibility and organizational capital; we analyze capital investments of the top ten technology companies by the value of their market capitalization, so they can serve as industry benchmarks. Finally, we investigate the relationship between stock return performance and organizational capital, using our methodology, and conclude by developing some assessment tools and directions for future research.

Game Theory, and Ethics, Fairness and Governance

Cluster: Game Theory, Market Design, and Mathematical Economics
Invited session
Chair: *Gerhard-Wilhelm Weber*
Chair: *Sona Taheri*
Chair: *Adil Bagirov*

1 - Chaos, granularity, and instability in economic systems of countries with emerging market economies: relationships between GDP growth rate and increasing internal inequal
Marco Desogus, *Elisa Casu*

Starting from empirical observations of macroeconomic data from emerging market economies recorded in the second decade of the 2000s, an economic analysis was conducted on these economies' prerogatives and prospects, with special attention given to possible risks of systemic instability and the general soundness of their social and socioeconomic structures. These assessments seem particularly relevant, not only for the countries in question, but because of their growing influence in determining international economic balance in the network of relations with developed countries at large. Indeed, alongside good performance trends in production growth, distribution of new wealth having exacerbated inequalities can be discerned. Moreover, emerging countries' economic policies often show a general accommodation to the sole objective of production growth, while neglecting to maintain equilibrium within the combined arrangement of all (other) macroeconomic variables. Hence, at first, we investigated the constitutive dynamics of these phenomena, using an income diffusion model based on a Pareto probability distribution, then on rheology for the analysis of the peculiar new wealth flows distributed over these countries' populations, as well as any spontaneous redistribution effects induced by transactions among resident agents. At that point, applying the Dynamic New Keynesian model, we represented the system and studied solutions. Finally, we offer a proposal for constant government monitoring of each system, adopting control procedures capable of intervening - by way of economic and monetary policy instruments - where trends showed certain critical levels of instability in the economic system, observable from the trajectory diagrams.

2 - Bounds on Choquet Risk Measures in Finite Product Spaces with Ambiguous Marginals
David Saunders

We investigate the problem of finding upper and lower bounds for a Choquet risk measure of a nonlinear function of two risk factors, when the marginal distributions of the risk factors are ambiguous and represented by nonadditive measures on the marginal spaces, but the joint nonadditive distribution on the product space is unknown. We treat this problem as a generalization of the optimal transportation problem to the setting of nonadditive measures. We provide explicit characterizations of the optimal solutions for finite marginal spaces, and we investigate some of their properties. We further discuss the connections with linear programming, showing the optimal transport problems for capacities are linear programs, and we also characterize their duals explicitly.

3 - Dimension of a significant sub-class of anonymous simple games with several levels of approval
Dani Samaniego, Josep Freixas

Simple games are important mathematical objects since they are used to model many real-world scientific and social sciences applications; of the latter, we highlight the applications to political science, social choice and cooperative game theory. Some of its properties, like completeness or weighedness, are widely studied in the literature.

In this talk, we generalize simple games by considering voting systems with more than two ordered levels of approval, and we specialise by considering anonymous voting systems, i.e., voting systems where all voters have the same influence in the decision-making of a certain company or committee. We mainly focus on the subclass of anonymous games with one model of minimal winning profiles and provide several examples of real-world situations modelized in this way.

We find for them its dimension, i.e. the minimum number of weighted games its intersection recovers in the original game, and discuss several consequences derived from its calculus.

Operational Research in Financial and Management Accounting 1

Cluster: Game Theory, Market Design, and Mathematical Economics
Invited session
Chair: *Matthias Amen*
Chair: *Lukas Benjamin Heidbrink*

1 - Allocation of orders to existing production sites with different German trade income tax rates in short-term production program planning
Matthias Amen

In medium-term tactical production program planning, one knows production locations and capacities. In the case of a short-term production decision, such as whether to accept an additional order, one must determine the relevant costs. With existing production locations, the production processes for manufacturing the product may differ, with regard to the use of labour and operating resources. If using the same manufacturing process, but with differences in the cost structure, e.g. due to different tariff areas, one must distinguish them from each other in cost-oriented planning. Also, one must know the contribution margin, regardless of any corporate profit tax or corporate income tax.

If taking into account the trade income tax (Gewerbeertragsteuer), however, the company may have different profit tax rates for various business locations, because of the municipality-specific assessment rates. In addition, trade income does not allocate where it arose, but divides among locations, according to the ratio of payrolls (Section 29 (1) No. 1 German GewStG), and then charged at the location-specific trade income tax rates. The effective trade income tax rate stood at between 7% and 31.5% in 2014, depending on the municipality. With the objective function no longer linear, the simple becomes a complex decision problem; the optimal production decision may differ significantly if taking trade income tax into account.

We present a general model formulation, considering the trade income tax in the objective function, and the solution of a conceptual example, based on the problem description with AMPL (A Mathematical Programming Language) and use of a common solver (e.g. CPLEX or Gurobi). Due to the separation of model and data in AMPL, one can easily transfer the approach.

2 - Analysing the optimal production quantity in case of stochastic carbon dioxide pricing
Anna Uhrmeister

The awareness of climate change and the related need for climate protection have become part of a company's day-to-day business. In 2005, the European Commission introduced the European emissions trading system to limit the effects of anthropogenic climate change and to make them more predictable. From 2027 on, as a result of the so-called Green Deal, companies will no longer be subsidized and will have to pay the entire costs of greenhouse gas emissions; impacts for companies are still uncertain. This research takes a closer look to investigate the impact of greenhouse gas emission costs on German companies; the effects will be most significant in carbon intensive productions, so we model and analyze an average company in the steel industry. In particular, the uncertainty caused by fluctuations in the pricing of CO2 certificates and varying raw material prices make it challenging for companies to determine the optimal production quantity.

3 - Verification of the recognition criteria for deferred tax assets on interest carryforwards
Carolin Famulla

Regarding the income tax base, many jurisdictions restrict the deductibility of interest expenses when they arise. For example, in all states of the European Union, there exist the legal commitment to apply an interest barrier. The non-offsettable interest expenses are carried forward to future tax periods, unless a carryback is permitted. Because of the tax restrictions, a difference between the earnings before taxes according to IFRS and the taxable income results in the period of occurrence. Companies have to recognize deferred tax assets on interest carryforwards, if there is a sufficient probability the interest expenses, carried forward, will be tax deductible in future periods. The recognition criteria according to IAS 12.34-12.36 are not fully applicable; a modification is necessary. Referring to this, I will present an approach to verify the recognition criteria for deferred tax assets on interest carryforwards. With regard to the tax issues, this is done particularly on basis of the German income tax law. The tax planning calculation includes, among other things, a forecast of the interest income, the earnings before interest, taxes, depreciation and amortization, as well as the capital structure. To verify the recognition criteria for deferred tax assets on interest carryforwards, it is necessary to specify a probability threshold. If the threshold is exceeded, it can be assumed the interest expenses will be offsettable in the future. Otherwise, possibly the decision-relevant values can be influenced through a plan revision and using tax planning opportunities.

Operational Research in Financial and Management Accounting 2

Cluster: Game Theory, Market Design, and Mathematical Economics
Invited session
Chair: *Matthias Amen*
Chair: *Christian Fritze*

1 - Financial Statement Information for Forecasting Profitability and Creating Robust Portfolios
Lukas Benjamin Heidbrink

Forecasting financial performance is vital and relies on the quality of financial statement disclosures. Accuracy in forecasting does not reflect the level of profitability, however; rather, it measures the predictability of profitability. This is why accuracy is considered a measure of robustness. Typically, accruals are known to increase risk and decrease reliability; particularly, discretionary accruals cause lower forecasting ability. As such, the proposed model maximizes earnings yield while restricting the level of discretionary accruals, as well as short-term and long-term out-of-sample forecasting errors, resulting in a robust, low-risk and highly predictable portfolio. Limiting the iterative forecasting error of future operating cash flows induces robustness, and limiting the share of discretionary accruals in profit reduces overall risk. With a slight modification, this model also allows for the identification of natural hedging strategies, in accordance with IFRS regulations. Given a company's financial assets and liabilities, the model identifies suitable shares for a macro-hedge, minimizing downside risk in the company's portfolio.

2 - Inflation risk and company valuation
Andreas Schueler

The proper way to handle inflation risk in company valuation gains in relevance in times of high and volatile inflation rates. This paper develops two valuation models to deal with inflation risk in the definition of expected free cash flows (FCF) and risk adjusted discount rate (RADR). For the first one, valuation starts in a world without inflation and implies stochastic nominal interest rates, while a world with inflation is the starting point for the second one, implying stochastic real interest rates. The premia for inflation and business risk are derived, in general, and for the capital asset pricing model (CAPM). The link between real and nominal beta is shown, and the conditions for using a beta value in real terms (also in a world with inflation) are derived. The deflated nominal value does not equal the company's value in a world without inflation, if inflation risk is not accounted for properly or if FCF and RADR are affected by different inflation rates. The rate relevant for the FCF is the weighted average of the specific rates on all cash outflows and inflows of the company. Companies might not be able to pass on inflation-induced prices of input factors to customers or might pass on more than these, causing nominal company values to deviate from company values in a world without inflation. The nominal beta is affected by the relation of company-specific inflation rate to economy-wide inflation rate. Practitioners usually estimate beta values by a regression analysis using historical data either for the company to be valued or for comparable companies (peer group). By doing so, they implicitly assume the relation between company-specific inflation rate and economy-wide inflation remains constant in future years; if peer beta values are used, they additionally imply the relation is the same for all companies analyzed. All these conditions need to be checked before making these assumptions. A number of papers written during the last era of high inflation are analyzed by referring to our valuation models; the majority of them are redundant - the equations presented can be reduced to the standard CAPM. This paper provides a normative framework taking inflation risk into account consistently and defining the corresponding valuation models.

Healthcare Service Delivery

Cluster: Healthcare Management
Invited session
Chair: *Yong-Hong Kuo*
Chair: *Jamal Abdul Nasir*

1 - Target-Oriented, Distributionally Robust Optimization and Its Applications to Surgery Allocation
Vincent Chow, *Zheng Cui*, *Daniel Zhuoyu Long*

In this work, we propose a decision criterion that characterizes an enveloping bound on monetary risk measures and is computationally friendly. We start by extending the classical value at risk (VaR) measure. Whereas, VaR evaluates the threshold loss value such that the loss from the risk position exceeding that threshold is at a given probability level, it fails to indicate a performance guarantee at other probability levels. We define the probabilistic enveloping measure (PEM) to establish the bound information for the tail probability of the loss at all levels. Using a set of normative properties, we then generalize the PEM to the risk enveloping measure (REM), so the bound on the general monetary risk measures, at all levels of risk aversion, are captured. The coherent version of the REM (CREM) is also investigated; we demonstrate its applicability by showing how the coherent REM can be incorporated in distributionally robust optimization. Specifically, we apply the CREM criterion in surgery block allocation problems and provide a formulation that can be efficiently solved. Based on this application, we report favorable computational results from optimizing over the CREM criterion.

2 - Optimizing Emergency Medical Services: A Comparative Study of Mathematical Models for Ambulance and Station Location and Relocation in Switzerland
Francisco Simore, *Félicien Hêche*, *Barakat Oussama*, *Thibaut Desmettre*, *Tania Marx*, *Stephan Robert-Nicoud*

Several deterministic and probabilistic mathematical models for the location of Emergency Medical Service (EMS) vehicles and stations have arisen in the last 40 years, to attend patients in a time-efficient manner. Each model considers different performance measures related to response times and is subject to different constraints. This research provides an in-depth analysis of a real-world scenario in a region of Switzerland, used to estimate the parameters of the later-mentioned models. Four different datasets (a large amount of historical data) were used concerning the occurrence of emergencies and available resources - providing accurate and representative information regarding the characteristics of an EMS system. We also extend some models to take into consideration time-intervals and probabilistic information. To compare them, we show several benchmarks using Key Performance Indicators relevant to the presented problem; this approach provides a better understanding of what each model optimizes and what compromises come with the optimization. We also provide an in-depth analysis of one of the models. We show different sensitivity analyses on the model's parameters to combine the strengths of the models and the know-how of EMS personnel to decide or evaluate the value of the models. Furthermore, we provide a modification to take advantage of the potential of a dynamic number of ambulances, so the expected coverage can be more constant throughout the day; it decreases the average difference of the expected coverage in-between time intervals by 19.46%, while obtaining an increase in expected coverage.

3 - Operating room capacity allocation to indoctors and outdoctors under uncertain surgery durations
Melih Celik, *Arsham Atashi Khoei*, *Serhat Gül*

Planning of operating room (OR) use, an important decision in determining the efficiency of resource use in a hospital, is exacerbated since exact surgery durations are unknown in advance. To improve the utilisation of ORs and generate further revenue, hospital managers allow surgeons who do not work as their full-time employees (called outdoctors) to use ORs in their hospitals in return for a rental fee. In particular, hospitals with high-tech equipment or specialising in specific areas may improve their revenues considerably by attracting outdoctors, needing the resources of a hospital they are not affiliated with, as they may regularly provide service in their own consultation offices or work for a smaller hospital providing insufficient equipment support for some operations. When outdoctors attempt to reserve OR times of a hospital, they have to compete for resources against the full-time surgeons employed by the hospital (called indoctors).

This study considers the problem of assigning days to indoctor surgeries, selecting the outdoctor surgeries to be performed, and assigning days to selected outdoctor surgeries over a fixed planning horizon. We formulate a two-stage stochastic mixed-integer program for this surgery planning problem with an objective function, consisting of four competing criteria: total revenue generated through acceptance of outdoctor surgery requests, patient waiting time, expected OR overtime, and expected OR idle time. We develop a scenario reduction-based heuristic to obtain high-quality solutions in reasonable time limits. Our computational experiments on data from a large medical centre

provide insights into the benefit of considering uncertainty in surgery durations, what percentage of OR capacity to be assigned to outdoctor surgeries, effects of surgery time windows on system efficiency, and how our proposed approach compares to well-known surgery planning heuristics in practice and in the literature.

4 - Does competition improve hospital performance: a DEA based evaluation from the Netherlands
Joel Joris Van de Klundert, *Liana van der Hagen*, *Peter Dohmen*, *Aniek Markus*, *Martin Van Ineveld*

Many countries have introduced competition among hospitals aiming to improve their performance. We evaluate the introduction of competition among hospitals in the Netherlands over the years 2008-2015. The analysis is based on a unique longitudinal data set covering all Dutch hospitals and health insurers, as well as demographic and geographic data. We measure hospital performance using Data Envelopment Analysis and distinguish three components of competition: the fraction of freely negotiated services, market power of hospitals, and insurer bargaining power. We present new methods to define variables for each of these components which are more accurate than previously developed measures. In a multivariate regression analysis, the variables explain more than half of the variance in hospital efficiency. The results indicate that competition between hospitals and the relative fraction of freely negotiable health services are positively related to hospital efficiency. At the same time, the policy measure to steadily increase the fraction of health services contracted in competition may well have resulted in a decrease in hospital efficiency. The models show no significant association between insurer bargaining power and hospital efficiency. Altogether, the results offer little evidence that the introduction of competition for hospital care in the Netherlands has been effective.

Genomic Analysis

Cluster: Healthcare Management
Invited session
Chair: *Piotr Lukasiak*

1 - Machine learning in genomic data analysis - the Genomic Map of Poland project
Piotr Lukasiak

The turn of the 20th and 21st centuries was when numerous earlier discoveries and inventions in the fields of physics, chemistry and biology found application in clinical research and practical medicine. With systematic increase in the number of known whole-genome sequences, the probability of specific phenotypic traits and disease states in humans can be determined with increasing precision. Bioimaging of single cells, tissues, organs or entire organisms has been made possible by the development of microscopy (e.g. confocal microscopy and electron cryomicroscopy) and techniques based on nuclear magnetic resonance (NMR), fluorescence and luminescence. As a result, instruments have been developed allowing multidimensional visualisation, detection and characterisation of structures and biological processes in real time. Each of the newly developed research techniques generated huge amounts of data describing selected features or functional elements of the organism in detail, but none allowed a holistic view of the human being. The next challenge facing researchers, therefore, was how to extract the most relevant elements from large, heterogeneous and often fragmented data sets and, then, to integrate them so they form a single coherent picture. The answer to these needs is the use of AI to conduct cutting-edge research, integrating multidimensional biomedical and clinical data to produce new knowledge and tools for universally accessible, personalised preventive, diagnostic and therapeutic medicine. Given the sensitivity of AI-based data analysis methods, attention to the homogeneity of the data set is a key issue. In our research, based on a group of several thousand individuals from Poland, we proposed various data processing pipelines and tools, created based on optimisation algorithms and machine learning algorithms, to enable efficient analysis of a dataset consisting of genomic, phentropic and clinical features. The database created, as well as the tools implemented, enable the application of artificial intelligence to conduct novel research, integrating multidimensional biomedical and clinical data to obtain new knowledge and tools for universally accessible personalised prevention, diagnosis and medical therapy.

2 - From Graph Theory to DNA Sequencing and the Genomic Map of Poland
Jacek Blazewicz

Graph theory, a universal tool, can model many phenomena, in the broad sense of the word, such as scheduling and communication problems. Surprisingly, it can also represent DNA Sequencing by Hybridization (DNA SBH). Several models of this problem have been proposed, including approaches by our team. The graph approach can also model a whole genome assembly. In the talk, we present different graph approaches to a DNA Assembly problem, finally resulting in constructing the Genomic Map of Poland.

3 - Pipeline for constructing a reference genome
Aleksandra Swiercz

The first draft of the human reference genome was published more than two decades ago. Due to technological limitations, it contained gaps, especially in the highly repetitive regions of centromeres and telomeres. It was updated and corrected several times, and, for many years, the newest version of the genome was GRCH38. Last year, Telomere To Telomere (T2T) consortium published a new release of haploid human reference genome, called CHM13, filling over 200 Mbp of gaps in repetitive regions [1,2]. DNA sequencing has become much cheaper, and new technologies allow for reading longer DNA fragments with decent quality. Many countries are sequencing large populations of individuals, resulting in population genetic maps, with the most common variants appearing in the population (e.g. US, UK, Finland, Hong Kong, China) [3,4]. One reference genome, although well-annotated, cannot represent a given population, however, with its most common variants. Several attempts were made in this area, and a few reference genomes were already published (e.g. Korea, China, Japan) [5].

We present a pipeline for constructing a diploid human genome within the Genomic Map of Poland project. The genome is assembled de novo based on a trio: mother, father, and child. In the pipeline, we used several technologies - short reads, long high-quality reads (PacBio HIFI), artificial long reads (stLFR), long-distance contact reads (Hi-C) and ultralong reads (Nanopore). The resulting scaffolds, spanning the whole chromosome, were compared with the GRCH38 and CHM13 reference genomes, showing the differences between the references.

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4 - Annotation of G4s in atom clouds
Marta Szachniuk

Motifs are key issues in computational biology and structural bioinformatics, one of the most interesting, found in nucleic acid molecules, being a quadruplex. Quadruplexes, also named G4s, take the shape of a quadruple helix and primarily form in the guanine-rich parts of the molecule, where tetrads (four-nucleotide formations) in the presence of metal ions, stack on top of each other to form a stable motif. Detecting quadruplexes in the 3D structure of a molecule, given as a cloud of atoms, is an important bioinformatic problem, which will be discussed in the paper. We will present a method to identify these structural motifs and a computational tool analyzing the motif architecture and describing it using a series of structural parameters. Studying the topologies of these special motifs, we discovered base-pairing patterns

in them and defined a classification based on these patterns; the so-called ONZ classification [1]. We then developed an algorithm to automatically assign tetrads and quadruplexes to each class [2] and implemented a tool to visualize these motifs in a simplified layered diagram representation [3]. We also created a database, in which we collect information about quadruplex structures determined experimentally [4]. Recently, we have developed a tool for annotating quadruplexes, which we will focus on during the presentation. All the tools are hosted on the server of the Institute of Computer Science of the Poznan University of Technology; they were subsidized by the National Science Centre (grant no 2019/35/B/ST6/03074).

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Healthcare Operational Planning

Cluster: Healthcare Management
Invited session
Chair: *Antoine Sauré*

1 - Improving Access to Stroke Prevention Consults through Enhanced Capacity Planning and Patient Appointment Scheduling
Antoine Sauré, *Shahryar Moradi*, *Jonathan Patrick*

Motivated by a problem faced by The Ottawa Hospital, this presentation focuses on the study of patient appointment scheduling practices at a Stroke Prevention Clinic (SPC). A patient who is referred to a SPC is typically scheduled for an initial consult with a neurologist; prior to the initial consult, several tests, depending on the patient's condition, need to be performed. Some SPCs face several challenges in reducing patient wait times for consults and in having all test results available before consultation. To address these challenges, we propose a dynamic multi-priority, multi-resource appointment scheduling model we approximately solve using Approximate Dynamic Programming (ADP) techniques. The main purpose of this model is to identify good policies for allocating available testing and consultation capacity to incoming patients, while reducing patient wait times and increasing the number of test results available before consultation in a cost-effective manner. The potential benefits from the proposed approach are evaluated by simulating its performance for a practical example based on data provided by The Ottawa Hospital. We also investigate the quality and practical implications of the resulting appointment scheduling policy by comparing its performance to other heuristic policies available in the literature. We believe the booking guidelines resulting from this research could be used in practice by SPCs to significantly improve the timing of stroke prevention appointments and, thus, to decrease the impact of delays on patients' health.

2 - Scheduling Elective Surgeries Considering The Affinity And Preferences Of The Surgical Team
Francisco Ríos-Fierro, *Guillermo Latorre-Núñez*, *Lorena Pradenas*, *Carlos Contreras-Bolton*

The scheduling of surgeries is a critical issue directly impacting the number of patients treated with a given set of operating room resources. In this work, we explore the surgery scheduling problem by incorporating the concepts of affinity and preference among the surgery team's members. Affinity can be quantified as a numeric value representing the compatibility between two team members. Preference, on the other hand, refers to a surgeon's preference for certain resources required for the surgery. Existing approaches to modeling affinity and preference in integer programming models have often added these factors as constraints or additional terms to the objective function forcing to work with multiobjective. This can lead to a reduction in the number of surgeries performed, however, due to constraints imposed by minimum affinity levels or the complexity of multiobjective optimization. To address these issues, we propose an alternative approach focusing on maximizing the number of surgeries scheduled, while taking into account the affinity between team members. We develop three versions of integer programming models: one without considering affinity or preference, one incorporating affinity as a constraint but not considering preference, and one considering both affinity and preference. In addition, we implement a genetic algorithm to solve the problem in significantly shorter computing times. Incorporating affinity and preference can lead to effective and realistic solutions for the problem. The genetic algorithm is also found to be efficient and produces feasible, high-quality solutions close to the optimum calculated by the programming models. In conclusion, considering affinity between team members is a valuable factor in the scheduling of surgeries, as it can improve the quality of the surgical team without impairing the number of surgeries performed. This approach has practical applications in hospitals and other healthcare facilities, where human resources are limited and efficient use of available resources is critical.

3 - Surgery planning and bed allocation in a military hospital, with multiple post-operative recovery units
Virgilio Jose Martins Ferreira Filho, *Gustavo Carneiro*, *Laura Bahiense*, *Edilson Arruda*

This paper addresses surgery planning in a military hospital, with multiple post-operative recovery units, with the objective of optimizing a weekly plan allocating surgeries and beds to balance supply and demand. The case study involves surgeries of various orthopedic specialties, offered to elective patients, represented by military personnel and their dependents. Integer linear programming techniques maximise the usage of the operating theatres, to ensure enough surgeries to meet the demand of each individual specialty and waiting times within reasonable bounds for all specialties. Concurrently, the approach partitions available beds among specialties for each post-surgical unit, to make sure they are available when demanded, avoiding surgery cancellations due to a lack of beds.

Healthcare Analytics

Cluster: Healthcare Management
Invited session
Chair: *Jamal Abdul Nasir*

1 - Data Science for Medical Programming in a Network of Public Hospitals
René Lagos

Introduction Public hospitals in Chile face high demand and need to align medical resources to populations' healthcare needs. Medical programming (or medical master scheduling) is a crucial process for this purpose, but data gathering and processing with spreadsheets makes it complex and time consuming for hospitals, reducing its utility. The South East Metropolitan Health Service (SEMHS) developed a system to optimize medical programming and to support waiting list reduction strategies.

Methodology A redesign of the process was conducted together with hospitals and SEMHS managers. A web platform to support the process was designed and developed using an agile project management framework. Prototypes were developed to apply data science and operations research tools to explore strategies to reduce waiting lists.

Results The Medical Programming Platform has five modules: staffing, clinical units programming, production forecasting, demand trends and physical resources. It was the first medical programming platform and was implemented in 5 hospitals and 10 mental health community centers; it programmed 4700 health professionals, including 1850 physicians, on a quarterly basis. The percentage of programmed contracts increased from 75% in 2019 to 96% in 2022. An Extract, Transform,

Load process supports reporting and analytics. Prototypes were developed for forecasting medical consultation demand, optimizing box allocation, outpatient waiting lists simulation and stochastic optimization of medical schedules.

Discussion The platform replaced spreadsheets, previously consuming valuable time from hospital managers, and enabled participation of clinical managers in the programming process. Medical programs are more reliable in terms of the staffing levels and clinical activities offered, turning into a fundamental tool for managers. The implementation of the platform constitutes a digitalization of public health as it provides value, based on a data centered process to understand populations' healthcare needs and the alternatives to align medical services. Visual analytics and OR prototypes have demonstrated the potential of medical programming as a tool for public health data science, setting a new standard for public hospitals in Chile.

Conclusion Operations Research and public health data science provide a solid framework to advance medical programming in Chilean public hospitals and set its technical and ethical standards.

2 - Clustering African Countries about their performance during COVID-19 widespread with data mining approach
Amir Karbassi Yazdi

In light of widespread COVID-19, many countries are eager to find out how they performed and how they coped with this horrible, worldwide event. Through these works, they will learn how they can serve better with similar diseases in the future. ANFIS, Metaheuristics methods, and K-means method were used in this study to classify African countries based on their COVID-19 performance. In the first step, it is crucial to determine if any factors influence the result by combining ANFIS and metaheuristics methods. As soon as these un-influencing factors have been eliminated, the K-means method is applied to cluster these countries. This research extends the literature on clustering countries, especially African countries, according to the essential factors of COVID-19 performance with Artificial intelligence methods. The results show the group of countries achieving the best performance and the group having the worst performance among the various groups.

3 - Optimal Policies for Cancer Screening Under Budget Constraints
Susana Mondschein, *Felipe Subiabre*, *Natalia Yankovic*

We develop a general framework for the formulation and evaluation of public policies for cancer screening, allowing a national healthcare program to compare the costs and benefits of a set of policies, and select one, optimal for a given measure of effectiveness. This framework also extends to other non-contagious, preventable diseases.

For this purpose, we consider a base model for the natural history of a specific cancer, calibrated to accurately represent the appearance and evolution of a tumor for various risk groups. We use it to build a public policy model for the optimization of an expected quantity across the whole population, e.g. maximizing the total life years or minimizing the total probability of death from this cancer, considering a global budget constraint representing a maximum expected expense per person.

The optimization problem decides over a set of policies for each risk group and includes in its cost-benefit assessment the crucial trade-off between more frequent and costly screening tests versus diagnosing later-stage tumors, with higher treatment costs and risk of death. The model also includes tests with associated risks and false positive and negative results, and its analysis is based on studying how the stationary distributions of semi-Markov chains change due to each policy.

We evaluate our model on two different sets of policies, one corresponding to a fixed testing frequency for each risk group and another to increasing testing ages, showing under general conditions the optimal global policy assigns more aggressive and expensive testing to groups at higher risk, in accordance with intuition.

By applying this framework to some of the main cancers affecting modern society, after selecting adequate base models from the CISNET database of models, we evaluate the current total costs incurred by healthcare programs for these cancers and find better policies according to our analysis, without a change of expected total expenditure.

This evaluation on realistic models and data should also lead to a classification of cancers into three main groups: (i) preventable according to the models, (ii) non-preventable according to the models, and (iii) unclear due to model uncertainty or discrepancy. Also importantly, we can evaluate how the realistic development of cheaper or better exams and treatments could effectively and positively affect this classification.

4 - Scheduling Visits for Dynamically Prioritized Home Care Patients with Fuzzy Demands: A Mobile Health Facility Location, Fleet Sizing, and Routing Problem.
Jamal Abdul Nasir, *Yong-Hong Kuo*

In this paper, we investigate a real-world home health care (HHC) problem, where there are insufficient caregivers to provide home care services to a large number of patients with uncertain demands. Since patients' health conditions fluctuate during a given planning period, we construct a priority function to define their priority level, then translated into a time-dependent potential healthcare cost, varying dynamically over the planning horizon. In practice, logistical services in the HHC supply chain network are frequently disrupted due to a variety of unforeseen events, necessitating resilient and adaptable HHC structures, easily implemented in response to long-lasting extreme weather events, pandemics such as COVID-19, and specialized door-to-door health campaigns. To address these concerns, the studied problem is defined as a multi-depot, multi-period fuzzy chance-constrained programming model with precedence constraints and demand quantities (drugs and vaccines), represented as fuzzy variables. The solution to the studied problem selects the locations for the appropriate number of base mobile health facilities, detects the required number of HHC vehicles, and creates scheduling plans for visiting patients based on patient-specific time windows. To solve the problem, we use a novel three-phased heuristic solution method, as well as stochastic simulation and local search approaches. Taking into account the problem structure, we first exploit the problem characteristics to create an excellent starting solution, then improved using a hybrid simulated annealing algorithm (HSA), various neighborhood structures, and a local search mechanism. The proposed model is tested using a realistic case of HHC services provision in Hong Kong. First, we conduct sensitivity analysis to determine the appropriate values for the threshold parameters regulating the credibility of patients' assignments to vehicles and mobile health facilities, and then we evaluate the performance of the HSA algorithm. The computational experiments involving a deterministic version of the studied problem and Solomon's benchmark instances indicate the proposed solution method can tackle real-world problems efficiently and effectively. Moreover, the proposed model is more resilient compared to the deterministic model in the context of uncertain demand.

Global Health Policies and Policy Aiding Tools

Cluster: Healthcare Management
Invited session
Chair: *Erin Roman*

1 - A Consensus Framework for Bundled Payments in the Management of Chronic Diseases
Erin Roman, *Niels Hilhorst*, *Filip Roodhooft*, *Jo Lambert*, *Brecht Cardoen*

With the continuous rise in health expenditure, it has become increasingly apparent the current fee-for-service system, emphasizing volume, is no longer sustainable for the sector. To tackle the growing expenditure problem, the reimbursement system must fundamentally change; a realignment of provider incentives with patient outcomes is necessary. Bundled payments have been endorsed as the reimbursement approach, within Value-Based Healthcare, as a driver of reform. While existing research has explored the impact of bundled payments across several factors, no clear roadmap exists for how best to construct them. This study provides a framework for developing bundled

payments for chronic diseases, using a mix-methods approach applying management accounting and operations management principles. First, we conduct a scoping review to outline the current state of the art regarding bundled payments. Secondly, we emphasize the importance of costs and transparency for designing bundles using a single case study applied to Psoriasis. Using Time-Driven Activity-Based Costing (TD-ABC), we construct treatment pathways and measure the costs of 215 patients. Finally, we conduct a linear regression analysis to identify significant patient and disease characteristics driving cost variability. In the context of bundled payments, the shift of financial accountability from insurer to provider will create considerable financial pressure. Thus, management is encouraged to find optimal ways to eliminate wasteful resources and activities, emphasizing the importance of operational management practices to address inefficiencies lessening the financial burden. To structure our framework, we use the five elements deemed relevant for constructing bundles outlined by Porter and Kaplan in the 2016 Harvard Business Review Paper entitled "How to Pay for Health Care." Using the insights from the scoping review, cost analysis, and operational improvement suggestions, we formulate a roadmap on how bundled payments can be designed for chronic diseases. Given the diversity of methods and lack of standardization in the literature, it becomes increasingly difficult to know how best to design bundles enhancing quality, reducing costs, and promoting better care coordination. We provide scholars, providers, and policymakers with an action plan to construct bundled payments for a more sustainable healthcare future.

2 - A Collaboration Model to Analyze and to Improve Healthcare Access in Rural Communities
Amarnath Banerjee, *Hrayer Aprahamian*

With access to quality care an important factor for everyone, but especially for sparsely populated rural areas in a state, region, or country, rural and critical access hospitals in the United States play an important role in serving this important need. Unfortunately, recent data reveals an alarming number of these hospitals closing nationwide due to economic factors, lower patient volumes, and low utilization of expensive resources required to provide the services. We present a data-driven quantitative model, exploring potential collaboration options between groups of nearby hospitals to achieve higher utilization of these expensive medical resources; the options will enable rural hospitals to provide the most crucial, and popular, set of services based on their specific patient needs and will potentially help preserve access to local care with shorter distances and reduced travel times for residents. The collaboration options from the model provide valuable insights for hospital administrators on the patient volume and variety of services (volume-variety mix), along with potential risk factors, and help them develop strategies to foster collaboration opportunities and sharing of expensive medical resources. The presentation will show the model and analysis from a group of six rural hospitals, with observed and potential demand for services and minimum threshold levels for each service. The model, scalable to include a larger network of hospitals and to encompass a much larger region, uses publicly available data and reduces the burden on hospitals of collecting and reporting additional data.

3 - A mathematical framework for joint modeling related infectious diseases and common social conditions- application to sexually transmitted infections
Chaitra Gopalappa

A model jointly simulating infectious diseases with common modes of transmission can serve as a decision-analytic tool to identify optimal synergistic intervention combinations for overall disease prevention - an example being sexually transmitted infections (STIs), a huge social and economic public health burden, globally. Data show interactions between STIs, such as higher risk of acquisition and progression of a secondary STI among persons with HIV, compared to persons without and vice-versa. These interactions are associated to both behavioral and biological factors. Further, social conditions are common drivers of behaviors increasing the risk of STIs; in the U.S., homelessness, mental health, and food insecurity are highly prevalent among persons with HIV, suggesting the need for structural interventions. Thus, independently modeling STIs would overlook the behavioral and biological interactions between diseases and the synergistic impact of the common structural interventions on overall disease prevention. Given the widely varying disease epidemiology, however, current simulation techniques alone are insufficient for joint modeling diseases. Further, models typically simulate behaviors and transmission as functions of those behaviors, but social conditions are typically not part of the mechanistic framework.

We developed a new mixed agent-based compartmental (MAC) framework for jointly modeling STIs; it uses a combination of network modeling for simulating people with at least one slower-spreading disease and compartmental modeling for simulating all other persons, including those with only faster-spreading diseases. An evolving contact network algorithm, developed using methods from machine learning and optimization, maintains the contact dynamics between the two populations. Further, we developed a methodological framework, using Markov random field model, to estimate joint probability distributions between social conditions and behaviors; this can be incorporated into MAC to model social conditions and simulate behaviors as functions of social conditions, prior to simulating transmissions as functions of behaviors. The framework can serve as a suitable decision-analytic model to identify optimal synergistic intervention combinations, both disease-specific and common structural interventions, for overall disease prevention. We will present an overview of this work.

4 - Modeling Interventions and Contact Networks to Reduce the Spread of Antibiotic-Resistant Organisms Between Individuals in the Hospital
Diego Martinez

Background: The spread of hospital-acquired infections due to carbapenem-resistant microorganisms is of paramount importance. Healthcare workers (HCWs) have sustained and repeated contact with patients and are a potential transmission source. There are a limited number of studies assessing HCW-mediated transmission, however.

Methods: We performed a cohort study of adults admitted to The Johns Hopkins Hospital medical ICU and solid organ transplant unit. Using perirectal vancomycin-resistant enterococci surveillance cultures collected upon patient admission and then weekly, we identified patients who were admitted with, or who acquired during their stay, carbapenem-resistant organisms (CRO). CRO results were not utilized for patient care; thus, not all patients who tested positive were on contact precautions allowing us to analyze the potential effect of contact precautions on acquisition. Electronic medical records data on carbapenem use, how often an HCW had contact with more than one patient, and hand hygiene and unit environmental cleaning compliance were collected and analyzed into probabilistic transmission models. These models estimated the likely contribution of these factors to CRO acquisition.

Results: Of 2,587 patients admitted without evidence of CRO colonization, 78 (3.02%) acquired CRO colonization during their unit stay. Contact precautions, hand hygiene, and environmental cleaning compliance were all negatively correlated with CRO acquisition (OR=0.08 95% CI 0.01-0.62, OR=0.02 95% CI 0.01-0.21, OR=0.01 95% CI 0.01-0.18, respectively). Carbapenem exposure was positively correlated with CRO acquisition (OR=2.16 95% CI 1.49-3.09). HCW-mediated connectedness between patients was not significantly associated with CRO acquisition.

Conclusions: Contact precautions effectively reduced the transmission probability from patients with unknown CRO colonization after adjusting for concurrent factors. Lack of a significant relationship between HCW-mediated connectedness and the effectiveness of environmental cleaning compliance suggests pathogen reservoirs may play a significant role in CRO acquisition.

Lean and Management Excellence in Healthcare

Cluster: Healthcare Management
Invited session
Chair: *Alejandro Mac Cawley*

1 - Simulation-Based Decision Support System for Emergency Services
Iván Alexander Olguín Plaza, *Alejandro Mac Cawley*, *Luis Enberg*

Emergency services operate under highly uncertain conditions: patient demand, requirements, and complexities; with continuous services - 24 hours a day, 7 days a week. Under this highly uncertain environment, it is difficult to forecast the needs of the system in terms of resources (medics, nurses, and technicians), generally leading to an increased length of stay (LOS) of the patients. Hence, the increased LOS of the patients is sometimes due to an overburden of activities on the medics, nurses, or technical staff, due to a surge in demand the Chief Emergency Officer could not predict.

The objective of this research is to develop and to validate a simulation-based decision support system helping forecast an increase in the demand for medics, nurses, or technical staff, allowing the Chief Emergency Officer to take action and bring more resources to avoid a collapse of the system.

Most of the research developed around the management and operation of these services generates an optimization of resources in the emergency department, using data and service behavior from the past and, based on this, determining bottlenecks, redesigning processes, and simplifying activities. In our case, the objective is to develop a tool predicting the behavior of the emergency department, considering the context and resources in the present. How would the emergency department behave on a Tuesday if we have the same trend of patients arriving, but we have half the resources? How would the system behave if we bring in 2 more doctors per shift? or 2 more nurses per shift? These are some of the research questions to be answered.

We developed a decision support tool providing indicators of what could happen in the future, considering some specific amount of resources in the present, and generating specific actions, to optimize resources within the emergency department and reduce patient care times.

2 - Can we detect potential breaches of the 4-hour wait at an A&E department using machine learning and routinely collected data?
Thierry Chaussalet, *Guilherme Fonseca Pacheco*

Background: The UK's healthcare demand has been steadily rising in recent years. Overcrowding in emergency departments and breaches of the 4-hour standard, determining at least 95% of patients attending the Emergency Department should be admitted, transferred, or discharged within four hours of their arrival, have become increasingly common throughout the national healthcare system. Methods: The Emergency Care Data Set (ECDS) is the national (England, UK) data set for urgent and emergency care in England (UK) and includes information about why people attend emergency departments and the treatment they receive. Using this routinely collected data over 210,000 patients who completed their treatment at a major A&E department located in northwest London, we developed and tested machine learning models, including Logistic Regression, Decision Tree, Random Forest, Extreme Gradient Boosting, Neural Networks and two stacked ensembles to predict the patients' breach of the 4-hour standard. The potential predictive performance of the models was assessed by using five different sets of input variables representing different points in time during the care process and a model comparison was performed. Results: Even though there was a notable reduction in performance when using the variable set representing the data available at early stages, the models based on stacked ensembles, Extreme Gradient Boosting, and Neural Networks all achieved a promising AUC greater than 0.755. Conclusion: it is possible to apply ML techniques to the ECDS dataset and achieve a good performance in predicting a patient's likelihood of breaching the 4-hour standard, even at early stages. Furthermore, machine learning methods can potentially be used to improve the operational dynamics of the A&E by supporting managerial decisions, such as streamlining or directing more resources to the patients with higher probability of breach, as well as providing real-time information to medical staff.

3 - Hospital Food Waste and Nutritional Intake: a Bi-objective Model to Minimize Waste and Cost
Mariana Arriz-Jorquiera, *Jorge A. Acuna*, *Marian Rodriguez-Carbo*, *Jose Zayas-Castro*

The healthcare system alone is estimated to contribute 1-5% of total global environmental impact, and it is responsible for air pollution emissions causing 1% of ozone depletion, 1-2% of air toxins, 10% of smog formation, and 12% of acid rain.

In the United States, the healthcare system generates 8.4 kg of waste per bed daily. Countries outside the US have also shown similar trends. Within one hospital in Bangladesh, food waste was determined to be 74% of all medical waste. Three hospitals in Italy found around 41.6% of the food served to patients was discarded. Not only does hospital food waste lead to a significant environmental footprint, but it also impacts patient nutrition and overall cost.

To tackle this issue, a Mixed Integer Programming (MIP) model was applied using the demand of a 1000-bed Hospital in Florida to build the ideal plate for each patient by minimizing the food waste and the plate cost. The MIP model considers different factors, such as the gender and age range of each patient, different wards, diets, and food intolerance, and it can be applied using the demand of other hospitals. The results allow going through every specific profile and analyzing the plate, the generation of food waste, the cost and the required (and the provided) nutrients for the patient. Furthermore, the model uses data from US government sites and published papers to generate real-world scenarios.

Three scenarios were created to compare the results. The first one sets a baseline, where the objective function is to build the plates, but not minimize the waste or the cost. A second scenario minimizing the food waste generated up to 22.57% of food waste reduction compared to the baseline, and a third one minimizing the cost of the plates resulted in a 36.99% cost reduction. Finally, a bi-objective optimization model was solved using the perpendicular search method to reduce food waste and cost. The solution considered to be the best for this study is the closest one to the utopic point, generating a potential reduction of 19.74% of food waste and 32.66% of the cost per plate.

The findings of this study have important implications for hospital food service operations, as they demonstrate the potential of bi-objective optimization to reduce waste and costs in large-scale food service operations and, therefore, reduce the environmental impact.

Iberoamerican Healthcare Systems Management

Cluster: Healthcare Management
Invited session
Chair: *Begoña Vitoriano*
Chair: *Fermin Mallor*

1 - Raising a robot
Catherine Polanco

Storing data at an early age (related to health, experiences and family) will reduce isolation and improve medication management, precision of therapies, treatments and transportation. We propose part of our contributions for retirement go toward obtaining this technology and it be made available to people with these needs, especially the elderly. This information will make it possible to optimally adapt machine learning and enable the use of humanoid robots, exoskeletons, and artificial intelligence. Currently, assistive technologies are for rehabilitation purposes, medical care and social interaction and are focused on working adults; the industry has little incentive to offer possibilities for the care of retired patients (over 65 years of age). A limited number of studies were found addressing the possible applications of the technology for this age group, made up of people who would have interest and positive expectations in the self-financed use

of robotic elements, allowing them to have quality retirement and aging. The tools exist, but they have another orientation - for example, the use of assistance in Industry 4.0, the one applying technology in a different way to rehabilitation. Social robots and exoskeletons are used with older people with the intention they can extend their working life and thus increase the retirement age. The challenge is whether technology can play a role in improving independence and quality of life -in the reduction of individual and social costs with the least need for assistance personnel. Developing technological, information and communication tools are available for personalized assistance - to maintain the autonomy and safety of older people. Human-computer interaction is feasible and sustainable to help older people with motility and cognitive deficiencies. The most attractive and promising clinical applications of the technologies are housing, health and safety, mobility and gait rehabilitation, communication, and community well-being, to ensure older people remain in their own homes and communities.

2 - Intensity Modulated Radiotherapy Planning through Linear Programming: a fuzzy approach
Nicole Cristina Cassimiro de Oliveira, *Aurelio Ribeiro Leite de Oliveira*

Radiotherapy is a form of cancer treatment that consists of using a source of ionizing radiation that destroys the tumor. When it is not possible to obtain a cure, radiotherapy can contribute to improving the quality of life, since the applications reduce the size of the tumor, reduce bleeding and pain, providing relief to patients. In the context of Radiotherapy with Modulated Intensity, these ionizing particles can vary the intensity of the fluence, achieving a dose distribution with superior compliance, also enabling concomitant irradiation of different targets and doses. As each patient is anatomically unique, an individualized treatment plan must be developed. This plan comprises information on how the dose and probability of physical damage from irradiation is distributed within the patient. In order to define the target volumes and organs at risk for the patient, CT scans are performed that allow the oncologist to prescribe doses. The main objective is to deliver enough dose to the tumor for healing, while minimizing the unavoidable dose to healthy organs. However, the prescription may be inaccurate based on the physician's experience, patient positioning, internal organ movement, likelihood of tumor control, and likelihood of complications in normal tissues. In view of this, to determine an efficient and effective treatment, Optimization techniques are used, such as Mathematical Programming, in order to improve the total dose of radiation applied to the patient. The present work proposes a comparison between the treatment plans obtained by applying the Primal-Dual Interior Point Method using different fuzzy numbers, due to dosage uncertainties, with the Surprise Functions approach. The proposed methodology was applied in different cases of cancer using the Radiotherapy Optimization Test Set (TROTS) database. The results obtained were compared by means of Dose-Volume Histograms, average dose analysis for each structure considered and verification of contour graphs and dose surface. In conclusion, both proposed fuzzy numbers produced viable treatment plans, inferring that the approached model is an important tool in decision making in the planning of Intensity Modulated Radiotherapy treatment.

3 - Optimisation algorithms to VMAT: A Systematic Literature Review
Liany Lizeth Tobón Castro, *Nicolle Ojeda Ortega*, *Mauricio Moyano*, *Guillermo Cabrera-Guerrero*

Volumetric Modulated Arc Therapy (VMAT) is an advanced radiation therapy technique using a linear particle accelerator (LINAC), a machine delivering radiation doses, while rotating around the patient, to a tumor with a variable intensity - continuously, precisely and efficiently. In this context, optimisation algorithms are essential for radiotherapy methods, such as VMAT, to be successful, as they seek to increase the precision of treatment by maximising radiation emissions to the tumor, while reducing the radiation dose to organs at risk or surrounding healthy tissue. As a result, the creation and analysis of optimisation methods for VMAT treatment planning has garnered more attention in recent years, making the review and study of algorithms and techniques currently used in literature more relevant. In this regard, this study presents a systematic literature review to provide a clear view of the optimisation algorithms used for VMAT in the most recent research. To achieve this, studies published in the last five years, indexed in four databases - PubMed, Science Direct, Scopus, and Web of Science, are analyzed.

4 - Dynamic Simulator
Helenice Florentino, *Janielly Vieira*

The proposed Dynamic Simulator consists of a computational technique composed of a matrix containing the necessary information for the process to be studied, with great potential in the study of disease transmission, and can be used in predictions, analysis and control of endemics and pandemics. In this sense, it showed success in the study of transmission of COVID-19. The matrix simulates a set of individuals carrying information necessary for analysis of the contamination process. The tested instances are related to some Brazilian cities. The characteristics and dynamics of the population in these cities, such as number of inhabitants, age group, gender, comorbidities, vaccination, mortality, personal routines, among others were considered. In this way, a matrix was created for each instance, in which each line represents an individual and the columns contain the characteristics of individuals in the proportions observed in each instance (in the initial time). The proposed simulator was used to simulate COVID contamination over a time horizon (months, years, etc.), observing the daily numbers of infected and dead people due to the disease. The results obtained were compared with real cases and proved very promising for aiding decision-making in the health area. The dynamic simulator is very simple, innovative and more versatile with regard to the insertion of features and controls, when compared to the classic mathematical modeling techniques in this area.

Analysis of Health Outcomes

Cluster: Healthcare Management
Invited session
Chair: *Fernanda Bravo*

1 - Similar-Performing Sets of Treatment Alternatives for Personalized Management of Hypertension
Wesley Marrero

Due to variability in physicians' opinions and patients' preferences, uncertainty in medications' effects, and implementation barriers, translating hypertension treatment guidelines to practice is often difficult. Although current treatment guidelines provide a single recommendation, physicians may prefer other alternatives not statistically different from them. To allow for physicians' expertise and to provide flexibility in implementing policies, this work presents a framework for identifying sets of similar-performing actions to the recommendations provided by treatment guidelines.

This research considers an adult population in the United States of America with no history of atherosclerotic cardiovascular disease (ASCVD). The effect of treatment guidelines on patients' risk for ASCVD is evaluated using a Markov decision process simulation model over a 10-year planning horizon. Based on this model, the sets of similar-performing actions are obtained by combining a simulation-based dynamic programming algorithm for policy evaluation with a simulation-based statistical multiple comparisons procedure. Specifically, the sets of choices are derived as simultaneous confidence intervals on the difference between the quality-adjusted life years obtained following certain treatment guidelines and the remaining alternatives.

In general, the estimates obtained with the dynamic programming algorithm converge to their true values with probability one exponentially fast on the number of observations. Moreover, the multiple comparisons procedure reaches the correct coverage asymptotically. Within the context of hypertension treatment, how much flexibility a physician may receive to treat a patient depends on the patient's characteristics. Patients with a higher risk for ASCVD events typically

obtain fewer treatment choices than patients with lower risk; for example, older patients typically receive fewer treatment choices and patients with low blood pressure levels usually acquire a higher number of treatment alternatives.

This work presents a novel method for obtaining personalized sets of antihypertensive treatment choices. The proposed methodology provides clinicians and their patients with treatment options, while ensuring similar health benefits to clinical guidelines they trust. Sets of similar-performing treatment choices could have many advantages in practice, such as increased robustness and flexibility.

2 - Analysis of Risk Factors for Second Primary Cancer in Patients with Hepatocellular Carcinoma
Chi-Chang Chang

Background: This study investigated the risk factors associated with second primary cancer (SPC) in HCC patients, compared predictive capacity and provided clinical risk management. Methods: We used the Taiwan Cancer Registry Center dataset from five hospital cancer registries with a total of 10,741 valid records; the opinions and use of statistics and classifiers were compared based on the literature and clinical experts. Additionally, the performance indicators of the prediction model were compared using the Delong test. Furthermore,the NRI analysis found the clinical utility of each prediction model was consistent with its AUC performance. Results Individual feature selection revealed the three most important factors for overall HCC with SPC were alpha-fetoprotein (AFP), curative treatment, and tumor size. Total bilirubin, curative treatment, and tumor size were the common factors of synchronous and metachronous. Chemotherapy was the most important risk factor affected by surgical resection; tumor size was affected by radiofrequency ablation therapy (RFA); and total bilirubin was affected by trans-arterial chemo-embolization (TACE). The highest AUC for both synchronous and metachronous SPC were C5.0. In the results of DCA, C5.0 has the most benefit for synchronization, while RF has the greatest beneficial effect on synchronization. The results of the NRI analysis showed RF was the highest among all prediction models. Conclusions Individual feature selection revealed the three most important factors were Alpha-Fetoprotein (AFP), curative treatment, and tumor size. Liver fibrosis is an independent risk factor for synchronous and clinical stage for metachronous. Furthermore, in the NRI analysis, the clinical benefit of each prediction model was in accordance with its AUC performance; it can provide various risk thresholds, as well as select the appropriate predictive model and risk factors to explain why a patient will benefit the most.

3 - Combining Clinical Trials and Spontaneous Adverse Event Reporting for Improved Safety Signaling
Fernanda Bravo, *John Silberholz*

Negative side effects from taking a drug, termed adverse drug reactions (ADRs), cause thousands of deaths a year in the U.S. alone. Regulators, such as the U.S. Food and Drug Administration (FDA), play a critical role in monitoring the safety of drugs on the market. Ideally, regulators would detect all safety issues prior to a drug's marketing approval, on the basis of clinical trial results. Trials are often too small or too short, however, to detect rare or slow-developing ADRs. As a result, regulators rely on post-approval surveillance from observational data sources, such as spontaneous adverse event reporting systems to detect potential safety issues; these systems (such as the FDA's FAERS system) contain large volumes of safety reports, voluntarily submitted by patients and their doctors. Regulators generate hypotheses about potential safety issues (termed safety signals) by identifying side effects occurring at a disproportionately high rate in patients taking a drug, versus patients taking other drugs for the same condition. Reliance on biased observational data - due to selection and reporting differences among patients - can result in regulators flagging safety issues not truly present or missing real safety issues. In this work, we seek to enhance the hypothesis generation step of safety signaling based on spontaneous ADR reporting systems, via a Bayesian methodology combining pre-approval clinical trials and post-approval observational data for multiple ADRs. We use data from more common adverse events to quantify the direction and magnitude of bias in observational data, as compared to clinical trial data, and use it to debias the observational data for more rare adverse events. We quantify the benefits of the proposed approach to regulators via both analytical modeling with a stylized model, as well as via a detailed numerical evaluation using real-world clinical trials and FAERS data. Our approach could improve the expected benefit of signal detection from roughly 1% to 10%, depending on the rare ADR or drug class.

4 - Measuring Patient Value in Value-Based Healthcare: The Role of Data Envelopment Analysis
Joke Borzée, *Brecht Cardoen*, *Filip Roodhooft*, *Jo Lambert*

Healthcare systems worldwide are under financial pressure due to annually increasing expenditures, financed with a budget not growing at an equal rate. To anticipate this mounting problem, health professionals must constantly seek efficiency improvements without compromising the quality of care. The value-based healthcare framework can help in this regard, as it stipulates seven steps to maximize total patient value, defined as the health outcome per cost unit over the entire care pathway. Although the framework's objectives are clear, a measuring tool for patient value is currently lacking. Therefore, by applying a multidisciplinary approach combining operations management, management accounting, and medicine, this research proposes a precise method capturing patient value in a composite score and leading to explaining observed differences within the patient population. To this end, an integrated approach of Time-Driven Activity-Based Costing (TDABC), Data Envelopment Analysis (DEA) and linear regression analysis is applied. According to existing literature, patients are rarely modelled as the unit of analysis of DEA and were never modelled in a way considering both health outcomes and accurate costs, making this study a novel application of the DEA methodology. To demonstrate the method's appropriateness, we use a dataset containing health and cost information for 215 patients undergoing treatment for chronic skin disease in a Belgian outpatient clinic. By modelling their clinical outcomes versus the incurred costs to treat the patient, the efficiency scores express how much value was created during their treatment compared to other patients. In the next step, these scores are regressed on different patient, disease, and treatment characteristics to identify parameters explaining patient value variability. In this way, areas of improvement and waste can be uncovered helping optimize processes within the clinic, as well as patient experience.

Healthcare Supply Chains

Cluster: Healthcare Management
Invited session
Chair: *Bernardo Quiroga*

1 - A Scoping Review for a Conceptual Framework of Sustainable and Resilient Healthcare Supply Chain
Niloofar Gilani Larimi, *Adel Guitouni*

Healthcare supply chains (HCSCs) play a crucial role in delivering quality patient care, by providing necessary equipment, products, and supplies. HCSCs have been slower than other industries to adopt the best sustainability and resilience practices, however, leaving them vulnerable to disruptions, such as those experienced during the COVID-19 pandemic. Therefore, investigating the sustainability and resilience of HCSCs (SR-HCSC) has become imperative. This scoping review evaluates existing literature on SR-HCSCs, drawing on (gray) systems theory and complex adaptive systems to propose a conceptual framework for SR-HCSC. Covering publications from 2000 to January 2023 in Scopus, Web of Science, Science Direct, and Business Source Complete, we considered articles published in the peer-reviewed literature on sustainability, resilience, HCSC, and supply chain (SC) management. The literature on this topic is primarily theoretical, with limited empirical studies focusing on HCSCs at different decision-making levels, from tactical to strategic, on various scales. We propose revisiting the definitions of HCSC, sustainable SC, and resilient SC. Accordingly, we develop a new framework for SR-HCSC management identifying the relationship between sustainability and resilience in an HCSC and how they can be integrated into a comprehensive framework strategy for improving social well-being, while reducing environmental and

economic concerns. The framework proposed in this study offers significant contributions to the field of HCSC management. Policymakers and practitioners can leverage the framework as a valuable decision-making tool, guiding strategies improving SR-HCSCs. By adopting the framework, HCSCs can better prepare for unexpected events, such as pandemics and social concerns. Additionally, the framework provides an exhaustive list of research directions for future studies, allowing for continuous improvement in this critical area of healthcare management. Overall, the proposed framework offers practical solutions to the complex challenges faced by HCSCs, allowing them to enhance their SC's sustainability and resilience, reduce vulnerability to disruptions, and provide high-quality patient care.

2 - Replenishing personal protective equipment for healthcare systems in rural America at the onset of a pandemic
Bernardo Quiroga, *Bradley Price*, *John Saldanha*, *Sally Hodder*

In the face of a worldwide shortage of personal protection equipment (PPE) at the onset of the COVID-19 pandemic, we report on our team's challenge of meeting hard-to-forecast PPE demand with supply, under challenging replenishment conditions, including the lack of appropriate data and PPE availability for a largely rural state in America. We describe the motivation to implement a novel agent-based epidemiological model for forecasting PPE demand of confirmed and suspected COVID-19 patients, extending the capability of popular epidemiological models. On the supply side, we describe our development of nonparametric approaches for setting inventory parameters, necessitated by the combination of nonstandard lead-time distributions and autocorrelated demand. Our simulation studies, grounded in the practical need of replenishing PPE stocks for the entire state, demonstrate considerable improvements in both a) forecast accuracy possible from our approach, over extant epidemiological models, and b) estimation improvement of our nonparametric inventory estimation approach, over the extant approaches. We detail a description of our implementation and discuss the relevance of our results beyond the COVID-19 pandemic to other public health emergencies and supply chain settings.

3 - Vehicle Routing Problem with Time Windows to Balance Staff Finishing Times in Home Health Care Systems
Payakorn Saksuriya, *Chulin Likasiri*

The vehicle routing problem with time windows (VRPTW), also called vehicle routing and scheduling with time windows, is a well-known logistics optimization problem with multiple real-world applications. In the context of home health care, efficient caregiver routing is essential for meeting patients' needs while also minimizing optimization costs or achieving intended objective functions such as balancing the number of tasks assigned to each caretaker, balancing the finishing times of all caretakers, minimizing total waiting time in the system, or maximizing caretaker satisfaction. Traditional VRPTW objective functions, and even solution-finding methods in literature, may not be suitable for home health care scenarios. In this work, we propose a solution-finding method for home health care with the objective of balancing caretakers' finishing times in larger cases. Our method is a 3-phase heuristic, featuring in the initial phase an inserting procedure to generate a solution; a swapping and moving procedure in the improvement phase; and in the final phase the random application of the swapping procedure to the solution in order to escape the local optimum. Then, to demonstrate the efficiency of our method, we compare the optimal solutions obtained via a branch and price method with the solutions from our proposed method of Solomon's benchmark problems with 25, 50 and 100 nodes. The results show that our proposed algorithm can find a near-optimum solution in small cases. We find that balancing caretakers' finishing times will increase the total completion time of all home visits but will result in each caretaker having a similar number of working hours. This can improve caretakers' job satisfaction, which in turn will lead to improved service efficiency. When total completion time is minimized, however, the total differences in finishing times increase at least two-fold compared to when balanced finishing times is the objective function. These results indicate that aiming for balanced finishing times can improve the solution's quality in terms of staff satisfaction.

Finalist Presentations Session 1

Cluster: IFORS Prize for OR in Development Finalist Presentations
Invited session
Chair: *Mario Guajardo*

1 - Improving Health Outcomes with Less Cost? Provision of Mobile Clinic in Developing Economies
Fang Liu, *Pengfei Guo*, *Yulan Wang*, *Yuejuan Xi*

Consider a public healthcare system consisting of a hospital, a mobile clinic (MC), and a population of potential patients. The government is concerned about the system's healthcare spending and the population's health outcomes; it needs to decide whether, and, if so, how, to provide the MC service to maximize the social welfare, consisting of the following two terms: the system's long-run average healthcare cost and the population's average quality-adjusted life year (QALY). We model the population's natural disease progression and derive both the average healthcare cost and the average QALY for a given MC delivery cycle. We then characterize the optimal MC delivery policy for both fast- and slow-progressive diseases; MC service occurs only when the setup cost falls below a certain threshold for both. Once provided, if the disease is fast-progressive, MC service is provided either every, or every other, period. In contrast, when the disease is slow-progressive, a larger MC capacity leads to a weakly less frequent provision of the MC service. The provision of MC service always results in a longer average QALY compared to no MC service. It can also reduce the average healthcare cost, when setup cost is sufficiently low and relative treatment cost-saving per person with provision of MC service is positive. The provision of MC service can result in both healthcare cost reduction and QALY improvement only when the incremental cost-effectiveness ratio (ICER) is negative. The ICER is more likely to be negative when (i) the government becomes less concerned about QALY improvement, (ii) MC treatment becomes more effective, or (iii) MC capacity becomes larger. When the ICER is negative, on average, the provision of MC service leads to a 141% improvement in average QALY and a 13.1% reduction in average healthcare cost, compared to those with no MC service; when the ICER is positive, on average, the average QALY can be increased significantly by 266.4% at the cost of increasing the average healthcare cost by 5.8% with provision of MC service. Interestingly, expanding MC capacity may not necessarily improve the population's health outcome.

2 - OCP Optimizes its Supply Chain for Africa
El Mehdi Er Raqabi, *Ilyas Himmich*, *Ahmed Beljadid*, *Mohammed Ali Bennouna*, *Rania Bennouna*, *Salah-Eddine Boumahdi*, *Latifa Boussaadi*, *Nizar El Hachemi*, *Issmail El Hallaoui*, *Michel Fender*, *Hicham Guellaf*, *Anouar Jamali*, *El Miloudi Mahboubi*, *Metrane Abdelmoutalib*, *Ilyas Rakhis*, *Nabil Si Hammou*, *Francois Soumis*

Operations research specialists at the OCP Group, the Mohammed VI Polytechnic University, and the Polytechnique Montreal operationalized a system optimizing OCP's supply chain downstream activities. The system simultaneously schedules production, inventory, and vessels, while ensuring the highest demand fulfillment. Therefore, it has become central to the planning process, fundamentally transforming the supply chain and operations management at the OCP Group. Planners now use the optimizer's solutions and insights to improve plans. The optimizer was initially a bottleneck curbing the usage of other supply chain management tools. After operationalizing it, however, OCP management credits the system with providing operational benefits, contributing to over a $240 million increase in annual turnover.

3 - Cooperative Traffic Light Signal Control: Optimization Models and Algorithms
Changzhi Wu, *Xinmin Yang*, *Chuanye Gu*, *Jiatian Pi*, *Wei Liu*, *Xu Sheng*, *Wei Liu*, *Zhi Huang*

Traffic signal control and optimization is one of the most important research topics in the field of operations research; traditional methods are typically model-based, however, without considering the interactions between traffic and environment. The system performance, under a control strategy, calls for further optimization due to the significance of the problem. With the emergence of big data, incorporating data into transportation systems to improve their performance has become a challenging issue for scholars in the field.

Despite extensive research on traffic signal control, an intelligent and adaptive controller is still relatively rare in practical applications, especially in China, where 95% still adopt traditional timing control strategy. Our research group has conducted extensive research since 2019 on adaptive traffic signal control, including modeling, theoretical analysis, computational simulation and practical application of the adaptive traffic signal control. To enable real-world implementation, we have been actively collaborating with traffic equipment suppliers to embed our proposed algorithm into actual signal control systems. To verify and evaluate the effectiveness of our approach, we are collaborating with functional government departments for implementation and real data collection from controlled traffic intersections, as well as feedback from road users.

Based on our close collaborations, we have proposed a data and model dual-driven approach for intelligent traffic signal control to improve traffic system performance. Theoretically, our approach bridges the gap between model-based and data-driven approaches by introducing a data-driven traffic modeling approach and model predictive control (MPC) to generate traffic control strategies. Practically, our approach can improve traffic flow efficiency with, on average, at least a 20% increase during peak hours, within a simulation environment. During test-bed implementations, we have observed the corresponding improvement to be about 15%.

According to data from the Ministry of Transport of China, traffic congestion results in an economic loss accounting for 20% of the disposable income of urban residents. Clearly, the widespread implementation of our approach could bring significant economic benefits and promote the development of operations research as a practical problem-solving tool.

Finalist Presentations Session 2

Cluster: IFORS Prize for OR in Development Finalist Presentations
Invited session
Chair: *Mario Guajardo*

1 - Data Science and Simulation Tools Developed at Public Universities for Supporting Argentina's COVID-19 Response Decision-Making
Rodrigo Castro, Daniel Feierstein, Ernesto Kofman, Rafael Grimson, Ezequiel Pecker-Marcosig, Guillermo Durán, Daniela Parada, Andrés Farall, Jemina García, Soledad Gonzalez, Nicolás Kreplak

This work summarizes the efforts and innovations of a group of computer scientists, engineers and mathematicians, working together with social scientists and biologists, in a project initiated shortly after the arrival of the COVID-19 pandemic in Argentina. Their work resulted in a series of contributions relating to management of the health emergency, including data processing and analyses, simulations of future scenarios, evaluation of policy impacts, alternative lockdown schemes and monitoring the evolution of key pandemic indicators. These tools were designed to function in real time in a context of great uncertainty, responding to frequently changing demands and situations and shaped by a close collaboration with public officials in a developing country, whose society and institutions are organized very differently from those of the developed world. All of these factors together required local aspects of social relations and their regional variations to be considered in adapting existing strategies and imagining new ones in support of evidence-based pandemic policy planning through the analysis of data and the projection of future scenarios.

2 - Safer Homeland: Developing Evacuation Simulation and Humanitarian Relief Logistics Models for Effective Disaster Preparation and Response in Taiwan
Kuo-Hao Chang

We developed two data-driven, practice-based streams of interrelated post-earthquake disaster operations research, one pertaining to pedestrian evacuation and the other to humanitarian relief logistics. The two studies, published in Decision Support Systems and European Journal of Operational Research, respectively, were carried out in collaboration with the National Science and Technology Center for Disaster Reduction (NCDR) in Taiwan - a think-tank established to strengthen disaster management and risk reduction for the government. Developing these simulation-based disaster operations frameworks was challenging because the post-earthquake environment is highly complex and stochastic, and the evacuation and relief goods distribution processes themselves are also characterized as dynamic and uncertain. In particular, the evacuation simulation model was built as an agent-based model, where pedestrian agents decide their walking paths and destination relief centers, based on dynamically-changing congestion levels at each cell in a cellular-based road network. Meanwhile, the humanitarian relief logistics models optimize the routing of vehicles and relief goods to meet demand at relief centers in minimal time. Extensive numerical experiments were carried out to explore important issues related to both evacuation and humanitarian logistics. Key insights have led to disaster management officials amending evacuation and humanitarian logistics policies resulting in a decrease in human suffering and lives lost. Moreover, these two lines of research have been integrated into a decision support tool called the Comprehensive Disaster Decision Support System, a key component of the all-hazard management approach, currently being developed by the NCDR and other government entities in Taiwan.

Keynote Address - Andrea Lodi

Cluster: Keynote Talks
Keynote session
Chair: *Paolo Toth*

1 - Machine Learning for Combinatorial Optimization
Andrea Lodi

The last decade has witnessed the impressive development of machine learning (ML) techniques - successfully applied to traditional statistical learning tasks as image recognition and leading to breakthroughs like the famous AlphaGo system. Motivated by those successes, many scientific disciplines have started to investigate the potential for the use of a large amount of data crunched by ML techniques in their context. Combinatorial optimization (CO) has been no exception to this trend, and the ML use in CO has been analyzed from many different angles with various levels of success. In this talk, we will review the state of the art of this scientific path, interpreting the level of maturity reached by the integration of ML techniques in CO and discussing the challenges. We will finish by presenting one particular area where we consider this integration to have remarkable potential, i.e., repeatedly solving CO problems with little data variations.

Keynote Address - Tava Olsen

Cluster: Keynote Talks
Keynote session
Chair: *Kate Smith-Miles*

1 - Agriculture 4.0 and its Opportunities for OR
Tava Olsen

Agriculture is changing in many ways; this talk gives an overview of these changes, with a particular focus on agricultural supply chains. Like many supply chains around the world, agricultural supply chains are subject to digital disruption in a variety of interesting ways. I will outline what these disruptions mean for agriculture today and make some projections for the future. New Zealand case studies will be presented. I will also discuss new agricultural technologies and precision agriculture, and what they mean for research in this important area. Ideas for future research will be discussed throughout the talk.

Keynote Address - Rene de Koster

Cluster: Keynote Talks
Keynote session
Chair: *Alexander Vinel*

1 - Warehouse Robotics - Insights from Research
René de Koster

The new generation of warehouses has gradually become robotized; warehouse automation started in the 1950s with AGVs, followed by automated storage and retrieval systems. Nowadays, managers can select from various competitive robotic techniques to store and to retrieve loads and to fulfill customer orders; in the near future, robots will work in close collaboration with human workers. In my talk, I will give an overview of new and current automated order picking methods and systems and compare them for use and fit, particularly discussing cobotic systems, where people work together with robots; to analyze these, we use both quantitative and empirical methods. I will also suggest some directions for future research.

Keynote Address - Anna Nagurney

Cluster: Keynote Talks
Keynote session
Chair: *Margaret L. Brandeau*

1 - Agricultural Supply Chain Networks: From Trade to Resilience and How OR Can Help
Anna Nagurney

Agricultural supply chain networks are essential to food security and are a major component of global trade. In this talk, I will describe how OR is being utilized to model and to solve agricultural supply chain problems, subject to a spectrum of trade instruments; how to capture fresh produce quality in multitiered supply chains; and how to measure resilience to mitigate against disruptions, like the pandemic, climate change, and wars. I will also discuss how we can better promote our research contributions to influence policy and effect positive change.

Keynote Address - Dolores Romero Morales

Cluster: Keynote Talks
Keynote session
Chair: *Stefan Nickel*

1 - OR and the Fight against Biases in Machine Learning
Dolores Romero Morales

Machine Learning and Artificial Intelligence aid data driven decision-making, and the benefits are ubiquitous. The dangers of making decisions based on biased data are well reported, however, in the academic literature as well as in mass media. The so-called black boxes, while showing state-of-the-art accuracies, may hide unfair outcomes for risk groups in high stakes decision-making, such as medical diagnosis, allocation of social benefits, or approvals in parole hearings. In this presentation, we will navigate through some novel mathematical optimization formulations to enhance the explainability and fairness of Machine Learning models and, thus, allow the user to understand and correct biases in these models.

Keynote Address - Brian Denton

Cluster: Keynote Talks
Keynote session
Chair: *Cole Smith*

1 - Healthcare Analytics: Leveraging Predictive and Prescriptive Methods to Prevent and Treat Diseases
Brian Denton

Many of the world's healthcare systems have amassed large amounts of patient observational data, including electronic health records, labs, and insurance claims, while the information technology infrastructure needed to connect the data has developed rapidly. Despite the abundance of data, many pitfalls associated with using observational data can lead to poor model performance, however, if not carefully addressed. This presentation will describe opportunities for using a fusion of analytics and operations research approaches to improve medical decisions, drawing on case studies of chronic diseases, such as cancer, diabetes, and heart disease, to illustrate the use of machine learning, Markov decision processes, and stochastic programming to address decision-making for disease prevention and treatment. Finally, the presentation will cover future opportunities for research and practice related to medicine.

Knowledge, Technology and Innovation Management

Cluster: Knowledge, Technology, and Innovation
Invited session
Chair: *A. D. Amar*

1 - Analyzing technological generation shift in materials for secondary battery, using BERTopic and Norton and Bass Model
Geon Hyeok Chun, *So Young Sohn*

The widespread acceptance of electric vehicles has accelerated growth of the secondary battery industry as the demand for batteries with expanded capacity and improved efficiency continuously escalates. With theoretical limitations on materials for a secondary battery currently in use, the global interest in new technologies regarding the next generation of materials is steadily intensifying. Most studies have focused on experimental comparison of the physical properties of new materials, however, while those of data driven approaches for their technological generation shift are scarce.

In this paper, we propose a framework utilizing BERTopic based dynamic topic modeling and Norton and Bass model sequentially to identify promising technologies on new materials along with their generational shift. Data used are related patents filed with the United States

Patent and Trademark Office up to 2022. The proposed framework contributes to the discovery of technological opportunities for the advancement of secondary battery by providing effective technological innovation strategies for related stake holders.

2 - Assessing Euro Area Monetary Policy Using Machine Learning Knowledge
A. D. Amar, *Januj Juneja*

We apply machine learning to overcome noted computational challenges of maximum likelihood estimation (MLE) for dynamic term structure models, by designing an algorithm framework (using an unsupervised neural network) to conduct MLE of a macro-finance model to assess the impact of changes in key variables - influencing monetary policy on a single interest rate associated with a policy rule governing euro area states. We also investigate the dynamic nature of these effects, by training the variables as predictors of yield convergence to a single interest rate (i.e., signal response) and using the resultant trained machine learning model to generate interest rate predictions. Finally, we group the predictions into clusters using density-based spatial clustering of applications with noise algorithm; proper training of key policy indicators (i.e., predictors) can yield convergence to a single interest rate (i.e., signal). We also find a strong disparity in variation in the coefficients driving the reaction of the signal to predictors across the member states, suggesting that achieving a convergence in practice on the part of decision-makers may not be easy. Keywords—optimization methods; machine learning, macro-finance models; euro- area monetary policy; reaction function dynamics

3 - Medical Appointment Scheduling: The Power of Data Mining and Optimization Techniques
Catalina Valenzuela-Núñez, *Guillermo Latorre-Núñez*, *Fredy Troncoso*

Medical appointment scheduling is a critical process helping health centers manage patient flow and ensure quality care. "No-shows" or "absenteeism" can significantly impact scheduling, however, and disrupt the patient care process. To address this challenge, health centers can adopt various strategies, such as optimization models, data mining, or a combination of both. Optimization models can consider variables directly affecting scheduling, such as the availability of healthcare providers, patient preferences, and medical urgency. Data mining, on the other hand, can study patient behavioral patterns, such as past attendance history, age, gender, and other relevant factors. By combining optimization and data mining, health centers can create an appointment scheduling process considering both viewpoints; it involves formulating a mathematical model, considering probabilities of attendance, patient characteristics and other relevant factors, to optimize scheduling, minimize no-shows, and maximize expected utility for the health center. This model ensures all daily available time slots are occupied, that the patients with a higher priority for attention and the first-time patients are schedule. Adopting an approach incorporating optimization and data mining helps health centers manage patient appointments more efficiently, delivering better patient care. The process ensures an optimal distribution of patients, considers their attendance and the penalty for overbooking, and achieves positive numbers in expected occupancy rate for the health center. Ultimately, this approach helps health centers provide an efficient care to their patients.

Applications of Knowledge in Finance

Cluster: Knowledge, Technology, and Innovation
Invited session
Chair: *Januj Juneja*

1 - The Capital Structure as Portfolio Optimization of the Modified Economic Value Added
Fernando Crespo, *Iván Araya*

This research measures the Economic Value Added (EVA) provided by debt and equity; its calculation method, "Modified Economic Value Added (MEVA)," is modified, however. We can optimize the Capital Structure, the composition of debt and equity, to maximize the MEVA restricted to asset value, where a portfolio problem appears, obtaining the level of indebtedness benefiting the company.

To test the goodness of the model, a quantitative-exploratory methodology was used with sixteen companies listed on the Chilean Stock Exchange with 432 observations under various scenarios: with freedom to choose debt, with the obligation to acquire a level of debt according to the shareholder, or with the obligation to acquire the maximum possible debt.

The results of the optimization models show the scenarios of requiring debt are suboptimal, because they require taking on debt when equity can momentarily generate greater economic value for the company. Period by period, a debt and equity policy can be generated improving the economic value of the company.

On the other hand, the MEVA multipliers capture the disaggregated performance of debt and equity and have the potential to be used as financial indices.

2 - Assessment of risk and ambiguity: Perception is a fine line
Michael Leyer, *Ayşegül Engin*, *Wieland Müller*

Everyday, individuals face risky or ambiguous, and sometimes risky and ambiguous, decision situations; though decision theory argues risk and ambiguity refer to different aspects of a decision situation, distinguishing them is neither straightforward nor self-evident for individuals. Decision theory defines risk as individuals' ability to assign probabilities to outcome of the decision alternatives. In other words, risk is "probabilized" uncertainty. Ambiguity is defined as the case when these probabilities are unknown, i.e., "non-probabilized" uncertainty. Empirical evidence often hints individuals are assumed to have difficulties in this assessment. Posited reasons are personal preferences or biases, such as overconfidence or misinterpretations of the situations, and, thus, wrong retrievals of perceived probabilities in the past. While both risk and ambiguity are clearly distinct concepts, however, even existing scales frequently use them interchangeably. This research considers the question of whether individuals are imprecise in distinguishing a risky situation from an ambiguous one, with experimental methodology. The experimental design presents the same decision situation to respondents either as a decision under risk setting or as a decision under ambiguity setting. To understand the underlying reasons for correct assessment of risk and ambiguity in the decision, we control for general risk and ambiguity preferences, as well as cognitive reflection and numerical understanding. It is important to consider both risk and ambiguity, and individuals are not always precise in their assessment. Second, we provide scales for measurement of risk and ambiguity, acknowledging the conceptual difference. From a practical perspective, our results are important when designing decision support solutions. Hence, only correct identification of risk and ambiguity in the support system, and in the perception of individuals, can mitigate decision errors.

3 - Monitoring the Trends in Use and Cost of Healthcare Services through Statistical Change Detection Using Medical Claims Data
Ta-Hsin Li

The global pandemic of COVID-19 has shocked the healthcare industry; utilization of healthcare services experienced dramatic changes in response to different phases of the pandemic. This talk presents a system designed to monitor the trends and changes in use and cost of healthcare services, using monthly releases of claims data in the MarketScan' Research Database. By applying various groupers created from healthcare taxonomy, medical and pharmacy claims are organized into a large number of clinically meaningful units and viewpoints depicting the hierarchy of medical conditions, treatments, and service providers. Fundamental factors of use and cost are calculated for these units and viewpoints. Changes of the resulting statistics in a time period of interest with respect to a baseline period are detected using statistical process control (SPC) techniques; financial impacts of

these changes on the overall cost of claims are also quantified. During the COVID-19 pandemic, monthly reports were produced based on the results from the monitoring system, using the latest data release. These reports were published as blogs for public consumption on the website https://researcher.watson.ibm.com/researcher/view_group.php?id=10570. This talk shows some interesting examples of the top drivers found in various phases of the pandemic.

Innovative Applications of Knowledge

Cluster: Knowledge, Technology, and Innovation
Invited session
Chair: *A. D. Amar*

1 - Artificial Intelligence in Customer Interactions of Small and Medium-Sized Enterprises: A Conceptual Framework
Tim Kanis

Artificial intelligence (AI) has the potential to significantly improve how companies interact with their customers. For example, AI can enable a better understanding of customer demands, automated responses to routine requests and 24/7 service availability. However, implementing AI requires specialised skills and sufficient resources - a prerequisite that is particularly difficult for small and medium-sized enterprises (SMEs) to achieve. Research has shown that SMEs often lack a clear understanding of the benefits AI can bring to specific tasks, lack the necessary technological know-how and data, and face scepticism both internally from their employees and externally from their customers. Consequently, research has shown that SMEs struggle to take advantage of the potential benefits of this technology. I address this problem by providing a conceptual framework for (1) application scenarios of AI in SME customer interactions and (2) strategies SMEs can use to successfully implement AI. Regarding (1), for example, SMEs can use natural language processing applications such as chatbots to make appointments with customers, answer routine queries and sell products and services. This comes with the advantage of relieving the often scarce human resources of SMEs. In addition, machine learning can facilitate the analysis of purchasing behaviour and predict customers' buying and decision-making behaviour. This can lead to higher sales and competitive advantages. Regarding (2), for example, SMEs can address the lack of data by using not only internal but also external resources (e.g. cloud providers, competitors). Furthermore, SMEs can introduce key performance indicators (KPIs) to measure the success of AI implementation - a field which is understudied. For example, measuring customer satisfaction in the context of AI interaction could not only help SMEs better address customer needs, but also overcome scepticism. This study contributes to research on SMEs and AI in two ways. First, it provides a comprehensive overview of the application scenarios of AI for SMEs, an area that has not been sufficiently addressed in previous research. Second, it provides a better understanding of what strategies SMEs can adopt to successfully use AI in customer interactions.

2 - Literature Review on Innovation Systems: From National Innovation Systems to Complex Adaptive National Innovation Level
Homero Malagon

This literature review aims to explore commonly used innovation systems - what are their objectives, how they work, and if they have any shortcomings. The literature review was carried out using specific search keywords, on different databases, filtering by year, article type, subjects, title and abstract, alongside bibliographic cluster analysis on vosviewer with metadata retrieved from the databases. The most used approaches on innovation systems are the National Innovation System, Technological Innovation System, Regional Innovation System, Triple Helix, Quadruple Helix, Quintuple Helix, Innovation Ecosystem, Entrepreneurship Ecosystem, National Innovation Ecosystem, Regional Innovation Ecosystem, and the not so common, but most recent, Complex Adaptive Regional Innovation System. Although all the above mentioned are or have been broadly used, the most common one is the Triple Helix; nonetheless, all of them share some characteristics such as their principal actors, government, universities, and industry. As they share some characteristics, they share some issues as well, such as limited scope, the conceptualization of innovation, and some unclear definitions, which can be addressed if innovation is considered as an emergent property of a system, instead of a system in itself. One could, therefore, analyze it as a Complex Adaptive Innovation Level.

3 - GIS-based optimization tool to determine future green hydrogen integration opportunities in urban energy systems
Stella Nadine Steidl, *Jannik Haas*, *Alaa Alhamwi*, *Wided Medjroubi*, *Rebecca Peer*

Green hydrogen has gained significant global attention in the urge for decarbonisation. With a plethora of hydrogen applications for different sectors, it is crucial to identify and prioritise the most suitable and economical options.

To assess the integration of green hydrogen in cities, we present the open-source, GIS-based model FlexiGIS-H2 applied to model the urban energy system in Christchurch, New Zealand. The tool supports decision-making for future energy system planning. Based on open-source data, the model detects existing urban energy infrastructure for a given city. For future expansion planning, land use and building models are assessed to determine energy demand. Future generation and storage technologies are also investigated, for example by correlating suitable rooftop areas to potential PV installations. By means of cost-minimization, a technology mix to meet current and future energy demand is proposed, leveraging renewable resources and flexibilisation technologies, including hydrogen. FlexiGIS-H2 assesses different energy scenarios, including a reference, a carbon-neutral and a hydrogen scenario, under current and future cost projections.

In this work, FlexiGIS-H2 is applied to the case study of Christchurch, but application to other cities is straightforward. The resulting energy portfolio and residual energy profiles can be used as inputs to national capacity expansion tools, to provide local detail that these tools often lack. Here, we discuss the application of FlexiGIS-H2, our modelling results for Christchurch, and our planned work integrating these results into a country-wide integrated energy system model.

General Network Design

Cluster: Location, Network Design, and Routing
Invited session
Chair: *Armin Lüer-Villagra*

1 - On Collaboration in Multi-period Discrete Location
Carmen-Ana Dominguez-Bravo, *Laureano Fernando Escudero*, *Elena Fernandez*, *Juan Francisco Monge*

In this work, we study discrete location models, where several agents operate on a common network and time horizon, and we consider cost-minimization models, where the existing demand at each time-period must be served, as well as prize-collecting extensions, including decisions on the users to serve. All models allow multiple-allocation of users to open facilities, varying throughout the time horizon. We operate on a modular capacity context; the initial capacity and potential future extensions serve as part of the decision-making process.

We compare a non-collaborative setting, where each agent makes its own location, facility capacity, and service decisions, with flexible collaborative policies, where agents make joint decisions. According to these policies, location and service decisions no longer link to their original agents; at any time, a plant originally "belonging" to one agent can open and operate under a different one. Furthermore, the demand of a user originally relative to a given agent may receive service by a different one, changing among time-periods. We propose

alternative mathematical programming formulations, both for the non-collaborative setting and for each of the considered collaborative policies.

Benchmark instances from the literature, adapted to the new models and used in a series of computational experiments, have their preliminary numerical results summarized. We analyze effectiveness of the alternative formulations, and we compare the performance of the collaborative models versus the non-collaborative ones and show the empirical advantages agent collaboration may produce.

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2 - Hub location models with time-sensitive demand and congestion

Elena Fernandez, *Carmen-Ana Dominguez-Bravo*, *Armin Lüer-Villagra*

The overall demand (commodities) routed through a network and congestion at its hubs substantially affect the efficiency of hub location systems. On the one hand, the demand associated with the commodities, determining the overall revenue, can depend not only on total travel times through the hub network and on the length of the origin/destination route through the activated network, but also on the time spent at each of the visited hubs. On the other hand, a higher congestion at the hubs increases the time required by the commodities to traverse them, and, thus, the total travel time of the commodities.

Increasing the capacity of the activated hubs would allow the circulation of higher flows and, thus, reduce their congestion, increase overall demand, and eventually produce higher revenues, since customers have a greater incentive to use the hub system if total travel times decrease. This congestion reduction involves higher setup costs for the activated hubs.

In this work, we study a profit-oriented hub location model, where the objective measures the tradeoff between the revenues of the served commodities and the overall network design and transportation costs. Commodities can receive alternative demand levels, each of them producing a different revenue and restricted to a maximum total travel time, and hubs can receive activation at different capacity levels, each with a different limit on the maximum flow circulating through it.

We develop mixed-integer mathematical programming formulations, analyze their properties, and present some elimination criteria, along with results from computational experiments.

3 - 2-index formulations for Multiple Allocation Hub Location Problems

Nicolas Zerega, *Elena Fernandez*

Hubs are facilities where demand is consolidated, sorted and rerouted to different destinations within a network. Reduced travelling costs can apply to flows routed through interhub connections, thanks to economies of scale; examples being airports and logistic centers. Hub Location Problems (HLPs) determine optimal hub locations and network configurations to transport commodities between their origins and destinations, following consistent paths traversing at least one hub node, according to a given criteria (cost minimization, profit maximization, etc). The network determined by hub nodes and the connections between them is the backbone network. In this work, we focus on multiple allocation HLPs (MA-HLPs), where commodities with the same origin can be connected to the backbone network using different hubs. Current formulations for MA-HLPs consider 4- or 3-index variables. 4-index formulations associate each commodity with a path connecting its origin with its destination. Although they usually provide very tight lower bounds, one of their main drawbacks is the number of decision variables, increasing to the power of four with the number of nodes in the network - limiting the size of the instances solvable efficiently. 3-index formulations address the previous issue by modeling HLPs as multi-commodity flow problems - implying decision variables increase in the cubic order with the number of nodes and resulting in smaller formulations at the expense of generally producing worse bounds than their 4-index counterparts. Our research focuses on deriving formulations for MA-HLPs using 2-index variables only; they use binary decision variables, defining the location of hubs and link activation, and continuous decision variables, associated with aggregated flows traversing each connection. Using these variables, we introduce several families of connectivity and demand constraints validating the proposed formulation and reinforcing the generic flow balance conditions. Since the new families of constraints are of exponential size in the number of nodes, we develop exact and heuristic separation procedures, involving the solution of auxiliary problems, so they can be embedded within a branch-and-cut algorithm. We present and analyze numerical results on well-known instances from the literature.

4 - Hub location problems with explicit redundancy requirements

Armin Lüer-Villagra, *Guillermo Latorre*

In telecommunications, the main goal is the design of a resilient and cost-effective network; while resilience can be achieved by equipment and link redundancy, cost-effective networks tend to consolidate traffic in high-capacity links, however, making the network more fragile. Hub location models have been used to design profitable or cost-effective hub-and-spoke networks, sometimes keeping the resilience of the resulting network in mind. Resilience has been addressed through stochastic and robust programming, modeling the situation as a Stackelberg game. We design hub-and-spoke networks for telecommunications, considering explicit redundancy requirements in the network, i.e., a minimum number of disjoint paths must connect an origin-destination (OD) pair to serve its demand. We study the impact of a network designed to add these redundancy requirements, together with some preliminary results regarding the estimation of the network's resilience under this conservative approach.

New Applications of Location Models

Cluster: Location, Network Design, and Routing
Invited session
Chair: *Justo Puerto*

1 - Modeling demand elasticity for the hub line location problem

Luisa I. Martínez-Merino, *Brenda Cobeña*, *Ivan Contreras*, *Antonio Manuel Rodriguez-Chia*

In this work, we introduce the profit-oriented hub line location problem with elastic demand (ED-HLLP), an extension of the hub line location problem (HLLP) using a gravity model to include the elasticity of demand. ED-HLLP maximizes revenue of the total time reduction provided by the hub line, considering elastic demand and taking into account the long-term impact on the demands that opening a hub line can have. We propose non-linear formulations to address this problem, differing mainly in how the line structure is modeled; due to the limitations the formulations present, we introduce three main linear formulations, using the possible paths of the hub line as variables. Consequently, it is necessary to use a preprocessing phase calculating the candidate paths for each origin-destination. We provide efficient algorithms to create all possible candidate paths and a computational experience evaluating the strengths and limits of these formulations for ED-HLLP.

2 - Constraint Relaxation for the Discrete Ordered Median Problem

Diego Ponce, *Luisa I. Martínez-Merino*, *Justo Puerto*

The Discrete Ordered Median Problem (DOMP) seeks to locate p facilities and the allocate each client to its closest open facility, so the ordered weighted average of the allocation costs is minimized. In recent years, the DOMP has been formulated using set packing constraints, known as strong order constraints (SOC). In this work, we explore a solution method based on the relaxation of SOC. This procedure starts with a relaxed formulation, where all SOC are removed and feasibility is enforced adding model constraints from the SOC family in the

searching tree. We also compare the performance of this row relaxation approach using callbacks based on specific tailor-made oracles with respect to the use of fixed pools of constraints defined in advance, and we compare this procedure with other previous solution methods for the DOMP.

3 - Partitioning a graph constraining the weight of its cuts
José L. Sainz-Pardo, *Justo Puerto*

We consider the problem of partitioning a graph into multiple components when the capacity of cut-edges is restricted; the objective function can be formulated in several ways. The different problems studied are the following: Maximizing Parallelism, Most Uniform Partition and also p-Most Uniform Partition. We provide an integer programming model, an exact combinatorial algorithm and a heuristic approach. Finally, an extensive computational experience and a comparative analysis between the different methods and considered problems is reported.

4 - Revisiting the second closest facility location problem
Justo Puerto

Emergency services can, in practice, fail. In particular, after a large disaster, an emergency center located in the affected area is likely to be destroyed or seriously damaged. For this reason, we extend the p-center problem in different directions. In the first situation, we study the problem where an unpredictable incident occurs in any of the p centers, forcing the center to close and all users allocated to it to be reassigned to another center - which must be the second closest center with respect to the user. In the second situation, users only realize their reference center is unavailable after arriving at it. Then, they will be redirected to the open center closest to the non-available center. In the last situation, each demand point can visit at least two acceptable centers, and the maximum sum of distances from any demand point to any of its preferred centers, plus the distance from any of the preferred centers to any of the centers the user prefers once there, is minimized. Properties of the models are studied; mathematical programming formulations are presented; and computational results illustrate the behaviour of the different models.

Risk and Resilience in Facility Location

Cluster: Location, Network Design, and Routing
Invited session
Chair: *Diego Ruiz-Hernandez*

1 - Minimising locational complexity in distribution networks: the K-MedianPlex Problem
Jesús Maria Pinar-Perez, *Diego Ruiz-Hernandez*

In this work, we address the issue of locational complexity in facility location problems - the intricated set of interactions and decisions related to the company's territorial strategy. An ever-growing number of facilities tends to introduce hidden costs hindering the capacity of the company to generate profits. By ignoring these effects, standard location models tend to generate oversized networks, inducing what other authors have called "an addition to growth". To account for the burden of locational complexity, we introduce the so-called pars-Complexity metric in a standard K-Median formulation, resulting in a non-linear highly combinatorial problem referred to as the K-MedianPlex problem. A maximum-ascent greedy heuristic is proposed for solving large instances of the problem.

2 - Facility location decisions under fluctuating capacity scenarios
Diego Ruiz-Hernandez, *Jesús Maria Pinar-Perez*, *Mozart Menezes*, *Serigne Gueye*

In this paper, we analyse a facility location problem where facilities have disruptions and their capacities may be reduced from their theoretical (design) value. Service facilities can and usually fail at different times; these failures may occur with high frequency, but low economic impact, or with low frequency, but high economic impact. Other combinations of frequency and economic impact are of less interest due to the triviality of the situation: if disruptions occur with high frequency and high economic impact, businesses are unlikely to survive, and they may seek alternative business models; alternatively; low frequency and low economic impact disruptions may not be a matter of concern for the decision-maker. Failures originate from different sources, ranging from natural disasters to locally disruptive events (street blockades or power outages) to temporary shortages of capacity (strikes). While the classical location theory tends to ignore the reliability aspects, the recent pandemic has brought a growing interest in better understanding the impact of imperfect reliability on optimal location patterns and resulting costs. In this paper, we examine a class of models where service facilities may fail. We describe as "failure" any deviation of the facility's capacity from its theoretical value. We propose a greedy algorithm emulating organic growth patterns typically observed in facility networks and compare results with the outcome of standard p-Median problems. Our results suggest increasing levels of centralisation and co-location as the likelihood and extent of increased capacity shortages.

3 - Bilevel formulation and two exact resolution approaches for the Maximum Capture Facility Location with Random OWA Utilities
Concepción Domínguez, *Ricardo Gázquez*, *Juan Miguel Morales*, *Salvador Pineda Morente*

In Maximum Capture Facility Location problems with Random Utilities (MCFLRU), a company intends to locate a series of facilities to maximize the captured demand with respect to existing competitors. Customers choose the facilities to be served from using a Random Utility Maximization (RUM), i.e., they behave rationally and maximize their utility, given by a random choice model accounting for uncertainty. In this work, we generalize the RUM followed by the customers, assuming their decision is influenced by a combination of the installed facilities, i.e., all facilities contribute to the coverage of a customer (the customer's decision is binary). This setting has realistic applications, such as the adoption of electric vehicles, heavily influenced by the placement of charging stations. Specifically, to model the customer decision rule, we propose a Random Utility Maximization with an embedded Ordered Weighted Average (OWA) Operator. The OWA operator serves as a means to compute the utility of each customer as an aggregation of the partial utilities of the facilities located. We introduce a non-linear bilevel formulation with an embedded assignment problem characterizing the OWA operator. For this model, two exact resolution approaches are presented. In the first one, a MILP reformulation and the inclusion of valid inequalities tailored to the problem allows its resolution, using modern general-purpose MILP solvers. The problem is also solved by means of an effective approach based on Benders decomposition, where an ad-hoc algorithm is developed to speed up the inclusion of Benders' cuts. Extensive computational experiments are provided to test our results, and an application to the location of charging stations to maximize electric vehicle adoption is discussed.

Topics in Competition and Games

Cluster: Location, Network Design, and Routing
Invited session
Chair: *Vladimir Marianov*

1 - Bilevel Mixed-Integer Programming Model for the Network Design of a Recycling Waste Collection: A Case Study in a Chilean Commune
Sebastián Dávila, *Marcela López G.*, *Franco Quezada*, *Sebastián San Martin C.*

Growing urban populations have led to increased waste generation, and authorities have been taking measures to reduce the amount of waste sent to landfills without being recycled, harming the environment and raising treatment costs. To address these challenges, authorities worldwide have proposed various strategies to encourage recycling, such as distributing recycling waste collection bins throughout the city for the population to deposit their recyclable materials (e.g. glass, cardboard, and plastic) for transportation to treatment centers, where they are converted into raw materials for new use.

To ensure optimal implementation of recycling waste collection bins, authorities must strategically determine the location, size, and bin category (glass, cardboard or plastic), based on user preferences. They must also define the collection frequency, to prevent micro-dumps near the bin due to exceeding capacity, and the routing to reduce logistical costs, including determining the model and size of collection trucks. Additionally, user decisions must be incorporated into the model to study their responses to incentives and/or costs associated with dropping off materials in the recycling collection bin.

This paper optimizes the location of recycling waste collection bins to increase recycling and reduce transportation costs. We mathematically formulate the problem as a bilevel mixed-integer programming (BMIP) model based on the periodic location-routing-inventory problem with users' preferences.

We present a case study of a commune in Chile to test the formulation and evaluate various decision-making strategies, including economic costs, penalty levels for lost users and excess waste, buying or leasing collection trucks, and changes in transportation costs and demand levels.

2 - Branch-and-price and novel constraints in Stackelberg Security Games

Pamela Alejandra Bustamante Faúndez, *Victor Bucarey*, *Martine Labbé*, *Vladimir Marianov*, *Fernando Ordonez*

Stackelberg security games are used as decision-support tools in security settings. The algorithms addressing these games generate optimal randomized schedules for distributing security resources. Unfortunately, finding optimal strategies for Bayesian Stackelberg games and Stackelberg security games is generally NP-Hard. Developing efficient methodologies to tackle large instances is essential to face this. We propose a branch-and-price scheme with novel and tighter constraints to find a Strong Stackelberg Equilibrium for Stackelberg games. We also provide a general algorithm generating upper and lower bounds for Stackelberg Security Games. We compare different methods and parameters for branch-and-price in these games, and we test and compare our proposed method to prior decomposition methods based on different integer programming formulations of Stackelberg games.

3 - The follower competitive facility location problem under the nested logit choice rule

Gonzalo Mendez-Vogel, *Vladimir Marianov*, *Armin Lüer-Villagra*

Recently, more realistic customer choice rules based on the Multinomial Logit have been proposed for the follower competitive facility location problem, together with efficient exact solution methods based on cut generation approaches. We address this problem where a new chain, the entrant, decides to locate some stores in a market where incumbent chains offer substitute products, differing from the entrant's product in secondary features. The entrant's stores are very similar to each other, as are the incumbent chains. For a given customer, purchases made at the stores of one of the chains are correlated, given the similitude between the stores, but the Multinomial Logit rule does not capture this correlation. We propose using a Nested Logit rule - capturing this correlation and, in addition, representing a sequential decision process by the customer, who first chooses the chain and then the store. We prove the concavity of the objective function in the problem and find exact solutions using Branch and Cut over a generalized linear reformulation of the problem and four different cuts: submodular and an improvement of these, outer-approximation, and a set of new cuts. Our results show locations fitting better intuition and practice. Furthermore, our computational times improve in many cases upon the known results for similar problems.

4 - Including correlated alternatives and hierarchical decision-making in customer choice rules for competitive facility location

Vladimir Marianov, *Gonzalo Mendez-Vogel*, *Armin Lüer-Villagra*

In competitive facility location problems, customers decide what facility to visit to satisfy their needs, by using some choice rule. The literature has proposed several customers' choice rules, used in competitive location models - the most popular ones based on the probabilistic gravity rule and the random utility rules, in particular the multinomial logit rule.

Most of the gravity and random utility rules used so far in location models have the property of Independence from Irrelevant Alternatives (IIA), a good representation of reality when the alternatives faced by a customer do not correlate with each other; for example, a number of stores, all belonging to different competitors and selling mutual substitutes, but not identical products. In practice, alternatives can correlate - implying, among other effects, adding a new alternative affects the ratio between the preferences for the existing ones, e.g. two competing firms with several stores, each offering the same products in all their stores.

Furthermore, the rules predominantly considered do not allow modeling sequential decisions, as occurs in practice when a customer decides to what marketplace to go and, then, to a store in the chosen marketplace.

A choice rule recently introduced in competitive facility locations, the nested logit, addresses correlation and allows modeling sequential decisions, with some developments also in hierarchical gravity-based rules. In this paper, we present nested logit and hierarchical gravity rules, compare them, and show options for formulating linear integer competitive facility location models using them - along with preliminary computational experience.

Location Applications for Disaster Management

Cluster: Location, Network Design, and Routing
Invited session
Chair: *Pamela P. Alvarez*

1 - Mitigation of the danger exposed to the population in the face of NATECH events

Victor Silva, *Pamela P. Alvarez*, *Andrés Bronfman*

Decisions about the location of facilities are made difficult when the facilities are of a "hazardous" nature (for example, chemical production plants); their proximity creates a danger to the population due to possible release events of hazardous material (HM). Release accidents can be due not only to faulty equipment, deteriorated materials, or operator errors, but also because of social-natural disasters. In these events, called NATECH (Natural Hazard Triggering Technological Disasters), many facilities can be affected simultaneously, easily exceeding the capacity of specialized response centers (SRCs); response personnel, equipment, and facilities may be unavailable. We address the NATECH event mitigation issue and consider the existence of a system made up of a set of dangerous facilities and SRCs in a large urban area, where a social-natural disaster (disruptive event) can trigger various HM spills simultaneously, negatively impacting the population. We propose a bi-level interdiction model with fortification. At the first level, the vulnerability of the system is evaluated, identifying those facilities and SRC generating the greatest danger to the population, when damaged. At the second level, we identify dangerous facilities and SRC requiring fortifications, so the resulting system is efficient in minimizing the danger exposed to the population and resilient when interrupted. The methodology is applied in the city of Santiago de Chile.

2 - Preparation plan to evacuate in earthquake scenarios
Pamela P. Alvarez, *Alejandro Lamas*, *Andrés Bronfman*

From the very earliest days of humankind, people have lived under the threat of socio-natural disasters, such as earthquakes, tsunamis, volcano eruptions, tornadoes, and hurricanes, affecting a large part of the population in a geographical area. Although societies prepare to serve people's needs, the occurrence of a socio-natural disaster makes the regular capacity insufficient to respond to needs and triggers particular requirements from the population (shelter, food, and medical supplies). To handle this problem, we propose a two-phase methodology for preparedness and response stages in natural disasters. Phase 1 (preparedness stage) solves the location problem of shelters and warehouses with multiproduct stock pre-positioning and capacity restrictions, generating a Base Plan for the response. Phase 2 (response stage) considers a natural disaster disabling parts of the Base Plan. A new model is proposed to re-optimize the system allowing the reallocation of various segments of the population and supplies. In both phases, evacuation travel times, supply times, and warehouse installation costs are minimized. The methodology is tested in the city of Iquique, Chile, based on a set of scenarios with various impacts on the population and infrastructure.

Periodic Vehicle Routing, Ridesharing and Crowdshipping Models

Cluster: Location, Network Design, and Routing
Invited session
Chair: *Cristian E. Cortes*

1 - A Vehicle Routing Problem for Marketplaces in the Shared Economy
Marcel Goic, *Pablo Azurduy*, *Cristian E. Cortes*, *Nicolás Aramayo*

In recent years, the development of information technologies has led to important changes in the design of the logistics systems companies use to distribute products to their customers. Among the most relevant changes is the emergence of digital platforms connecting firms needing to deliver their products with drivers who can address the transportation of the last mile. One of the central attributes of these platforms is the lack of contractual relationship with potential drivers, and, therefore, when a platform offers a possible route, drivers will accept only those routes they find more attractive. This logic requires modifying traditional approaches to solve the resulting vehicle routing problem (VRP) to generate solutions not only providing reduced transportation costs, but also generate attractive routes for drivers. In this paper, we propose a conceptual framework to address the vehicle routing problem with crowdsourced drivers (VRPCD) and propose a solution scheme allowing learning from drivers' preferences and incorporating them to generate solutions meeting business objectives. By applying our solution approach to a real problem of a digital logistics platform, we can reduce nearly 15.6% of the acceptance time compared to the current implemented solution.

2 - A vehicle routing problem in industrial waste management
Natalia Paz Gonzalez, *Pablo A. Rey*, *Cristian E. Cortes*

A fundamental element in achieving sustainable resource management has been the responsible treatment of waste and its reuse, promoting the reduction of domestic and industrial waste generation. Due to the complex nature of these services, municipalities have decided to handle only domestic waste in Chile. In contrast, industrial waste should be managed by specialized companies.

From a logistical point of view, the designated operators must be in charge of efficiently and safely managing the transportation between the waste-generating entity and its final disposal. This task has recently become increasingly complex, due to increased fuel, labour, and machinery costs and the rise in demand.

This study develops an integer programming model for a periodic vehicle routing problem aimed at minimizing operational costs and rescheduling failed visits for a waste management holding company, specializing in collecting hazardous industrial, household and recyclable waste. In this problem, weekly visits to each client should be scheduled according to the requested frequency, while balancing daily workloads and minimizing the total route length. We apply our approach in a case study based on a waste-management company operating in the Metropolitan Region of Chile.

3 - Ride-sharing system with hierarchical pick up and drop off points
Francisco Vilches, *Cristian E. Cortes*, *Andres Fielbaum*

Thanks to technological advances of recent years and the widespread use of smartphones, various ways of incorporating technologies in the modeling and optimization of transportation systems have emerged; in particular, demand responsive mobility systems have become a transportation option, allowing dispatching and routing decisions, almost in real time. Ride-sharing is one of the most efficient of these mobility systems, in terms of both cost and time; the former related to the fleet required to satisfy the demand, and the latter directly associated with the passengers' level of service offered by the ride-sharing system. The implementation of a ride-sharing system involves a computational challenge, due to the difficulty of correctly synchronizing trips between vehicles and passengers, and becomes more intense with a more realistic representation of the city. In the present work, we add conditions to previous state-of-the-art models, generating more realistic and more efficient formulations; among the features we can highlight are the following: the incorporation of walking distances and pickup and drop off points, variations in the weights of the network arcs and the technique of hierarchization of nodes, the latter inspired by research related to Customizable Contraction Hierarchies. For this purpose, the Inertial Flow algorithm calculates the contraction order of the nodes in the network, and, thus, obtains the ranking of each node. In this work, we propose the implementation of a ride-sharing system model, where the network node is classified using the hierarchization technique mentioned, and, then, the nodes representing the different meeting points, from/to where the passengers must walk, are defined, corresponding to pickup and drop-off points. In the case of a variation in the arcs' weights, the hierarchy of the nodes will be recalculated and the meeting points updated. The model has been validated and various scenarios have been simulated in an urban context, using a section of the city of Santiago as a reference. Results show the advantages of including these new features in the ride-sharing model, not only in terms of efficiency, but also in service level offered to customers, compared with more traditional ride-sharing configurations.

4 - A Set-Partitioning Formulation and Heuristic Decomposition Solutions for the Crowdsourced Shared-trip Delivery Problem
R Jayakrishnan, *Dingtong Yang*, *Michael Hyland*

Crowdsourced delivery, as a new urban logistics service option, has grown rapidly in recent years; some delivery orders could be served by crowdsourced drivers with their daily commuting or shopping trips. The problem of routing shared personal vehicles (SPVs) and dedicated vehicles (DVs) for package delivery is named as the crowdsourced shared-trip package delivery problem; this paper presents the formulations for the delivery and solves the problem, especially at large scale, with a novel decomposition heuristic (D-H). As the first step, the D-H enumerates the set of routes each SPV can feasibly traverse. Second, the D-H algorithm obtains a quality initial solution by assigning package orders to SPV routes and routing the DVs for the unassigned orders. The solutions are improved iteratively by a package switching process between SPVs and DVs, inspired by the simulated annealing algorithm. The steps of generating new candidate solutions are regulated by three switching rules. The D-H algorithm significantly outperforms a commercial solver in terms of computational time, while keeping the optimality gap within 3%. In addition, the D-H heuristic is used to analyze the impact of several relevant factors on city-scale

system performance, namely the number of participating SPVs and the maximum detour willingness of SPVs. Consistent with the existing literature, crowdsourced delivery can substantially reduce delivery costs. The results and findings provide meaningful insights for industry practice, while the algorithms illustrate promise for large real-world systems.

Last Mile Delivery

Cluster: Location, Network Design, and Routing
Invited session
Chair: *Germán Paredes-Belmar*
Chair: *Guillermo Latorre-Núñez*

1 - The Vehicle Routing Problem with Drone-Based Replenishment at Transshipment Platforms
Juan Carlos Pina Pardo, *Matthias Winkenbach*

We study a last-mile delivery problem, where customer orders become available for dispatch at various times throughout the delivery horizon. Once delivery trucks have started their routes, last-mile logistics operators normally use two strategies to manage the arrival of new orders: instruct an en-route truck to return to the depot to collect these orders or dispatch a new truck to deliver them. In this presentation, we investigate an innovative alternative for this problem: drones can be used to send newly available orders to transshipment platforms strategically located throughout the delivery area, where en-route trucks collect them for delivery. We leverage the problem's decision structure to formulate the problem as a two-stage mixed-integer linear program, where the first stage defines truck routes and the second stage the optimal transshipment decisions. To solve the problem, we propose an exact solution framework based on the integer L-shaped method, solving both the truck-and-drone and truck-only versions of the problem. The exact solution framework is enhanced with several problem-specific valid inequalities. Through extensive numerical experiments, we show the benefits of this new drone-based resupply strategy to reduce the number of truck return trips to the depot, expand truck capacity over time, and reduce customer waiting times.

2 - Design of PVRP heuristic for parcel deliveries in a metropolitan area
Juan Cantillana, *Cristian E. Cortes*, *Fernando Ordonez*, *Claudio Cerda*

The Periodic Vehicle Routing Problem (PVRP) considers multiple visits to a set of locations over a planning horizon, typically of multiple days, leading to large, difficult to solve routing problems. To address this challenge, we propose a heuristic approach dividing the PVRP into two parts: a daily routing problem and a scheduling problem. By using well-known and fast routing solutions, we can efficiently solve the routing problem. The scheduling problem determines the locations to be visited each day of the planning horizon, aiming to minimize an approximate routing cost estimate for each day.

On small instances, our heuristic method has, on average, a 16.9% gap to the best bound, where 9% of this gap is explained by the scheduling problem. We also tested our method on a real-world, large food producer, with over 30,000 stops per month, comparing our method to the current company solution and to using a routing solution with the current daily customer assignment. Our heuristic solution achieved savings of 32% compared to the current company solution and 11% with respect to using a routing solution in the case of high demand. In a scenario with low demand, we achieved savings of 35% compared to the current company solution and 1% with respect to using a routing solution. Our method makes use of VRP algorithms already in use in the industry, making it a practical and accessible solution for real-world applications.

3 - The Delivery Worker Assignment Problem with Time-Dependency for distribution in Multiple Buildings
Antonia Ilabaca, *Germán Paredes-Belmar*, *Guillermo Latorre*

The world's cities have seen substantial change in recent times. Population is increasing, and a large percentage of it is moving to urban areas, causing an expansion of cities, not only on the horizontal plane, but also at height, with the construction of numerous buildings to contain the new urban population in conjunction with their needs. We are interested in including buildings in city logistics, particularly in the distribution of goods through parcel companies. These new features cause problems, such as an increase in vehicles, congestion, noise and pollution. In this paper, we introduce, model, and solve the deliverymen assignment problem with time dependency; it consists of determining routes for a set of vehicles serving a set of demand points in an urban area. We focus our research on those demand points located within buildings. Unlike the traditional vehicle routing problem, we require an efficient crew assignment for the delivery vehicles. The crew can be a combination of drivers and delivery workers or include a multifunctional worker (driver and delivery worker) to minimize the total distribution time. We consider service and travel time dependent on the moment of the day and the location of each vehicle, due to the traffic flow of people in the building and congestion on the streets. A mixed integer linear programming model is proposed to solve the problem, through exact methods, with the objective of minimizing total time and total transportation costs, resulting in a set of efficient routes supporting decision-making and a crew vehicle assignment for each vehicle providing better customer service.

4 - A route relaxation based on the spatial aggregation of nodes for the generalized vehicle routing problem
Claudio Contardo, *Matthieu Gruson*, *Francois Lamothe*, *Rafael Martinelli*

We consider the generalized vehicle routing problem (GVRP), an extension of the classical capacitated vehicle routing problem (CVRP), where customer nodes are clustered and exactly one node in each cluster must be visited by one vehicle, at minimum total cost, while respecting the vehicle capacities. We consider a route relaxation for the GVRP aggregating nodes belonging to the same cluster, using a spatial criterion in a dynamic way. The relaxation, when embedded within a column generation solver, triggers a decrease in the computational complexity associated with the pricing subproblem. The proposed route relaxation copes well with several other state-of-the-art techniques for the GVRP, such as cutting planes and branching. As a result, problems with dense clusters can now be solved to proven optimality much faster when compared to a classical pricing mechanism.

Distribution and Telecommunications Network Design

Cluster: Location, Network Design, and Routing
Invited session
Chair: *Alejandro Cataldo*

1 - Incorporating Edge Upgrades in the Constrained Bottleneck Spanning Tree Problem: An Effective Edge Elimination Algorithm
Bryan Coulier, *Hatice Çalık*, *Greet Vanden Berghe*

Upgrading the connections of an existing network is common in the context of telecommunication and electric grid networks. Constructing a new network from scratch is typically not a viable option due to resource constraints, especially for low-voltage grids. Moreover, if the underlying network structure necessitates a tree configuration, this results in a novel variant of the Constrained Bottleneck Spanning Tree Problem (CBST), referred to as the Constrained Bottleneck Spanning Tree Problem with upgrades (CBSTU). This novel variant facilitates edge upgrades by investing a certain cost for these upgrades.

To address this problem, we undertook an exhaustive review of relevant literature to identify potential solution methods and identified two polynomial-time algorithms capable of effectively addressing the CBSTU; they can tackle this problem after transforming the network into a CBST instance, accomplished in linear time. Furthermore, we conducted a computational study to assess the strengths and weaknesses of these algorithms. To address the weaknesses of the existing algorithms, we have developed a novel polynomial-time Edge Elimination (EE) algorithm, building on the strengths of both existing algorithms, by incorporating progressive network reduction and binary search techniques. Specifically, the EE algorithm identifies a subset of edges to remove during each iteration, simplifying the network and reducing the overall complexity of the problem; it utilizes a binary search technique to efficiently reach an optimal solution. Our new algorithm outperforms both previous algorithms, in terms of computation speed, and lays the foundation for further research into the CBSTU.

2 - Model for planning delivery structures and define supplying policies
Maria Laura Cunico, *Julio Rolando Flores*, *Aldo Vecchietti*

As a supplier, increased profitability margins and enhanced competitiveness are typical objectives of business management. However, to reach these goals often requires careful planning of the commercialization structure. Inspired by this situation, this paper addresses the design of a merchandise supply network and the delivery logistics jointly. In the commercialization configuration, it is assumed that some locations could operate as warehouses (WH) or as a cross-docking (XD). Given this, different possibilities can be evaluated through a multiperiod model, with the capacity to make discrete decisions to install, close, expand or replace WH by XD terminals. Furthermore, demand uncertainty of articles belonging to different categories is considered that also affect the volumes of merchandise to be transported. Also, the model analyzes and provides delivery routes to supply the commercial network composed of many retail outlets whose replenishment volume is uncertain. The objective function is the minimization of operating costs, made up of the following factors: the cost of merchandise transportation, the operation of the WH in activity (labor, operation and stock) and the start-up of locations that could eventually begin to operate as WH or as XD. A case study is implemented with a time horizon of ten years. It is aimed to show the capabilities of the model as a support tool for decision-making on distribution and planning policies. In this case, three WH are initially assumed to be in operation and more than one hundred points of sale, located along the Argentine territory. A normal distribution is considered for the projections of the volumetric stores' demands. In addition, trucks of different sizes are used to deliver the merchandises, and this cost is calculated based on the size of the vehicle and the traveled distances. Several delivery routes are defined from the WH to the stores, being able to make intermediate deliveries. In this way, the model selects a route according to the amount to be delivered, the size of the truck, and the stores located along the route. Within the set of decisions provided, the most relevant ones correspond to investment decisions (cost and installation time, expansion or closure of WHs and XDs) and operation decisions (routes, number of trips, flow of goods and their costs from WHs and XDs to stores).

Facility Location - Heuristic and Exact Methods

Cluster: Location, Network Design, and Routing
Invited session
Chair: *Masoud Amel Monirian*

1 - Detection of critical elements in location problems
Peter Czimmermann

Identification of critical elements (edges or vertices) in transport networks is a long-time studied topic. Our approach differs from previously published results since we provide a method for the detection of elements critical for designed public service systems (for example, emergency healthcare systems), but need not be critical for transport networks in general. The design of the public service system can be obtained as a solution of an appropriate location problem (for example, weighted p-median problem, weighted p-center problem and uncapacitated facility location problem). Concerning the detection of critical edges for a weighted p-median and a weighted p-center problem, we present suggested methods using real data from self-governing regions of Slovakia. We also introduce methods for the identification of vertices critical for a given public service system.

2 - Revisiting the outer-approximation technique for the facility location problem with a limited choice rule.
Thalles Mota, *Ricardo Camargo*, *Gilberto Miranda*, *Fatima Lima*

We revisit the outer-approximation approach devised by Lin and Tian (2021) for the facility location problem with a limited choice rule, consisting of locating a set of facilities to serve a set of clients, while maximizing the profit attained from the observed revenues and the involved fixed costs. It is assumed clients patronize a subset of the installed facilities to split their buying power, following Luce's choice axiom. This location problem can be seen as a generalized framework for many competitive facility location problems, with clients following either a proportional or a partially binary choice rule. Lin and Tian proposed a branch-and-cut algorithm based on the generalized Benders decomposition method (BCGBD) to solve the problem, outperforming an outer-approximation approach and a state-of-the-art exact solver tackling a conic formulation for the problem, both in terms of the computational run time and the number of instances solved to optimality. Lin and Tian solved instances with up to 300 candidate facility points and 3,000 clients. Here we enhance their outer-approximation approach by solving the outer-approximation master problem (OAMP) with a Benders decomposition algorithm. Given the decomposition structure of the problem, we can separate one Benders feasibility cut per client per turn. Instead of adding them all at once to the OAMP, we bundle these cuts following a clusterization of the clients in small groups; this prevents overloading the OAMP at each branch-and-bound node, while retaining some of the benefits of adding multiple cuts per branch-and-bound node. To further speed up the solution process, we separate the Benders feasibility cuts by inspection. The proposed strategy turns out to be very competitive when compared with their BCGBD, being, therefore, a viable alternative to tackle the problem. Lin, Yun Hui & Tian, Qingyun. (2020). Branch-and-cut Approach based on Generalized Benders Decomposition for Facility Location with Limited Choice Rule. European Journal of Operational Research. 293. 10.1016/j.ejor.2020.12.017.

3 - A Conic Integer Programming Approach for a Class of Competitive Facility and Hub Location Problems
Masoud Amel Monirian, *Onur Kuzgunkaya*, *Navneet Vidyarthi*

We present a novel approach for solving competitive facility and hub location problems, using Mixed-integer Second-Order Cone Programming (MISOCP). In competitive facility location problems, the decision is to choose the location of facilities to maximize the market share of a firm against existing competitors. The market share is maximized under the assumption customers pick a facility among competing firms based on the relative utility provided, depending on attributes (e.g. travel time or price). Applications of competitive facility location problems include bank offices, warehouses, retail malls, and park-and-ride car parks; competitive hub location problems appear in transportation, such as airlines and car sharing.

We provide an alternative conic reformulation for the two classes of competitive location problems in facility and hub location problems. The proposed conic reformulation is further strengthened with McCormick, polymatroid, and sub-modular inequalities to improve computational efficiency. To assess the effectiveness of our approach, we compare the computational performance of the proposed MISOCP reformulation with the following solution methods from the literature: outer approximation, Lagrangean relaxation, Lagrangean cutting plane algorithm, and existing MISOCP reformulations. Compared with the best methods reported in the literature, on average, the proposed conic

reformulation performs 6 times faster in the competitive facility location problem and 2.5 times faster in the competitive hub location problem. Our second-order conic reformulation approach is applicable to a wide range of competitive location problems, where the gravity model is implemented.

4 - A competitive facility location problem for street markets with urban planning criteria
Gonzalo Enrique Mejia Delgadillo, *Daniela Granados*, *Valentina Cardenas*, *María Alejandra Castañeda Sánchez*

In traditional facility location models, a set of predefined locations, supposedly meeting several constraints (availability of public utilities, street and parking infrastructure) and urban regulations, is one of the inputs of the model. These models usually aim to maximize coverage or to minimize costs, when, in practice, there are many criteria to be considered. In this paper, we formulate a competitive facility location model to locate street markets in the city of Bogotá, Colombia, incorporating qualitative criteria. The results will show how this strategy can improve the current practice.

Facility Location - Applications

Cluster: Location, Network Design, and Routing
Invited session
Chair: *M. Grazia Speranza*

1 - Vehicle allocation to demand areas using prescriptive analytics
Alexandra Holmes, *Luis Aburto*, *Felipe Lago*

Our problem is based on a company distributing liquified gas to customers, who place their orders online dynamically throughout the day; the dynamic routing decision-making tends to be myopic, because assigning vehicles to customers does not consider future demand, causes long vehicle routes and problems with the SLA with customers (84% of orders in less than 30 minutes). The main topic addressed in this work is geographical demand estimation. We used an additive regression model with nonlinear yearly, weekly, and daily seasonality to obtain an hourly forecast, providing an accurate representation of the demand faced at various times. Subsequently, we analyzed the geographical distribution of the data using Gaussian Kernel Density Estimation (KDE) in two dimensions to identify areas with a higher probability of demand throughout the day. Knowing future demand and where it is likely to fall, we can inform vehicles where to locate and to move to better satisfy demand and SLA requirements. The model proposed combines the prediction demand estimated with a myopic routing policy to dynamically assign vehicles to customer orders. We tested in a small district sample, obtaining a 34.7% reduction in travel distance and a 97.56% success rate in SLA.

2 - The Angular Covering Problem: Case of Valparaíso, Chile.
Fredy Barriga, *Armin Lüer-Villagra*, *Gabriel Gutiérrez-Jarpa*

The Set Covering Problem (SCP) is one of the most known location problems, consisting of finding the minimum-cost set of facilities from a finite discrete candidate set, covering all demand points of a geographic area, including the service quality through the distance between facilities and demand points with applications, such as bus stops, the location of recycling facilities and the establishment of healthcare facilities. New applications have appeared, however, with the technological development and aspects of the problem; for example, security cameras (called "servers") for surveillance consider a particular covering structure, called "angular covering", where it is necessary to cover an area at specific angles. This structure guarantees covering angular zones (with demand points) from at least one camera, avoiding covering unnecessary spaces where there are no demand points or, when necessary, a requirement of level service to some geographic areas. The cameras are installed in facilities supporting a set of them; it is essential to decide on the located facilities and select the set of cameras for each one guaranteeing all point demands cover at least one camera. We called this type of structure the Angular Covering Problem. We relax one of the SCP assumptions, considering the facilities establish covering 360' around, to propose an angular covering design extending the classical SCP. In this extension, with the decision on the location of facilities and the selected servers, we also consider the positioning of servers. We propose a mathematical formulation and a model for the angular covering problem, where the coverage area is represented by discrete demand points, considering multiple servers and angles to cover all demand points and minimizing the total cost of the located facility and selected servers. The structure of the model allows specialized preprocessing procedures, reducing instance size before being solved, improving their solution performance for a set of proposed medium/large instances. Finally, we present and solve a real case applied in Valparaíso, Chile.

3 - Optimal location of charging stations for electric vehicles
M. Grazia Speranza, *Carlo Filippi*, *Gianfranco Guastaroba*, *Lorenzo Peirano*

A massive use of electric vehicles is nowadays considered to be a key element of a sustainable transportation policy, and the availability of charging stations is a crucial issue for their extensive use. Charging stations in an urban area have to be deployed so they can satisfy a demand dramatically varying in space and time. In this paper, we present an optimization model for the location of charging stations, taking into account the specific features of the problem and demand depending on space and time. To measure the importance of incorporating time dependence in an optimization model, we also present a simpler model, extending a classical location model and not including the temporal dimension. A worst-case analysis and extensive computational experiments show ignoring the temporal dimension of the problem may lead to a substantial amount of unsatisfied demand.

4 - Optimizing security post placement in a municipal park through deterministic mathematical programming and coverage approach.
Fabrizio Recalde, *Jorge Recalde*, *María Margarita López*

This work addresses the problem of security and surveillance management in public places, specifically in the Botanical and Zoological Garden of Asunción (JBZA), managed by the Municipality of Asunción in Paraguay. We propose a mathematical location model to support the surveillance and security system of JBZA park, specifically the maximum coverage location problem (MCLP); this model locates service centers optimally to maximize specific values important for users. In this case, it is desired to cover the recreational and sports areas of the park by locating mobile security posts within designated zones. Criteria have been established to zone the area and determine the need for coverage in each zone. We calculate the potential demand of each zone and define a mathematical model to approximate the covered demand. The zoning of the Botanical and Zoological Garden of Asunción was based on three criteria: visible divisions, specific sites designated by the administration, and characteristics of the flora; this process resulted in the identification of 28 zones covering the recreational and sports areas of the park. The proposed methodology maximizes the demand covered by the security posts, taking into account the perceived potential risk for security. Additionally, we approximate the covered demand, considering the limited availability of information for specific model parameters. The methodology is valid as a first approach to the system, allowing for the optimization of resource use, and can be adapted to support the management of the surveillance and security system in other public places. The proposed solution has economic and social benefits, achieving cost reduction and increasing perceived security by citizens. The proposed solution manages to cover 100% of the 28 zones in the study area, ensuring the safety and protection of around 493 people. Furthermore, the specific coverage requirements for each zone are met. We recommend implementing the proposed coverage plan in the Botanical and Zoological Garden of Asunción as an effective tool for improving the security and surveillance system in recreational and sports areas, providing a safe and protected environment for visitors and users of the park.

Routing - Applications

Cluster: Location, Network Design, and Routing
Invited session
Chair: *Aldo Vecchietti*

1 - Keys performance indicators for consistent vehicle routing problem
Guillermo Bianchi, *Hernán Lespay*

We propose a mixed-integer linear program (MILP) for the consistent vehicle routing problem with time windows (ConVRPTW), solved with a heuristic method. This study is motivated by the necessity of increasing the service level of companies in the logistics area; it considers a schedule of routes in multiple periods, where the set of clients and their demand fluctuates in the planning horizon. The objective is to minimize the length of routes fulfilling the requirements of service consistency. The solution is evaluated through Keys Performance Indicators(KPIs) to analyze the balance between routes, design strategies to perform routing plans, and improve future benchmarks in the literature.

2 - Multi-depot arc routing for spring sweeping operations
Amina Lamghari, *Omar Foutlane*, *Jean-Francois Audy*

Spring sweeping, the process of cleaning up abrasives (sand and gravel) from roadways where it was spread in the winter, is an important step in road maintenance in countries with severe winters. We introduce a multi-depot arc routing problem for spring sweeping operations, consisting of designing a set of routes covering all road segments to be cleaned, with the objective of minimizing costs under resource constraints and other precedence and safety requirements imposed by road authority regulations. A mixed integer formulation and a decomposition-based matheuristic solve this practical problem. Computational results on artificial and real data show the efficiency of the proposed solution approach.

3 - Hybrid Heuristic for Split Delivery Vehicle Routing Problem with Backhauls
Pitchaya Pongmanawut, *Chulin Likasiri*

This paper proposes a solution to the Vehicle Routing Problem with Backhauls (VRPB) incorporating the split delivery property, to allow multiple visits to customers for greater flexibility and cost savings. Our approach includes modeling the problem with Integer Linear Programming and implementing a hybrid heuristic method, combining the benefits of heuristics and metaheuristics. We start with a heuristic to solve for the initial feasible solution for VRPB, including split delivery (SVRPB), and, then, we improve the solution with metaheuristics to avoid being stuck in local optima and ensure an optimal solution. We test the efficiency of the proposed hybrid heuristic by comparing the obtained results against some benchmark instances.

Inventory and Logistics

Cluster: Logistics
Invited session
Chair: *Frank Chen*

1 - Estimation and Optimization for a Multi-product Inventory System with Stockout-based Substitution
Frank Chen, *Carl Philip Hedenstierna*, *Jian Yang*, *Yijie Zheng*

We deal with a retailer's multi-product inventory system where customers randomly seek acceptable substitutes if their initial requests are not satisfied. If the substitute is also unavailable, the sales request is lost. Besides the already complex multi-product inventory management problem involving substitutions, we face further challenges in the absence of knowledge regarding base demand distributions and substitution probabilities. In their stead, all we can rely on are historical sales data that are compromised by censoring and substitution effects. We develop a method that carefully screens the data and subjects the useful portion to a Kaplan-Meier estimation. Notably, a very effective estimation of the substitution probabilities is also developed. Using large deviation tools, we establish guaranteed convergence rates of our estimates on top of consistency. The precision in parameter estimates also translates into accuracy in replenishment decisions. For inventory management, we take advantage of a submodularity property to obtain an exact algorithm for the two-product case and a good heuristic for the general multi-product problem. Computational studies based on simulated and actual data confirm the merits of our approach.

2 - Product Line Pricing under Utility-based Choice Model with Ambiguity Aversion
Qi Cheng, *Jingwen Lin*, *Yimin Yu*

We study the robust multiproduct pricing problem under a general utility-based discrete choice model. In the robust version, the seller is ambiguity-averse and only knows the true customer utility distribution is in the neighborhood of a given distribution. The customer preference is given a multiplier preference with a relative entropy penalty. An ambiguity-averse seller overestimates the purchasing probability of products with small profit margins and underestimates the purchasing probability of products with more significant profit margins compared with an ambiguity-neutral seller, leading to lower prices. Furthermore, we consider a multinomial logit (MNL) model as a reference distribution with product-differentiated price sensitivities. We provide an explicit solution for optimal prices, and our results recover the classical constant markup property. We also consider a generalized extreme value (GEV) model as a reference distribution with constant price sensitivities. Similarly, the adjusted markup is constant over all products. Thus, our results show that the MNL and GEV can be still robust to model uncertainty.

3 - Optimum Pricing Policy for Synthetic Telemedicine System Considering Heterogeneous Patients
Yunzhi Cao, *Houmin Yan*, *Xiaoyan Zhu*, *Yedong Wang*

Chronic patients need periodic treatments and continuous health diagnoses, suffering difficulties in life and work arrangements and high travel burden for in-person visits. The situation became even more severe after the outbreak of the COVID-19 pandemic. Consider a synthetic telemedicine system that provides telemedicine in addition to in-person treatments. For chronic conditions, some treatments, such as the first visit and acceptance of patients, must be performed in-person. Others can be performed by either in-person visits or telemedicine, e.g., regular follow-up visits. It induces the telemedicine feasibility coefficient, which is the portion of telemedicine treatments among all the treatments. This study explores analytical optimal pricing policies from multiple perspectives, addressing the geographical heterogeneity and geographical distribution of patients. First, from the perspective of hospital profit, a deterministic price optimization model is established, given the expected telemedicine feasibility coefficient. Then, considering government subsidies on telemedicine, three-stage Stackelberg sequential game models between the patients, hospital, and government are established to address three different optimization criteria. Furthermore, consider the circumstance that the telemedicine feasibility coefficient is difficult to estimate and demonstrates great uncertainty due to the heterogeneity of patients in sickness severity and perception of telemedicine. A distributionally robust optimization model is formulated to achieve a robust pricing policy, assuming that the telemedicine feasibility coefficient is random. Theoretical analysis and numerical experiments are conducted to show the impacts of the introduction of telemedicine, subsidy policy, geographical distribution of patients, and key factors, such as the telemedicine feasibility coefficient and reimbursement rate. This study provides managerial insights and suggestions for the hospital and the government with respect to the implementation and promotion of telemedicine for chronic conditions.

4 - The Rise of Conscious Consumers: The Cash Flow Implications of Corporate Workplace Equality
Chang Liu, *Ling Cen*, *Yanru Han*, *Jing Wu*

We construct a corporate workplace equality measure based on textual analysis of equal employment opportunity statements in online job postings of US public companies. We verify this measure by demonstrating its predictive power for future employment discrimination lawsuits and identifying the cost that deters low-equality firms from mimicking high-equality peers. Based on this measure, we show that US households spend more on products produced by firms with higher corporate workplace equality, and this pattern is stronger among consumers of racial or gender minorities. We establish causality by taking advantage of quasi-exogenous social events, including the #MeToo movement in 2017, the passage of the California Gender Board Diversity Law in 2018, and the Black Lives Matter movement in 2020. Overall, our study provides direct cash flow implications of corporate workplace equality through the purchase decisions of conscious consumers and establishes a micro-foundation of consumer behaviors for the asset pricing of ESG/CSR factors.

Warehouse Logistics

Cluster: Logistics
Invited session
Chair: *Susan Sanchez*
Chair: *Xuefei Liu*

1 - An Order-picking problem for warehouse operations with human-drone coordination
Juan Pablo Morande, *Daniel Silva*, *Alice Smith*

The applications of drones in the industry are varied and continuously evolving; while mainly used for surveillance, inventory control, or last-mile logistics, the focus of this work is the implementation of drones in an order-picking context inside warehouses. Specifically, we explore using drones to reduce the time a set of orders is collected and returned to a specific point in the warehouse. To do this, the coordination of a human worker (who can also pick orders) and drones was modeled in a mixed-integer linear program. By deciding on the subset of orders to be picked by the drone and the worker, the sequence these orders are picked, and where the worker will meet with the drone, the model minimizes the time all the orders are visited in the context of warehouse operations. Finally, the results of various instances were evaluated to assess the effectiveness of this application.

2 - A column generation approach to solve the Joint Order Batching and Picker Routing Problem including picker congestion
Pablo Torrealba, *Dominique Feillet*, *Maxime Ogier*, *Frédéric Semet*

Order picking is a crucial process in warehouse operations; in a human-operated warehouse, pickers prepare different customer orders. From a managerial perspective, two major decisions need to be made: (i) grouping orders to be collected together by a picker, and (ii) for each picker, determining the route to retrieve the needed items. The Joint Order Batching and Picker Routing Problem (JOBPRP) integrates both decisions into a single problem, usually minimizing either total distance or time. In the literature, the JOBPRP usually assumes a situation without any congestion caused by the pickers, however - unrealistic when there are many pickers in a warehouse.

In practice, congestion causes inefficiency, increases costs, reduces performance, and leads to accidents; it occurs when multiple pickers use the same space simultaneously, resulting in a delay in normal picker operations. To estimate congestion levels, we divide the planning horizon of the picking activity into different time intervals and timing variables are introduced. If two or more pickers are in the same sub-aisle during the same time interval, a delay in travel time is imposed. The delay is determined by an increasing function, depending on the number of pickers. Because picking activities are performed by humans, practical considerations must be taken into account when defining a feasible picking route, e.g. a picker cannot unnecessarily wait and cannot follow complicated or long paths between two consecutive picking positions.

To solve the JOBPRP, including the effect of picker congestion, an extended mathematical formulation is presented, with the main objective of minimizing the total time, including delay. A heuristic solving approach is proposed based on solving of the linear relaxation of the formulation by an exact column generation procedure. In each iteration, a negative reduced column is produced using a dedicated labelling algorithm, exploring routes associated to congestion level for each sub-aisle and time interval. When the linear relaxation is solved, variables are defined as binaries to provide a feasible solution for the problem. To evaluate the modelling and the performance of the solutions provided by the proposed approach, a discrete event simulation tool is developed. Several experiments are performed to compare the results with optimal JOBPRP solutions not considering congestion.

3 - A simulation-based two-phase surrogate method for the scattered storage location assignment
Xuefei Liu, *Ek Peng Chew*, *Kok Choon Tan*, *Haobin Li*

The scattered storage strategy has already been applied by Business-to-Consumer online retailers and has also been employed in third-party logistics warehouses. With this storage strategy, items belonging to the same stock-keeping unit (SKU) will be separated into individual units and assigned to different locations. At the same time, different SKUs with high correlations can be placed in adjacent storage positions.

To reduce the non-productive travel time and increase the picking efficiency, this research introduces a two-phase surrogate method to minimize the picking travel time, decided by the picking distance; and the picking distance mainly depends on the storage location assignment, picklist generation, and routing method.

For the scattered storage assignment problem in the mixed-shelves warehouse in this research, we do not know any information about these future orders; all of them are random factors. Also, the number of orders can be large. Incorporating these orders inside the math model might not be trivial. It is complicated to establish a direct optimization model to describe this problem. On the other hand, if only the simulation method is adopted to find an assignment solution with the least working time, plenty of feasible solutions need to be tested.

To solve these issues, this research proposes a two-phase method. In Phase 1, we use a multi-objective mixed integer programming model as the surrogate measure to describe and to optimize the scattered storage assignment problem. It considers the weighted average distance based on the demands of SKUs and the overall correlation between SKUs within one order. Using these two pieces of information, we can build a surrogate measure to determine the storage location. In this process, an enhanced binary grey wolf optimizer is utilized to solve experiments with large datasets.

In Phase 2, solutions obtained from the optimization model will be used as the input data of the simulation model. Then, the object-oriented discrete-event simulation framework is introduced and applied as the fundamental engine for implementing this simulation model. Therefore, the total travel time of each solution can be calculated in the actual picking process, and then the storage assignment with the least travel time can also be analyzed and found.

Logistics in Agriculture, Forestry, E-Waste Management and Delivery by Drones

Cluster: Logistics
Invited session
Chair: *Monique Guignard-Spielberg*
Chair: *Lorena Pradenas*

1 - Integrating the zoning and the harvest scheduling problems in the logistic of fresh fruit supply chains under uncertainty
Victor M. Albornoz, *Carolina Arias-Padilla*, *Iñigo Sagaseta de Ilurdoz*

Agricultural markets are currently facing major challenges as the world's population continues to increase; these challenges impose greater efficiency on fresh food supply chains to avoid losses and take into account its short life cycle. In the case of fresh fruits, to maintain their quality and avoid obsolescence, an adequate harvest scheduling, a production process contributing to controlling the deterioration and timely shipment to the different markets, is required.

This paper presents a two stage stochastic optimization model for the logistic of a fresh food supply chain in an integrated approach, considering different agricultural management problems previously studied as part of a supply chain, but in a hierarchical approach. On the one hand, the model includes the management zones problem to divide the field into homogeneous management zones for harvesting. On the other hand, the problem of harvest scheduling is to ensure the harvest is carried out in the corresponding time windows according to each zone; to determine the amount of labor required during the harvest horizon; and, finally, to set the production and distribution process.

The proposed stochastic optimization model was solved for different instances of a real case-study, providing a better solution than the underlying deterministic model, considering the uncertainty in the yields and the weather conditions present in the harvest planning horizon. The integrated model is also contrasted with the hierarchical approach, normally used in the literature for this problem, demonstrating the advantages of the proposed model over the hierarchical one.

2 - Optimization of Forest Planning Using High Detail GIS Data
Rafael Epstein, *Jorge Alarcon*, *Carlos Villa*, *Rodrigo Sobarzo*, *Claudio Parada*, *Alvaro Morales*, *Hugo Ubilla*

We present an optimization framework to incorporate detailed geographical elements to optimize tactical and operation forest planning. We show how to optimize the tactical planning problem for a large company, by using a linear formulation as a master problem and a combinatorial system to optimize the harvesting of each unit using high quality GIS data obtained by Lidar technology. We use a decomposition approach, where the timber shadow prices indicate the premium of each year and season to schedule the harvesting of a land or unit. We show how to use this approach in forest short-term planning to optimize mechanized scheduling. We optimize detailed decisions, such as where to set the lines when using aerial equipment or the route for terrain equipment to minimize compactness of the soil.

3 - Algorithms for the flexible drones traveling salesman problem
Benjamin Brandt, *Lorena Pradenas*, *Carlos Contreras-Bolton*

Thanks to the capabilities and potential of drones, distribution companies have been willing to incorporate these aerial vehicles into their operations, mainly to solve problems associated with last-mile delivery, providing an opportunity to reduce costs, time, or travel distances. Our work aims to enhance the effectiveness of last-mile delivery by utilizing a combination of a truck with drones. Specifically, we address the flexible traveling salesman problem with a single truck and multiple drones (FDTSP), involving the truck making deliveries and acting as a launching and retrieval platform for drones. Thus, the ultimate goal is to minimize the truck's arrival time and its drones at the depot after serving all customers - that is, the makespan. We propose a compact mixed-integer linear programming (MILP) model capable of solving FDTSP instances optimally, although limited to smaller sizes. To address larger instances of the problem, we propose three heuristic algorithms - a metaheuristic, a matheuristic, and a hybrid algorithm. These approaches are effective in achieving competitive outcomes when compared to the current state-of-the-art approaches.

4 - Optimizing vehicle routes for e-waste collection
Nicolás Netz, *Raul Raggio*, *Lucas Parada*, *Lorena Pradenas*

As more electronic devices are developed, more electronic waste is thrown away as products fail or become obsolete, creating a problem for any city in the World, where this waste may affect the environment, health and well-being of the population. Economically attractive strategies must be generated for the collection and recovery of these wastes. We model this problem as a variant of the vehicle routing problem. The objective is to minimize total routing cost and expected cost of the emissions generated by the collection vehicles, removing the waste from a set of nodes, called clean points. In addition, the visits to each node are restricted by given time windows. To solve this problem, CPLEX is used for the mixed-integer linear programming (MILP) model. Furthermore, a metaheuristic approach is developed. Finally, the effectiveness of both approaches is evaluated through a comparison of their results.

Scheduling in Natural Resources

Cluster: Logistics
Invited session
Chair: *Alexandra Newman*

1 - Stochastic Open Pit Mine Planning: A computational study
Marcos Goycoolea

The strategic open pit mine planning problem, a highly standardized scheduling optimization problem, solved regularly by mining engineers throughout the world, consists of scheduling the extraction time of "blocks" making up the orebody and deciding the best corresponding "downstream processing" (i.e., if the extracted block should be processed for metals or sent to a dump or stockpile). This problem, receiving much attention in the academic literature, has been studied since the early 1960's and has several sophisticated software packages offering both heuristic and exact optimization methods for tackling it. Unfortunately, all of these software systems have an important weakness - they fail to consider the inherent uncertainty of the problem. In this talk, we present a stochastic programming methodology for this problem and computational results. Not only is it possible to tackle industrial-sized problems, but, also, stochastic solutions can significantly change when compared to their deterministic counterparts; we explain these differences intuitively and analyze how the stochastic solution significantly mitigates risk and provides improved value, even when analyzed out of sample.

2 - Optimizing Steel Coil Production Schedules under Continuous Casting and Hot Rolling
Alexandra Newman

In continuous steel casting operations, heats of molten steel are alloyed and refined in ladles, continuously cast and cut into slabs, and hot-rolled into coils. We present a mixed-integer program that produces a daily casting schedule and that is solved using state-of-the-art software for a 100%- direct-charge steel mill with two casters that concurrently produce slabs are rolled into coils at a single hot rolling mill. This model minimizes penalties incurred by violating plant best practices while strictly adhering to safety and logical constraints to manage risk associated with manufacturing incidents. An efficient formulation, combined with variable reduction and cutting planes, expedites solutions for small instances containing hundreds of variables and thousands of constraints by factors of at least two or three (and sometimes even 100); instances an order of magnitude larger along both problem dimensions suggest solutions that reduce costs incurred using plant best practices by as much as 40%.

3 - Scrap Metal Collection Recycling Optimization
Julio Montecinos, *Amin Chaabane*, *Valentin Cherbonnier*, *Marc Paquet*

This research proposes a new optimization model for a metal recycling company's reverse logistics routing problem. The model combines the classical vehicle routing problem with the pick-up and delivery problem in reverse logistics, heterogeneous fleet management, multi-products, multi-trips, multi-depots, time window constraints and external carriers. The model deals with customer prioritization delayed requests in a two-day horizon and the direct exchange between suppliers and end customers. The resolution and validation of small sizes instances were performed with company's real data. The validation process shows consistency results and provides useful managerial insights.

4 - Advanced MILP-based strategies for logistics decisions in industrial gases supply chains
Mendez Carlos, *Sergio Gabriel Bonino*, *Luis Zeballos*, *Ignacio Grossmann*, *Akash Moolya*, *José M. Laínez-Aguirre*, *Jose M. Pinto*

This work introduces an efficient sequential MILP-based procedure to deal with the distribution scheduling of industrial size problems of gases. This procedure is based on heuristics rules to generate efficient routes for product distribution and an MILP formulation to represent the inventory routing problem (IRP). The addressed problem considers a predetermined time horizon, available plants with their min/max production rates, a set of customers and their demands, a fleet of trucks available in each plant, storage capacities in plants and customers, and duration of the routes considered for the correct inclusion of the lead time effect. As part of the problem, trucks can make multiple visits per route; routes can have a duration of one, two or three days; and every vehicle can make multiple routes per day. To solve the IRP, the developed technique consists of two main stages: one, for finding feasible solutions, and, the other, for improving solutions; in each step, the MILP model is solved. In the first step, a reduced set of available routes is considered, while seeking to minimize production and purchase costs. In step 2, the model starts from the initial point found previously, the set of routes considered is the same, but now the distribution costs are added to the objective function. The third step uses the best solution of the second step as its initial point. The objective function is the same used in step 2, but new routes are added to the existing set, with the idea of giving more flexibility to the model. Finally, only the routes chosen in step 3 are considered in the last step. The model starts from the last feasible solution found, and the objective function seeks to maximize deliveries to use the trucks' capacity as much as possible. The procedure was tested with an industrial case considering 5 production plants, an available fleet of 13 trucks, and 2 possible products, demanded by 114 customers. In this case study, approximately 400 visits per month need to be scheduled to meet the monthly customer demands. Different scenarios were tested, and the time limit for each step was changed; good, feasible solutions were obtained in short processing times. Therefore, the presented procedure proved to be robust and efficient for solving the IRP at low CPU times.

Emerging Issues in E-Retailing and Delivery

Cluster: Logistics
Invited session
Chair: *Candace Yano*

1 - Optimising Replenishment Order Quantities in E-Grocery Retailing
David Winkelmann

E-grocery retailing entails ordering fresh products online to be delivered at a future time slot chosen by the customer. This emerging field of business, growing dynamically during the Covid-19 pandemic, provides retailers with very large and comprehensive new data sets, yet creates several challenges for the inventory management process; for example, due to the personal cost caused by attended home delivery, the risk of cancelling the whole virtual basket during the online ordering process, in case of a single item's stock-out, is high. Therefore, retailers aim at very high service level targets, to provide satisfactory customer service and to ensure long-term business growth. In a dynamic stochastic inventory environment, retailers need to properly take into account the uncertainty, caused by stochastic demand, supply, and shelf lives, when determining replenishment order quantities. We propose to integrate all sources of uncertainty into a joint inventory management framework, explicitly modelling them by suitable probability distributions learned from historic data. As the resulting optimisation problem is analytically intractable in general, we rely on a stochastic look-ahead policy, incorporating Monte Carlo techniques to fully propagate the associated uncertainties, to derive replenishment order quantities. Our findings illustrate the benefit of using appropriate probability distributions for a cost-effective inventory management process.

2 - Customer Satisfaction and Differentiated Pricing in E-Retail Delivery
Alan Erera, *Dipayan Banerjee*, *Alejandro Toriello*

We study a system where a common delivery fleet provides service to both same-day delivery (SDD) and next-day delivery (NDD) orders, placed by e-retail customers who are sensitive to delivery prices. We develop a model of the system and optimize with respect to two separate objectives. First, fulfilling e-retail orders ahead of promised delivery days increases a firm's long-run market share. Motivated by this phenomenon, we optimize for customer satisfaction by maximizing the quantity of NDD orders fulfilled one day early, given fixed prices. Next, we optimize for total profit by setting prices in a two-level scheme with discounts for early-ordering customers. Our analysis relies on continuous approximation techniques to capture the interplay between NDD and SDD orders and, particularly, the effect one day's operations have on the next, a novel modeling component not present in SDD-only models; a key technical result is establishing the model's convergence to a steady state using dynamical systems theory. We derive structural insights and efficient algorithms for both objectives. In particular, under certain conditions, total profit is a piecewise-convex function with polynomially-many breakpoints, efficiently enumerated. We validate our model's results via simulation on a case study derived from real-world data.

3 - Optimizing Fees Charged to Restaurants and Customers and Payments to Drivers by a Food Delivery Platform
Candace Yano, *Gabriel Deza*

Restaurant food delivery platforms, grown dramatically in the past several years, need to decide a policy for service charges to customers and restaurants and how much to pay drivers for delivery. Increasing payments to drivers increases their supply and, thereby, reduces waiting times for customers whose demands are affected by both waiting times and the platform's service charge. A restaurant's willingness to participate on the platform depends on the platform's service charge and the demand generated by the platform. We take a first step in analyzing these complicated multi-party interactions, focusing on the platform's problem of setting service charges and driver pay, when restaurants and customers also seek to maximize their profit or utility, and the platform must compete for drivers.

Improving Agility in Supply Chains and Travel Planning

Cluster: Logistics
Invited session
Chair: *Candace Yano*

1 - A New Paradigm to Deploy AI/ML to Build Supply Chain Agility and Resilience

Morris A. Cohen, *Naren Agrawal*, *Vinayak Deshpande*

The strategic importance of resilience and agility in supply chains is well understood by senior executives today. Unfortunately, many firms have discovered their current methods to carry out supply chain planning, impacting a wide range of decisions, have failed to deliver the required performance for resilience and agility. Much has been written about the promise of recent technological developments, such as artificial intelligence and machine learning, big data, and cloud computing, for the design of resilience strategies. The results have been disappointing, however. In this talk, we explain why the application of machine learning has fallen short for the delivery of supply chain resilience and discuss Optimal Machine Learning, a new paradigm we have developed, realizing the full potential of AI and ML for enhancing its impact on supply chain planning. This prescription is based on exploiting deep domain knowledge about the way a company's supply chain operates over time and space, and how decisions, data and performance impact each other; it is especially relevant to support the development of strategies enhancing agility and resilience by optimizing the use of extended data inputs to support resource allocation decisions. We illustrate the power of this new approach for supply chain planning by reporting on two successful implementations in complex global supply chain environments. The talk concludes with a framework to guide efforts to design effective strategies for supply chain resilience and agility.

2 - Scenario-Based Distributionally Robust Optimization for the Stochastic Inventory Routing Problem

Yong-Hong Kuo, *Runjie Li*, *Zheng Cui*, *Lianmin Zhang*, *Janny Leung*

We consider a class of the inventory routing problem in a discrete and finite time horizon, where the demands at retail stores are uncertain and vary across different scenarios. The supplier is required to determine the times to visit retailers, the replenishment quantities to each retailer, and the routing of a vehicle, to minimize the sum of stockout, holding, and transportation costs. We propose a scenario-based distributionally robust optimization framework to tackle this problem. We transform the distributionally robust optimization model into a mixed-integer problem, solved efficiently by our proposed algorithm. We adopt a warm-start procedure utilizing the solution to the nominal model in our methodological framework. Then, we apply a Tabu search algorithm, integrated with column generation, to solve a set-partitioning-like integer linear programming model, to identify a better route set. By doing so, a large-scale scenario-based distributionally robust optimization model can be solved. We conduct a case study of a fuel company and construct realistic instances to demonstrate the performance of our proposed method. The model taking into account various scenarios is more effective when random demands can be classified; the model with a linear decision rule outperforms a non-adaptive model; and the model with the route set identified by an improved algorithm can deliver a better solution than the original route set.

3 - Time dependent TSP and its application to travel planning

Fernando Ordonez, *Juan Cantillana*, *Juan Manuel Cuadra*, *Jose Miguel Gonzalez*

We consider the problem of finding the best tour, visiting a given set of nodes, where the cost of traversing an edge depends on when the edge is traversed and the edges traversed previously. We formulate the problem as finding a shortest path on a time expanded network with side constraints. This problem is motivated by a travel planning application, where travel fares can vary depending on the date a specific flight is taken and whether it is a round-trip or a one-way trip.

This application requires solutions within a few seconds and also motivates different problem variants, such as selecting a higher fare class if available, planning a trip within a budget, preferring certain airlines, and considering specific connecting constraints. In this talk, we discuss different modelling alternatives and the central ideas of the exact and heuristic solution methods developed, efficiently solving a rich set of problems within an acceptable time limit for the application.

Vehicle Routing in City Logistics and Urban Mobility

Cluster: Logistics
Invited session
Chair: *Pedro Munari*
Chair: *Bruno Bruck*

1 - Flight recovery in the oil and gas industry: optimization models for a real-world case

Thiago Vieira, *Pedro Munari*, *Reinaldo Morabito*

We study an aircraft recovery problem (ARP) based on the real-world case of a Brazilian oil and gas company using a heterogeneous fleet of helicopters for employees' transportation between mainland aerodromes and maritime units. Often, daily flight schedules cannot be carried out as previously planned, as a result of mechanical failures, crew reassignments, airport closure, variations on travel times, unavailable fuel supply, problems with air traffic control, or even because of inclement weather conditions. If the disruptions caused by these unexpected events are not addressed in a timely and appropriate manner, they will affect crew connections and passenger itineraries and may result in significant damage to the airline's profitability and image. Consequently, the company is concerned with recovering (or rescheduling) their flights from previous plans, as a way of mitigating the prejudice arising from past disruptions. The daily reschedule must take into account the original timetable and the departure aerodrome of each flight, the number of runways at the aerodromes and maritime units, the helicopters available in each aerodrome, postponement and shift regulations, flight departure priorities, and aerodrome and crew time windows. Hence, the problem needs, in determining joint daily flight reschedules for all aerodromes, to satisfy operational constraints and recover all pending flights (cancellations), while minimizing flight transfers among aerodromes, usage of aircraft and overall flight delays. For this ARP, we propose a detailed continuous-time mixed-integer programming model to appropriately represent all relevant characteristics of the operation, an extension from the traditional network-flow formulation of the heterogeneous fleet vehicle routing problem with time windows. Furthermore, we present a discrete-time simplification of the former model. The discretization of time horizon allowed this second model to have a much stronger linear relaxation than the first one, reflecting better primal solutions. The results of computational experiments with real-life data by using a general-purpose optimization software revealed the solver found optimal solutions for the continuous-time model only on small-sized instances, while for the discrete-time formulation on all instances, the solver produced effective recovery plans suitable for successful application in practice.

2 - Optimizing Aircraft Recovery in Offshore Operations of a Brazilian Oil and Gas Company: A Discrete-Time Formulation with Hierarchical Goal Programming

Tarley Mansur Fantazzini, *Thiago Vieira*, *Reinaldo Morabito*, *Pedro Munari*

We address the aircraft recovery problem faced by a Brazilian oil and gas company during its offshore operations; it relies on helicopters from an outsourced company to transport personnel from an airport to its offshore units. Disruptions, such as unplanned maintenance, mechanical failures, and adverse weather conditions, often result in flight delays or rescheduling, however, causing difficulties to the overall operation. To assist with decision-making in these scenarios, we propose a discrete-time optimization model with a lexicographic objective function prioritizing: (i) the reduction of flight transfers to the next day; (ii) the reduction of helicopters utilization; and (iii) the reduction of flight delays of the day. The proposed model considers several company-specific attributes, including different rescheduling priorities, time windows based on airport operating hours and helicopter restrictions (e.g. no flights after sunset), single landing and departure runways at airports, single landing points at platforms, and a heterogeneous fleet of helicopters. To address the lexicographic priorities in the

objective function, we develop four different approaches using hierarchical goal programming, aided by enhancements and valid inequalities. Computational experiments on both real-world and simulated instances demonstrate our approaches can provide optimal or near-optimal solutions for most instances, using a general-purpose mixed-integer programming solver within acceptable computation times.

3 - The robust static bike rebalancing problem: compact formulation and branch-and-cut algorithm
Bruno Bruck, *Pedro Munari*, *Walton Pereira Coutinho*

Often, bike-sharing systems become unbalanced during their operations, meaning stations with excess or lack of bikes can be found at certain moments. In these situations, system-wide rebalancing operations must be regularly performed to ensure everything works as designed. In practice, uncertainties regarding the demand of each station should be considered, even if rebalancing is performed when the system is closed. This paper proposes the Robust Bike-Sharing Rebalancing problem (RBRP), aiming at planning rebalancing operations under demand uncertainties by means of robust optimization. We present a compact mathematical formulation and a tailored branch-and-cut algorithm for the RBRP. Computational experiments on 65 benchmark instances from the literature show the effectiveness of the proposed approaches and the benefits of applying robustness to support decision-making.

4 - A Three-Stage Heuristic Approach for the Electric Vehicle Routing Problem with Time Windows and Station Capacity
Akane Seto, *Junko Hosoda*, *Kazuya Uyama*

Electric vehicles for the last-mile delivery have been introduced to reduce greenhouse gas emissions, but cruising distance of electric vehicles is short, since battery capacity is limited. Therefore, an electric vehicle has to visit charging stations when the distance of a delivery route is longer than the travelable distance with the remaining battery. The Electric Vehicle Routing Problem with Time Windows (EVRPTW) is an extension of the VRP with time windows (VRPTW) for electric vehicles. The EVRPTW aims to find delivery routes, including pickup and delivery destination locations and charging stations under battery capacity constraints, to minimize delivery costs. In this study, we propose a three-stage heuristic approach to solve the EVRPTW in a short computation time. In addition, the proposed method handles practical constraints, such as the business hours of charging stations and charging time limits. In the first stage of the proposed method, a VRP without battery constraints is solved using a hybrid approach of heuristic and Mixed Integer Programming (MIP). Then, the charging stations for each vehicle are determined using a clustering-based heuristic in the second stage. Finally, the EVRPTW is solved using a hybrid approach of heuristic and MIP, the same approach used in the first stage. The results of numerical experiments show the proposed algorithm will be applicable to practical problems in terms of solution accuracy and computation time.

Vehicle Routing in City Logistics II

Cluster: Logistics
Invited session
Chair: *Pedro Munari*
Chair: *Bruno Bruck*

1 - Two-echelon location routing in last-mile delivery: formulations and exact solution approaches
Fernando R. Senna, *Reinaldo Morabito*, *Pedro Munari*, *Leandro Coelho*

The growing demand for fast and cost-efficient delivery in urban areas has promoted the emergence of increasingly complex last-mile transportation systems to meet customers' needs, while keeping high service levels. In this work, we study a variant of the Two-Echelon Location Routing Problem (2E-LRP) designed for dense and congested urban areas. The 2E-LRP comprises a depot, a set of potential satellites, and customers. Large vehicles travel in the first echelon, transporting goods from the depot to the satellites, while smaller vehicles travel in the second echelon, serving customers from the satellites. In addition to routing vehicles on both echelons, one must determine the satellites to effectively open. In the variant studied in this work, vehicles act as mobile satellites, and carriers serve customers on foot (or by bike) while the vehicle is parked. Customers are clustered to be served by the carriers from a vehicle stop. Each vehicle can travel with more than one carrier, enabling customers to be served in parallel, reducing overall service times and cost. Routes of both vehicles and carriers are optimized considering cost minimization, customer clustering and service times. This problem extends the 2E-LRP by including time windows and synchronization constraints, since the vehicle must be parked while the carriers perform the second echelon routes. This problem also extends the vehicle routing problem with time windows and multiple deliverymen, disregarding decisions involving deliverymen's routes and the customers served at each stop of the vehicle. We present a mathematical formulation for the problem with novel sets of valid inequalities and elaborate on exact solution methods. Finally, we present and discuss results of instances with different cost structures to assess the performance of our approaches and discuss possibilities for future work.

2 - Robust Vehicle Routing under Demand and Travel Time Uncertainties
Pedro Munari, *Rafael Campos*, *Leandro Coelho*

The Vehicle Routing Problem (VRP) is a challenging optimization problem with a wide range of applications in City Logistics and Urban Mobility. Recent research has focused on developing innovative models and algorithms incorporating uncertainty into the VRP, considering traffic conditions, inclement weather, demand fluctuations, and vehicle breakdowns. In this talk, we review the main approaches in this context, with a particular focus on robust optimization techniques, providing routes protected against uncertainties. Furthermore, we introduce new compact models and branch-and-cut approaches for the robust VRP with time windows under cardinality- and knapsack-constrained demand and travel time uncertainties. We describe effective techniques for modeling uncertainty using these approaches and demonstrate how to check robust feasibility and separate valid inequalities using a dynamic programming procedure. We evaluate the performance of the proposed approaches using benchmark instances and real-world data provided by an airline company operating on-demand flights. The results highlight the benefits of incorporating uncertainty into route design and provide insights into the advantages and disadvantages of each uncertainty set.

3 - Vehicle Routing with Two-Dimensional Loading Constraints and Split Delivery: An Improved Branch-and-Cut Approach
Kamyla Ferreira, *Pedro Munari*, *Reinaldo Morabito*

We address the Split Delivery Vehicle Routing Problem with Two-Dimensional Loading Constraints (2L-SDVRP), involving designing routes while considering packing and split delivery requirements. The problem consists of serving a set of customers with demands represented by two-dimensional rectangular items, using a homogeneous fleet of vehicles from a central depot. The items of a given customer can be packed into different vehicles and, thus, a customer may be visited by more than one vehicle, if beneficial. Moreover, motivated by the delivery of pallets or fragile items, each vehicle has a base where items cannot be stacked, and only the load delivered to a customer can be moved in the base of the vehicle in the visit to the customer, known as multi-drop requirements. The objective of 2L-SDVRP is to find a set of least-cost routes with a feasible packing pattern satisfying the customer demand. Despite its practical relevance, this problem has received little attention in the literature; only two papers propose mathematical models for the 2L-SDVRP, and they are based on three-index vehicle flow formulations with variables indexed by vehicles. Moreover, only one of these papers proposes an exact approach. In this talk, we propose an improved branch-and-cut approach for the 2L-SDVRP based on a new two-index vehicle flow formulation. We describe a tailored procedure avoiding subtours and verifying the feasibility of packing constraints, resorting to eight different techniques,

including heuristics, lower bounds, and a constraint programming procedure. The results of computational experiments using benchmark instances indicate the effectiveness of our proposed method, outperforming previous results in terms of solution quality and computation time.

4 - Robust pickup and delivery problem with time windows under demand uncertainty
Alex Abreu, *Hélio Fuchigami*, *Pedro Munari*

The pickup and delivery problem with time windows (PDPTW) is a variant of the vehicle routing problem (VRP) arising in several logistics operations, including passenger transportation, freight delivery, and disaster relief. In this problem, a fleet of homogeneous vehicles is available at a central depot to serve customer requests, requiring paired pickup and delivery operations. Each request consists of two locations: one for pickup demand and the other for delivery demand. Additionally, each location has a time window when the service must start. The PDPTW involves finding the least-cost routes subject to constraints, such as vehicle capacity, time windows at pickup and delivery locations, and the pairing and precedence requirements for pickup and delivery. Since real-world data is often incomplete, estimated, fragmented, unavailable, or defective, we aim to develop formulations immune to uncertain parameters. To this end, we employ robust optimization to incorporate demand uncertainty into the PDPTW, considering the cardinality-constrained uncertainty set. In the resulting robust PDPTW, certain requests may assume their worst-case value, according to a parameter known as the budget of uncertainty, defined in advance by the decision-maker, based on their risk aversion. We show how to obtain the robust counterpart formulation through the dualization scheme, a commonly used approach in the literature, and through the linearization of dynamic programming recursive equations. The latter was recently introduced in the literature and has demonstrated superior performance in relation to the dualization for several VRP variants. We compare the performance of these formulations using benchmark instances and different choices of the budget of uncertainty and demand deviations.

Humanitarian Logistics and Sustainable Transportation Planning

Cluster: Logistics
Invited session
Chair: *Heletje van Staden*

1 - Evaluating the cost-emissions trade-off in synchromodal transportation
Heletje van Staden, *Hannah Yee*, *Robert Boute*

Reducing freight shipped by unimodal road transportation is a viable strategy to improve the carbon footprint of freight transportation, but road's reliability, flexibility and speed usually outweigh the more sustainable rail or waterway transportation modes. To encourage a modal shift reducing transportation emissions, we develop a bounded cost strategy using a k-shortest path intermodal transportation planning model; it incorporates minimum load requirements, time windows, freight consolidation and stochastic travel times. Consolidation facilitates utilization of transportation modes otherwise infeasible due to, for instance, minimum load requirements. Using stochastic travel times extends the model to synchromodal transportation, where we evaluate re-planning and re-consolidation options given disruptions. We numerically illustrate the work of our model using a representative network setting and visualize trade-offs concerning costs, emissions, travel time and reliability of sustainable intermodal and synchromodal options versus unimodal road. The result is improved economies of scale for both cost and emissions, while respecting lead time requirements.

2 - Exploring Synchromodal Transport Strategies Using Agent-Based Simulation
Shafagh Alaei Jordehi, *Javier Durán-Micco*, *Cathy Macharis*

Synchromodal Transport (ST), known as synchronized multimodal transport, is a novel concept involving using different modes to deliver freights from their origins to their destinations; it optimizes the transport process, making it more sustainable, reliable, and efficient. Although ST has many benefits, however, its implementation by companies still seems far away. There is still the lack of a mechanism describing the current and future state of the system and allowing the decision-makers to plan while staying flexible in their decisions. In this work, we create a (virtual) simulation model representing the physical system and helping to understand and analyze it. This paper presents an agent-based simulation model (ABM) for ST planning, focusing on re-planning under disruptions. Using ABM, we study the behavior of multiple actors involved in a ST system, their interactions, and the impact of their behavior on the entire network. The model studies a regional ST network at the operational level and from the Logistics Service Providers' (LSPs') perspective; it represents the movement of vehicles and cargo within a GIS environment and considers trucks, trains, and barges as the available modes. The main agents in our model are nodes (origins, destinations, terminals, depots), vehicles (trains, trucks, barges), services (trains services, barge services), orders, and LSPs. The overall dynamics of the system then emerge from the interactions of these agents. Within the model, agents are equipped with optimizations and decision-making algorithms allowing them to choose the best synchromodal route in response to disruptions or pulsations in demand. The model minimizes transportation costs, reduces carbon emissions, and ensures reliability. A numerical experiment is conducted in the Benelux region (Belgium, Netherlands, Luxemburg) to evaluate cost savings and emissions reduction, considering different collaboration and re-routing strategies. We compare ST with traditional transport planning to assess the flexibility and reliability in the two cases. Moreover, we study different strategies of relations between LSPs. The results show synchromodal scenarios lead to a 15% cost reduction, create 6% lower CO2 emissions and lead to higher flexibility and reliability than traditional scenarios. The model also verifies the cost saving is considerable when LSPs collaborate, rather than compete.

3 - Mix Programing Model for the Enablement of Humanitarian Help Gathering Centers for Endangered Areas by the Wild Fires in Valparaiso
Raúl Fernando Soto Concha

The concept "humanitarian logistics" refers to the study of planning and distributing products in case of disasters - particularly important in remote areas ("difficult areas"). Because of its complicated access, it satisfies the requirements of the beneficiary, meaning it relieves human suffering. We examine emergency logistics in the fires of Valparaiso, specifically studying the creation of gathering centers for the delivery of basic help kits after the incident, through a whole mix programing model, deciding what government locations would be enabled. In 2014, a fire in the city of Valparaiso left 15 dead, 5 hurt, over 500 ambulatory treated and over 12,000 victims; events like this make it necessary to have politics and preventive strategies to lower these numbers. As an initial result of the proposed methodology, 25% of the potential applicants are covered, up to 62% at the end, with a variation on the maximum distance traveled by applicants. We also analyzed (for the same amount of facilities) ten different distances to travel; the more the maximum distance is allowed, the more people are covered. The bigger the maximum distance allowed, the higher the percentage of demand covered - higher than the objective value for the amount of facilities installed, indicating the importance of this variable.

4 - Maintenance planning optimization for a bridge management system
Andres Medaglia, *Esteban Prada*, *Daniel Yamin*, *Nicolas Robayo Pardo*, *Diego Noriega*, *Juan Francisco Correal*

Road and bridge system networks are key for economic growth, since they support the transportation infrastructure and allow the efficient flow of goods and people. Bridges are particularly exposed to multiple sources of deterioration mechanisms and natural hazards leading to

severe structural damage or even collapse. To avoid significant social impact and economic losses, national road agencies need to invest their budget in rehabilitation and maintenance plans cleverly. Bridge Management Systems (BMS) support these maintenance processes, ensuring the safety and functionality of the transportation infrastructure by extending the bridges' life cycle and mitigating the negative impact of their failures and closures. We present an optimization model embedded in a BMS prioritizing maintenance operations in a national bridge network. Due to the sheer size of this network, it is possible to decompose the original problem, unveiling and taking advantage of the underlying network beneath. We illustrate the use of this model embedded in a real-world BMS developed for the Colombian National Road Agency (INVIAS, for its acronym in Spanish).

Decision Support for Manufacturing and Other Operations

Cluster: Logistics
Invited session
Chair: *Ricardo Giesen*

1 - Decision support for allocating farmed fish to customers using a bi-objective optimization model

Sunniva Haukvik Knudseth, *Arild Hoff*, *Johan Oppen*, *Lars Magnus Hvattum*

Aquaculture is an important and growing industry in coastal Norway, and in need of technological support as there is currently a lot of manmade decisions. With focus on farming of salmon and trout, an operational planning problem arises with the goal of allocating supply of fish to demand while also achieving cost-effective high utilization of vehicles used for transport. The customer orders have several specifications that should match the specifications of the fish within certain bounds. In addition, there is a prioritization of customers, which should be met as much as possible. The biggest challenge is the uncertainty regarding the supply - the initial allocation plan is made based on forecasted values, and re-planning often occurs after harvest and slaughter starts and these values are updated.

This work is based on a conceptual model of such a planning problem which defines a corresponding bi-objective mathematical programming model. The augmented epsilon-constraint method was chosen as the most fitting, as it guarantees Pareto optimality of obtained solutions when having two objective functions. This real-world problem is novel with respect to the structure of the transportation of fish, and the rules for satisfying customer orders with respect to fish size, quality, and certification.

2 - Improving parking decisions from an operational perspective: Application of a Markovian decision model for parking on urban distribution routes.

Matías Gutierrez, *Ricardo Giesen*, *Juan-Carlos Ferrer*

Urban distribution has had an exponential growth in recent years; as it develops intensively in dense areas, it has among its main features the chaining of large numbers of customers (Holguín-Vera y Patil, 2005; Figliozzi et al., 2007), to take advantage of economies of scale. Finding parking can lengthen total travel times by up to 28% in an urban context (Dalla Chiara and Goodchild, 2020), without considering extra costs associated with illegal parking - not measured in these results. Therefore, understanding parking decisions is essential to reduce costs, while keeping the customers' level of service under control. We present a model of parking decisions made during the execution of a defined route based on a Markovian decision process and propose an optimal decision policy regarding operational costs. The modeled stages range from arrival in the vicinity of the customer to the customer being served, encompassing the stages defined by parking decisions. Each customer is defined according to the following state parameters: potential parking spots in their area, the probability of availability, and the expected time for the following parking spot to be released. Upon reaching the customer, parking availability is revealed. The driver must then decide, based on current information and estimates of future information, when and what will be released at the next parking spot, currently occupied. Once availability is revealed, the driver can choose between the following alternatives: park legally in the best available parking spot, wait for a better parking spot or park illegally. The costs considered are costs for illegal parking, customer access cost for each potential parking space, and cost for delays - associated with the loss of customers' level of service and extra operating costs. The model is solved analytically for small test cases, since for larger chains the "curse of dimensionality" occurs. Sensitivity analysis is performed on customer status parameters and costs. The proposed model allows one to analytically obtain a decision policy with a guarantee of optimality, and it provides valuable perspectives on the impact of considering the state characteristics of customers for the design of routes.

3 - A new method for the measurement of robustness in reverse logistics supply chains based on entropy and nodal importance

Daniel Morillo Torres, *Germán Maya Rodríguez*, *John Willmer Escobar*

This paper proposes a new methodology for measuring robustness in Reverse Logistics (RL) supply chains. First, an integer-mixed linear programming model is proposed to design an RL network and to analyze its robustness, using a new method based on entropy and the importance of each node, adapted from measurement in electrical systems. The entropy of a node allows for determining important fault dynamics in the distribution network. Similarly, the node's importance is considered a measure of centrality by quantifying its importance in the network in the context of possible disturbances. In particular, when a disturbance occurs in a flow originating in one of the nodes, leaving it disabled, the flow must be redistributed to the rest of the network echelons. A company producing animal feed has tested the proposed methodology in a case study applied to recovering wooden pallets and big bags. A validation with 500 scenarios has been carried out to evaluate the robustness metric's adaptation and group the solutions into 16 categories. This classification has been performed to compare them in a set of 5000 new scenarios and to select the one providing the most excellent robustness for the logistics system under study. The results obtained show the efficiency of the proposed methodology.

4 - Exploring the benefits and challenges of drone-assisted material handling in manufacturing

Julio Jiménez-Sarda, *Daniel Silva*, *Alice Smith*

Automation has served as a fundamental catalyst in the evolution of logistics chains; amid labor shortages and higher land prices in the post-pandemic world, it is necessary to make the next technological leap. Automated material handling systems are usually sizeable and require processes built around them, but with mass customization as a key component, Industry 5.0 needs a cost-effective, flexible, highly scalable, and low-footprint material handling system to meet future demand. Uncrewed aerial vehicles (UAVs) can fill the role of a viable alternative to more traditional material handling systems; they are affordable, do not need significant investments in infrastructure, can change routes dynamically, and have been used successfully in swarm configurations. Our research involves the development and application of mathematical models to schedule and route drones in 3D space, to aid in material replenishment tasks; in this approach, we used a version of the capacitated vehicle routing problem (CVRP), with a discretized representation of a realistic manufacturing environment. As a proof-of-concept, we outfitted a commercially available drone with pickup-and-carry capabilities; even with a single UAV and limited carrying capacity, potential benefits arise compared to a traditional ground-based material handling system. At the same time, we have identified potential challenges and safety considerations when developing pickup and carrying mechanisms.

Sustainable Multimodal Transportation

Cluster: Maritime Logistics
Invited session
Chair: *Breno Alves Beirigo*
Chair: *Bilge Atasoy*

1 - Pareto-improvement of public transport via line-based integration of on-demand ridepooling

Andres Fielbaum, Alejandro Tirachini, Javier Alonso-Mora

Ridesourcing companies have worsened congestion in numerous cities worldwide, as many users are attracted from more sustainable modes. To reverse this trend, it is crucial to leverage the technology of connecting users and vehicles online and use it to strengthen public transport, which can be achieved by integrating on-demand pooled services in existing fixed-line transport. We propose an efficient integration idea that can be implemented in practice: namely, to complement fixed bus lines with a fleet of smaller vehicles that follow flexible routes side-by-side with the fixed routes, so that part of the demand that would have used the fixed line can ride the flexible service instead. With this scheme, a smaller bus fleet is required, partially compensating for the increase in operational costs stemming from the flexible vehicles. This integration strategy favours mostly two types of users: those travelling in low-demand periods, through lower waiting times, and those located far from the bus stops, because the flexible vehicles can pick them up and drop them off close to their origins and destinations, hence reducing their walking times. The operation of this system requires modifying a state-of-the-art assignment algorithm for the on-demand subsystem, to prioritise those users that would receive the worst quality of service in the fixed-route subsystem.

Simulations in real-world scenarios from Santiago, Chile, and Berlin, Germany, reveal that: i) A small number of on-demand vehicles can reduce average walking times from approximately 12 to 2 minutes for those being served by the flexible service, while reducing operational costs, leading to a Pareto improvement, ii) a larger number of on-demand vehicles can diminish total costs by 13%-39%, through a drastic reduction in users' costs, although increasing operators' costs, and iii) this mixed system also outperforms the use of on-demand ridepooling only.

2 - A deep reinforcement learning approach for on-demand ride-pooling in high-capacity water transportation systems

Breno Alves Beirigo, Bilge Atasoy

Efficient ride-pooling has the potential to significantly increase the capacity of transportation systems, while reducing congestion in cities, as fewer vehicles can fulfill the same number of trips. In the related literature, robust ride-pooling strategies to solve real-world instances include re-optimization methods, lookahead algorithms, and, more recently, deep reinforcement learning (DRL). Although theoretically, the problem consists of a cooperative multi-agent system (centrally controlled vehicles work together to service requests), in practice, to curb the curse of dimensionality, learning frameworks for ride-pooling systems are modeled using an independent DRL approach, where each agent learns its own policy, treating other agents as part of the environment. In these frameworks, vehicle states often comprise a spatiotemporal feature list corresponding to the vehicle's planned route and features capturing the vehicle's immediate surroundings (e.g. requests and vehicles within a range). To mitigate the impact of non-stationarity (other vehicles are learning and affecting the environment at the same time), most studies consider (besides vehicle states) global states, capturing information shared by the whole fleet, such as the current or forecasted request distribution throughout the zones of a service area and the ratio of requests and vehicles per zone. In turn, candidate routes are generated at each time step for the whole fleet and optimally assigned to vehicles aiming to maximize current and future rewards (value-function based). Standard experimental settings of studies on DRL for ride-pooling typically consider small-capacity vehicles, slow speeds, and short passenger waiting times, however, thus constraining pooling feasibility and ruling out direct applicability in more complex scenarios. This study analyzes the impact of lifting these limiting assumptions to model a DRL approach for a real-world water transportation system, where high-capacity and high-speed vessels dynamically pool requests. We derive insights from the request-based, on-demand water transport system operating in Rotterdam, the Netherlands, using a 12-seat, 18-vessel fleet to pick up and deliver passengers at 50 docks along the Nieuwe Maas river.

3 - Determining port hinterlands using road network data: the case of South American ports with different destinations

Sergio Maturana, Alejandro Mac Cawley, Luz Flórez-Calderón, Javier Vega

Port hinterlands have been studied for many years, from different perspectives. In this paper, we focus on how to determine the geographical area of influence of different ports; I.e., how exporters choose the port to ship their products. Obviously, many factors influence this decision. Many studies have determined, however, inland and sea distance, together with transportation costs, tend to be the most relevant factors; they are also objective, and there exists easy-to-obtain, reliable data. In this study, we also consider relational port hinterlands, depending on the overseas origin or destination of the shipment.

Early studies used Euclidean distance to determine a port hinterland. Some more recent studies, using the gravity model, also use Euclidean distance as an input for their model. Other studies have used inland transport cost to determine the port hinterland, but are also based on the Euclidean distance.

Euclidean distances do not accurately represent the routes a truck can travel, however; to address this shortcoming, we determined port hinterlands using real road distances based on road network data. Then, we added a cost function accounting not only for travel distance, but also for the fuel cost expressed as a function of load, speed, road network slopes, travel times, and other parameters.

To test these different methods for determining a port hinterland, we applied the two highly data-driven methodologies to determine the hinterland of six South American ports. We then compared the resulting port hinterlands with those using the simpler, Euclidean distance. We analyzed the differences between these three methods, and the impact of the main cost variables and travel times on the port hinterland was quantified. We performed a sensitivity analysis to determine the effects of fuel cost, port cost, and congestion on the hinterland of each port.

Finally, we apply the methodologies to six ports in South America and four destinations: Rotterdam in Europe, Los Angeles and Savannah in the US, and Shanghai in China. The differences between the hinterlands modeled by the three methods are considerable, reaching up to an 8% difference in the area captured for some ports.

4 - A matheuristic for the multi-product maritime inventory routing problem

Arild Hoff, Homayoun Shaabani, Lars Magnus Hvattum, Gilbert Laporte

This paper considers a multi-product maritime inventory routing problem, where the routes of the vessels are determined while inventories in the ports must remain within given bounds. Since there is more than one product, each port can be a consumption port for one product and a production port for another product. We propose a matheuristic to deal with large-size instances with a planning horizon of 60 days. The first phase of the heuristic identifies a subset of the arcs to use them as input parameters for the second phase. In the second phase, a mathematical model is solved with the selected arcs fixed. These two phases are iterated until a stopping criterion is satisfied. The solutions produced by the matheuristic are compared with those obtained by CPLEX. Comparing the single-product version of the problem with the multi-product version revealed instances with multiple products require significantly more run time compared with the single-product instances.

Decision Support Systems for Port Operations

Cluster: Maritime Logistics
Invited session
Chair: *Karol Suchan*

1 - Optimizing personnel and equipment scheduling at a container terminal

Julio Mar-Ortiz, *Maria D. Gracia*, *Eugenia Villarreal-Snyder*, *Jannya Pancardo-Perez*

Container terminals compete for a market moving over 791 million containers around the world in 2022. The global competition to offer better quality services raises the constant need for container terminals to seek and to develop more efficient strategies and solutions to increase their operational efficiency to adjust their capacity service on demand. The productivity and quality of services provided by container terminals, to trucking and line shipping companies, critically depend on the nature and efficiency of the decisions made during equipment and workforce planning activities. The performance of manned equipment, such as quay cranes or yard cranes, is extremely impacted by their operator's productivity, making the operator assignment decision a relevant element in the manned equipment scheduling. Accordingly, the overall efficiency and profitability of a container terminal can be greatly improved with proper personnel and equipment allocation and scheduling decisions. These decisions will result in serving vessels either timely or with significant operation delays. In the literature, this topic has received little interest, and, in practice, personnel and resource scheduling decisions have been commonly based on container managers' experience. This research concerns the workforce-scheduling problem and determines the optimal allocation of crane operators, trailer drivers and operative workers per shift; it involves two decisions - scheduling and assignment. The scheduling decision determines the roster of workers for each shift. The assignment decision determines the appropriate operator, based on their skills and category, to each piece of equipment during their assigned shift. The objective is to guarantee the operational continuity of the equipment during shift changes and mealtimes, while maximizing its average productivity and satisfying the demand of moves during specific time slots in a working day. Additional constraints include the assignment of operators to equipment according to their ability to operate each piece of equipment, their hierarchical level or category, as well as other constraints established by human resource policies, such as rests guaranteed after a duty and mealtimes. Results from a case study are presented to derive managerial insights.

2 - Underground Reefer Container Storage System design: a case study

Adriana Moros-Daza, *Rene Amaya*, *Dariela Castro*, *Jose Bonifacio*

On average, the total energy in a port is consumed by STS cranes (33.90%), terminal lighting (12.70%), offices (5.53%), and reefer containers (47.87%). Reefer containers account for almost half of the total port energy consumption, with a seeming growth tendency, since perishable food products increased by 119.2 million tons between 2000 and 2017, when it reached 259.4 million tons, featuring an impressive compound average growth rate of 3.9%. To supply the energy demand, ports mostly use fossil fuels, and their use currently represents 3% of the world's total greenhouse gas emissions. Over the years, the pressure on maritime ports to reduce energy consumption, and mitigate the environmental impacts related to the use of fossil fuels, has increased, driven by many factors, such as national regulation on air quality and climate change mitigation affecting port authorities, operators, tenants, and land transport. Most of the extant literature addressing this problem relates to energy simulation, energy consumption, digital storage, architectural design, and energy efficiency. Mainly, those articles assessed the impact of energy consumption from fossil fuels and focused on ways to reduce or replace them, by performing renewable energy simulations. Distinctively, the present paper addresses this problem from a fresh perspective focusing on new alternatives for reefer container storage. This work introduces a new underground storage system aiming to drastically reduce the energy consumption of reefer containers. Our purpose is to model the implementation of this storage system through a discrete event simulation (DES) to analyze its feasibility, environmental impact, and cost-benefit. The simulation showed a modular design of 2 underground yards is selected as the best scenario. According to the DES, this scenario guarantees underground storage of 39% of the port's total refrigerated container capacity. In turn, it leads to a reduction of approximately 61% in CO2 emissions generated by an electrical consumption of 2703805114 kWh from refrigerated containers. In this way, it fulfilled our purpose to design improved port operations complying with an environmentally responsible standard. This design offers a reduction of approximately 196 000 USD per year from the savings in energy consumption.

3 - Optimizing container terminal operations: A methodology for improving storage space allocation policies

Karol Suchan, *Felipe Condore*, *Rosa G. González-Ramírez*

Seaports and dry ports play a critical role in a country's foreign trade, as 80% of cargo volume moves via maritime transport, and logistics costs account for 5% to 30% of the price of products traded on international markets. Furthermore, the global economic slowdown resulting from the COVID-19 pandemic and recent geopolitical tensions has made it imperative for global supply chains to be more efficient than ever before. As the main nodes of international supply chains, ports must evolve and adapt their operations to reduce operating costs and improve service levels, all in the hope of a rapid economic recovery.

At a container terminal, storage space allocation policies are crucial for improving operational productivity. A suboptimal policy can lead to unnecessary container movements (known as "rehandles") not adding value, as well as non-uniformity in container handling operations across the yard, with some parts remaining relatively idle while others are congested. In addition, deficient planning based on imprecise workload forecasts can result in excessive stress on certain resources in the yard, leading to overburden, ultimately hampering productivity.

One of the main sources of difficulty in designing good allocation policies is the high level of uncertainty associated with container reception and dispatch sequences. Our partners in Chile face this challenge, as traditional methods cannot predict container dwell times with any degree of certainty. Therefore, one of the main elements of our research is to forecast the time each container will spend in the yard. This information serves as a basic input for algorithms, assigning a location to a container upon its reception and recommending the appropriate rehandling method, if necessary.

In this talk, we present a methodology we designed for a dry port in Chile to develop a highly accurate regression model to predict the number of days a container will stay at the terminal. The methodology is flexible and can be adapted to the data available and container flow characteristics of other terminals.

4 - Workload distribution in a multipurpose port terminal yard in Chile

Valeria Castro, *Karol Suchan*, *Rosa G. González-Ramírez*

Our study focuses on analyzing the container flows in a port terminal yard in San Antonio, Chile, a multipurpose terminal. Our objective is to determine the distribution of the workload among different areas of the yard and the vehicle flows between them, to be used to develop a simulator of the yard. This simulator will enable us to evaluate the impact of different vehicle dispatching rules controlling traffic between the gate, storage blocks, and other parts of the terminal. While the focus of our analysis is on container flows, we must consider other cargos handled at the terminal, since it is a multipurpose terminal.

Studies have shown uniform workload distribution (both in time and space) leads to better productivity, resulting in fewer unproductive movements, shorter service queues, and less burden on individual personnel or machines. We conducted a comprehensive analysis of the workload distribution at the terminal to assess its productivity.

First, we modeled the main processes of the terminal based on technical visits and interviews. The port terminal has a unique shape and is

divided into three areas for container storage and a break-bulk cargo (vehicles) area. In addition to the gates where external trucks enter the terminal, there is a gate for cargo transported by rail to either this terminal or the neighboring container terminal. This implies a significant flow of vehicles entering the terminal to transport cargo to/from the neighbor.

Second, we analyzed a dataset provided by the port terminal, including the movements of containers and vehicles from 2016 to 2022. We followed the Cross Industry Standard Process for Data Mining methodology to find patterns describing the dynamics of the terminal.

The distribution of workload at the port terminal under study can be far from uniform at times, indicating room for improvement. In future work, we plan to use the simulator we are developing to study possible policies to enhance the terminal's productivity.

Maritime Transportation and Port Logistics

Cluster: Maritime Logistics
Invited session
Chair: *Peter Schütz*

1 - Optimal flow of load carriers in the martime transportation network of a Norwegian aluminium producer
Peter Schütz, *Hans Markus Jahle*

We study the problem of planning the optimal flow of load carriers in the maritime transportation network of Norway's largest aluminium producer; in 2021, it changed the logistics set-up for Norwegian smelters. To improve efficiency and flexibility, as well as the CO2-footprint of the logistics system, the old set-up with different vessels and many different handling methods was changed, so products are loaded onto standardized load carriers and shipped using Roll-on Roll-off (RoRo) vessels, having weekly port calls at all Norwegian smelters. One of the challenges with the new set-up is the smelters do not have a regular flow of goods; the amount of finished products or raw materials can vary week by week and, therefore, the number of load carriers needed varies week by week. This may result in the smelters ending up with either too few or too many load carriers from time to time, creating a lot of discussions and dissatisfaction from the smelters. We present an optimization model, for planning the flow of load carriers between the Norwegian smelters and ports in Europe, solved using real-world data from the aluminium producer. The results are compared to current shipping practice. We also study how uncertainty in production volumes affects the optimal flow of load carriers.

2 - Optimizing Supply Chain Management in Antarctica: A Hybrid Electric Fleet Routing Model
Dagoberto Cifuentes, *Lorena Pradenas*, *Víctor Parada*

Operating a fleet of hybrid electric vessels in the challenging and remote environment of Antarctica, presents government entities with unique challenges in terms of cargo delivery and collection for scientific bases. To address these challenges, this study proposes a first mathematical model for the Periodic Routing Problem (PRP) in Antarctica, using a fleet of hybrid-electric vessels. The model considers the limited resources and harsh conditions in the polar region and aims to optimize route and planning decisions for the ship fleet.

The proposed model includes a Mixed Integer Linear Programming (MILP) formulation considering the feasibility and cost of each routing decision. The MILP optimization algorithm is then applied to find the optimal solution to the PRP, considering an additional decision on the arcs about the shipping mode. The results of the study demonstrate the potential of the proposed model to provide valuable insights for government institutions operating ships in Antarctica and recognize the importance of considering the specific limitations and conditions in the polar region, when developing mathematical models for real-world problems.

This study contributes to the growing body of research on mathematical modeling for supply chain management and specifically focuses on the application of the PRP in Antarctica's unique environment, considering alternative means of energy sources for the ships. Findings have implications for organizations operating in similarly challenging and remote environments and demonstrate the potential for mathematical modeling to support decision-making in real-world applications.

3 - Recent container storage space allocation advances - are there lessons to be learned to address uncertainty?
Jana Ries, *Rosa G. González-Ramírez*

Recent years have seen an increasing, and diverse, level of uncertainty, whether of a political, global health or socio-economic nature. While the literature shows evidence of a continuous focus to understand and to integrate the unexpectable into our decision-making, complex systems continue to be rattled by uncertainty.

With ports being a strategic hub in the global systems of transport and operations, yard management is one area becoming increasingly impacted by disruptions and unexpected dynamics within the network. Scientific advances in yard management related contributions, therefore, continue to seek elements of agility in the methodological design of decision-making, to ensure its ability to adjust to uncertainty. These uncertainty aspects have been reviewed in the context of seaside operations in a port, such as maritime shipping transport and berth allocation, but there is no structured review for yard management-related problems.

This work investigates the consideration of uncertainty in container handling operations and its impact on recent developments in modelling and solving the problem. Specific focus will be drawn toward the consideration of methodological design and differences in relevant contextual information. The aim is to emphasise how methodological approaches are used and whether lessons can be learned in the wider context of the Container Space Allocation problem. Relevant gaps for future research are presented.

4 - The multi-objective dynamic berth allocation problem
Javier Maturana-Ross, *Eduardo Lalla-Ruiz*

In this paper, we study the multi-objective dynamic berth allocation problem (MO-DBAP), a well-known optimization problem aiming at allocating incoming vessels into berthing positions. The term "dynamic" means ships can arrive during the planning horizon (contrary to the "static" case where all ships are at the port at the beginning). Usually, researchers and practitioners minimize the vessel's turnaround time due to its impact on port performance, without simultaneously observing other objectives, such as allocation costs and make-span. In this study, we aim at closing this gap in the literature by providing a thorough analysis of the trade-offs of different objective functions for the problem. The MO-DBAP is solved by means of the state-of-the-art exact multi-objective algorithm AUGMECON-2 and the NSGA-II heuristic to compare the quality of the exact and approximated Pareto fronts. Furthermore, we also use improved mathematical formulations. Early computational experiments using classic instances from the literature are promising in terms of execution time and complete Pareto front analysis.

Port Performance and Miscellaneous. Part 1

Cluster: Maritime Logistics
Invited session
Chair: *Rosa G. González-Ramírez*

1 - Competitiveness and performance in the port supply chain: an analysis of Latin American ports
Luis Ascencio, *Rosa G. González-Ramírez*, *Pilar Arroyo*, *Diego Muñoz*

This work presents a comprehensive literature review on the topic of port competitiveness and performance to define a framework identifying the main drivers and best practices of a group of ports in Latin America. Due to the wide variety of studies existing in this line of research and the various approaches and factors affecting the competitiveness of a port, various categorizations have been proposed in the literature. One of the first categorizations came from Goss (1990), who proposed five scales of competition between ports. On the other hand, Pallis et al. (2010) propose seven port research subfields - port competition and competitiveness being one of them. Four categories to measure competitiveness in ports are proposed in this subfield: (i) Port competition, (ii) Strategy analysis, (iii) Port performance, and (iv) Port choice. Munim and Saeed (2019) present a review on port competitiveness based on a bibliometric study of co-citation and extended the previous categorization, presented by Pallis et al. (2010). Based on this theoretical framework and empirical data, a port competitiveness index is derived. The first phase of the empirical methodology used a qualitative approach. Semi-structured interviews with port representatives were conducted to identify the best practices in ports, fostering their competitiveness. Six factors or dimensions of port competitiveness were identified after the analysis of the qualitative information; they are: (i) Sustainability, (ii) Operational integration, (iii) Inter-organizational information systems, (iv) Governance, (v) Efficiency and quality service, and (vi) Regulation and port public policies. The second phase of the methodology was the design of a survey, responded to by professionals and authorities of fifteen ports in Latin America and the Caribbean region. The survey data was analyzed and each participant port contrasted with respect to a "reference port" to elaborate academic implications and managerial recommendations.

Ref. Goss, R., 1990. Economic policies and seaports: Strategies for port authorities. Maritime Policy & Management 17, 273-287 Munim, Z.H., Saeed, N., 2019. Seaport competitiveness research: the past, present and future. International Journal of Shipping and Transport Logistics 11, 533-557 Pallis, A.A., Vitsounis, T.K., De Langen, P.W., 2010. Port economics, policy and management: review of an emerging research field. Transport Reviews 30, 115-161

2 - Efficiency evaluation of Atlantic-Pacific port terminals from the Tropic de Capricorn's bi-oceanic corridor for improving cargo transport

Magdiel Agüero Tobar, *Marcela C. Gonzalez-Araya*, *Rosa G. González-Ramírez*, *Luis Ascencio*

The Tropic de Capricorn's bi-oceanic corridor involves the commercial exchange between Brazil, Paraguay, Argentina, and Chile, offering a transport alternative to the current flow of trade goods, usually initiated in an Atlantic port. In this study, an analysis of cargo transport efficiency between Pacific and Atlantic ports is carried out, using data envelopment analysis (DEA) models. In this way, 14 port terminals are analyzed; three terminals from the northern macro-zone of Chile, six terminals from Brazil, and five terminals from Argentina; all are focused on the transfer of containerized cargo. In this analysis, infrastructure variables are considered, and a variable return to scale DEA model is used. Two of the three port terminals from the Pacific coast of the corridor are inefficient. In this way, for valuing the corridor as a good alternative, it will be necessary to improve the operations of the Pacific terminals. Additionally, the analysis allows identifying slack in port infrastructure, where the Argentinian terminals have the greatest slack average. This analysis could support investment recommendations to take advantage of port terminals' infrastructure and to recognize cargo opportunities related to the corridor implementation.

3 - Factors Influencing Exporters and Importers in Choosing a Container Port: A Study in Santa Catarina State, Brazil

Vanina Macowski Durski Silva, *Natália Manoela Da Costa Morales*, *Gustavo Adolfo Alves da Costa*

Brazil is a country of continental extension, with about 8,500 km of navigable coastline, providing optimal conditions for maritime transport. According to the National Confederation of Transport (CNT, 2018), maritime transport in Brazil encounters problems related to infrastructure, such as urban pressure, when ports are located in consolidated urban areas (hindering expansion and connection with other modals), and bottlenecks, limiting the flow of cargo by land access. The road modal transports 60% of domestic loads in TKU (tons per useful kilometer) - scarce, less dense and of low quality - and the rail modal has low availability and problems of tracing and integration (CNT, 2019). This study analyzes determining factors in the choice of container ports in Santa Catarina State, from the perspective of two groups of users - cargo owners and logistics operators. Some steps needed to be taken: Carry out a literature review to define the Port Logistics Chain; Identify the main ports of Santa Catarina State handling containers and those who use them to transport cargo; Implement the Quality Function Deployment (QFD) matrix to identify factors influencing the decision of the port to move their loads; Use the QFD results and propose a model of Analytic Hierarchy Process (AHP) to analyze the preference of users in relation to the ports of Santa Catarina State, as well as the preferences between the determining factors; Analyze the results to identify the determining factors of the choice of port, as well as identify whether logistics infrastructure impacts this choice. Thus, it is necessary to analyze both the perspective of a user group and also of a specific geographic location, to identify the factors focusing on the study region. This paper focuses on certain groups of users in the region of Santa Catarina State and on the transport of containers. From analysis of the QFD, we elaborate a hierarchical structure and use the Analytic Hierarchy Process (AHP) method to find port competitiveness. The factors vary depending on the perspective of who evaluates and on how competitive the ports and users consider themselves.

OR Towards Net Zero Maritime Transport

Cluster: Maritime Logistics
Invited session
Chair: *Frederik Schulte*

1 - The Refueling Station Location Problem with Green Maritime Corridors

Xiaohuan Lyu, *Frederik Schulte*

The maritime shipping industry, responsible for 3% of global greenhouse gas (GHG) emissions, is facing increasing pressure to transition towards decarbonization and, ultimately, zero-emission operations, in response to the escalating threat of climate change. To this end, the International Maritime Organization (IMO) has established an ambitious target of reducing 50% of GHG emissions by 2050 (compared with their level in 2008). Green corridors are now recognized as one of the most promising approaches aiming to create zero-emission shipping routes between ports. Significant investment is required to establish the refueling infrastructure supporting alternative-fueled ships, however, and, as of yet, these refueling stations are still undeveloped. Moreover, due to the collaborative nature of the partnership among ports, reasonable distribution of revenue generated from ship refueling is critical for successfully implementing green corridors. Therefore, in this work, we propose the refueling station location problem with green maritime corridors and a general solution framework to assist the government and companies confronted with this problem. We further design a cooperative game to allocate collaborative refueling revenue among involved ports. Specifically, we first develop a flow-refueling location model (FRLM) for the maritime corridor to maximize the ship flow volumes. Then, we develop a row-generation-based algorithm to calculate the core solution for revenue sharing by decomposing the core calculation into the master problem and the subproblem; the output of the subproblem provides a new lower bound for the master problem. To accelerate the computational experiments, we design a metaheuristic to enhance the row-generation algorithm obtaining near-optimal results for the subproblem and more quickly reaching exact core solutions. Depending on the settings of the problem instances, it is possible no sharing strategy can reach the core condition; in these situations, the devised row-generation algorithm can provide lower bounds, defined as the potential revenue for individual port operators, so they are willing to cooperate. Overall, by providing the location of refueling stations and the core allocation of collaborative

revenues, this work contributes to establishing maritime green corridors from the operational level.

2 - Net Zero Port Operations: A Literature Review and Conceptual Framework
Frederik Schulte, *Xinyu Tang*

With the increasing awareness of climate change, decarbonization has become a pivotal challenge in the maritime industry. Policies, such as The European Green Deal, aim at climate neutrality in 2050 and set ambitious intermediate goals for the upcoming decades. As the essential nodes in the international logistics network and one of the main contributors of emissions in the maritime industry, ports have to take responsibility for achieving net zero in their operations, referring to a state where greenhouse gases (GHG) going into the atmosphere are balanced by removal out of the atmosphere, to halt global warming.

There is some research close to the aim of net zero port operations, such as general decarbonization research, emission control or reduction, and sustainability. Existing literature presents systematic reviews on technical and operational measures to reduce GHG and improve energy efficiency, while less attention is paid to conceptualizing operational challenges on the way to net zero ports. Operational problems arising from port operations are incorporated with explicit environmental considerations, like emissions and alternative fuels, with operations research taking a central role in the optimization of these complex decision problems.

In this work, we conduct a literature review of the operational problems to reach net zero ports, integrating our findings into a conceptual framework and research agenda on the topic. We categorize detailed modeling challenges for port operations and put an emphasis on energy management where the uncertainty of energy (e.g. generation and price) requires further exploration, as energy supply is always fluctuating and the demand is also hard to predict due to operational complexity. A trade-off between emission-related considerations and operational efficiency also draws attention. The application of bi-objective or multi-objective optimization of net zero considerations and port operation efficiency can help decision-makers gain better insight into the trade-off between environmental and business objectives. In many problems, machine learning is integrated with classic optimization approaches to help solve these operational problems with high uncertainties and diverse data sources.

3 - Platooning of automated ground vehicles to aid green port hinterland corridors
Rosa G. González-Ramírez, *Nadia Pourmohammad-Zia*, *Frederik Schulte*, *Stefan Voss*, *Rudy Negenborn*

Nowadays, ports face significant challenges as strategic nodes of global supply chains, being responsible for the coordination of inbound and outbound flows of cargo with maritime and hinterland transport corridors. The adoption of disruptive technologies can support ports to overcome operational challenges and help them to manage their resources more efficiently and in a more sustainable way; ports can become an enabler for initiatives, where new technology aids the green transition and decarbonization of maritime and port activity. Automated Ground Vehicles (AGVs) have been adopted in may ports, especially for horizontal transportation in container terminals. Automated transport outside of the terminal areas, however, has not yet been used. In this work, we present an analysis to show the potential benefits of applying AGV platoons to establish an efficient and sustainable port hinterland transport corridor. We develop a bi-objective mixed-integer programming model, simultaneously minimizing time and cost elements and also considering emissions reduction. Each transportation task can be carried out by AGVs or conventional trucks, while the number of available vehicles for each mode is uncertain. To deal with uncertainty, a robust optimization model based on an ellipsoidal uncertainty set is proposed. Two case studies are analyzed: the Port of Rotterdam in The Netherlands and the Port of Valparaíso in Chile, with different traveling distances in corridors to a dry port (200 km) and a pre-terminal (11 km), respectively.

Vessel and Terminal Operations

Cluster: Maritime Logistics
Invited session
Chair: *Dario Pacino*

1 - Fluid models for liquid bulk terminal performance
Werner Scheinhardt, *Jan-Kees van Ommeren*, *Debjit Roy*

Bulk liquid terminals play a crucial role in timely (un)loading of liquids from tankers and facilitate transport to and from the hinterland via pipelines, trains or trucks. At an import terminal, tankers berth at a liquid terminal jetty, where the liquid is transferred from the tanker to a storage facility via loading arms and pipelines. When the storage is full, the unloading rate essentially decreases to the drain rate of the storage, increasing the handling times of tankers, considerably. On the other hand, when the storage is empty, the demand on the landside cannot be met. Both of these undesirable effects can be mitigated by having a large storage capacity, but at higher cost. Throughout, we assume tankers arrive at the terminal, according to some random process, and each tanker carries a random amount of liquid. Also, we assume the terminal has a single berth, leaving the multi-berth situation for future work. When the berth is occupied, arriving tankers will experience some delay before being served. We assume a finite waiting area; tankers arriving when the waiting area is full are blocked (and unloaded elsewhere). To analyse the performance, we develop mathematical fluid queue models, considering customers (tankers) queueing up for service, as well as the fluid level in a connected reservoir (storage). Focusing on a single fluid, the storage level depends on tanker behaviour, but there is also a reverse dependence: the unloading rate decreases to the drain rate when storage is full. This makes the model a "feedback fluid queue", applicable to find performance measures of interest: the delay of tankers, their blocking probability, and performance measures related to the storage level. We also consider models for two non-mixable liquids. Due to the feedback mechanism, it proves difficult to analyse the two fluid queues interacting with the same tanker process. When both storages have ample capacity, however, there is no feedback, and we can find analytic results. These can help to trade-off between using dedicated unloading arms for the two liquids, or to share these resources. In a sequel presentation "Numerical results for liquid bulk terminal performance", it will be shown how to circumvent the difficulty of incorporating feedback in the two-liquid model (as in the single-liquid model), so we can also present (approximate) numerical results for this case.

2 - Numerical results for liquid bulk terminal performance
Jan-Kees van Ommeren, *Werner Scheinhardt*, *Debjit Roy*

This presentation is a follow up on the presentation "Fluid models for liquid bulk terminal performance". Bulk liquid terminals play a crucial role in timely (un)loading of liquids from tankers and facilitate transport to and from the hinterland via pipelines, trains or trucks. At an import terminal, tankers berth at a liquid terminal jetty, where the liquid is transferred from the tanker to a storage facility via loading arms and pipelines. When the storage is full, the unloading rate essentially decreases to the drain rate of the storage, increasing the handling times of tankers, considerably. On the other hand, when the storage is empty, the demand on the landside cannot be met. Both of these undesirable effects can be mitigated by having a large storage capacity, but at higher cost. Assuming tankers arrive at the terminal randomly, each tanker carries a random amount of liquid and the terminal has a single berth (leaving the multi-berth situation for future work), when the berth is occupied, arriving tankers will experience some delay before being served. Assuming a finite waiting area, tankers arriving when the waiting area is full are blocked (and unloaded elsewhere). In the companion presentation, we analyzed the single-liquid case using feedback fluid queues, as well as a simplified model for two liquids (unmixable) with ample storage. In this presentation, we focus on a mathematical model for the two-liquid case with limited storage. This is an important extension, since it also captures the effect of both storage facilities on the delay of tankers. Analyzing the joint behavior of both storage levels seems intractable, but we can analyze the case where the storage for one liquid is finite and for the other, infinite. To obtain results for

the case where the storage tanks are finite for both liquids, we iterate over models where we let the liquid with finite storage capacity alternate; the size of tankers for the other is adjusted, so the unloading time closely follows the characteristics of the unloading time in the previous iteration. The performance of this approximation is evaluated in terms of the expected sojourn time of tankers and the blocking probability of a tanker, as well as the performance measures related to the storage level of the tanks. Our results are verified by simulation.

3 - Stochastic Optimization for the RORO Stowage Planning Problem

Alastair Main, *Dario Pacino*, *Filipe Rodrigues*, *Cecilia Lund*, *Siv Hansen*

The reduction of green house gas emissions(GHG) is one of the United Nations' sustainability development goals; we present a study of how stowage planning for Roll-on/roll-off (RORO) vessels can be optimized to reduce GHG emissions, by reducing the fuel consumption of RORO vessels. RORO shipping is dedicated to the transportation of wheeled heterogeneous cargo, e.g. cars, semi-trailers, buses, and farm equipment. A known way for ships to reduce GHG emissions is by reducing time spent at the port, increasing sailing time, and utilizing slow steaming.

The study focuses on optimizing the stowage planning process of RORO shipping. A stowage plan designates where cargo goes on board the vessel and the sequence. Certain restrictions have to be taken into account when creating stowage plans, such as variations in cargo arrival time, cargo size, port loading, and unloading succession. As handling the cargo in a RORO vessel follows a FILO queue, resulting in blocking cargo when loading and unloading the vessel at multiple ports, it is essential to consider the paths taken by the cargo on board the vessel. All previous studies assume all the cargo is available for stowage when the ship arrives at the port - usually not the case.

We present a novel stochastic optimization model to reduce time spent handling and re-handling cargo at each port by scheduling the cargo loading sequence. The scheduling of cargo takes into account cargo arrival times and also takes into account the pathing of cargo within the ship during loading and unloading. For industry-scaled problems, we also present an accompanying metaheuristic inspired by Variable Neighborhood Search. This project has opened up new research within the use of stochastic programming for RORO stowage planning problems, and future research might examine the use of stochastic models in a more practical setting.

4 - Robust Optimization for the Berth Allocation Problem Including Right-Hand-Side Uncertainty

Stefan Voss, *Marco Caserta*, *Yingjie Fan*

The Berth Allocation Problem (BAP) is an important problem within maritime shipping; it assigns and schedules incoming vessels to berthing positions along the quay of a container terminal. Unfortunately, disturbances and changes to elaborated plans may arise. Besides having uncertainty in various issues related to the BAP, e.g. estimated time of arrival, we also consider uncertain infrastructure (data) within the port. We need to transform the deterministic formulation of the BAP into a robust one, where some of the parameters of the model are uncertain; the probability distribution function of the uncertain parameters is unknown. A decision-maker can collect some historical data to come up with a bounded uncertainty set, however, where the uncertain parameters are known to change. Besides the classical way of handling uncertainty, we also consider right-hand-side uncertainty as it arises, e.g. with respect to uncertainty in given infrastructure components, like quay cranes or horizontal transport vehicles.

We utilize different formulations for the arising robust BAPs, including a robust heterogeneous vehicle routing problem with time windows, as well as a generalized set partitioning problem formulation. The basic idea is to define models, robust with respect to the uncertainty in the input data, and, subsequently, to solve the robust counterpart of these models by assuming the uncertain parameters will vary within a well-defined uncertainty set. These robust counterparts are deterministic optimization problems capturing the worst-case scenario of the original robust formulation. Numerical results on various settings are provided.

Port Performance and Miscellaneous. Part 2

Cluster: Maritime Logistics
Invited session
Chair: *Rosa G. González-Ramírez*

1 - A review on bilevel optimization models applied to maritime shipping and port logistics

José-Fernando Camacho-Vallejo, *Rosa G. González-Ramírez*

In this research, a bibliometric analysis of published papers devoted to study maritime logistics problems under a bilevel optimization approach is discussed. First, some basic introductory concepts regarding bilevel optimization are given. This research area is suitable to handle problems considering a hierarchy among decision-makers; i.e., two different decision bibliometrics participate in the problem. In the upper level, a decision-maker (the "leader") aims to optimize its own objective function, while considering some functional constraints, but ensuring a subset of variables is determined by the optimal solution of another lower-level optimization problem (the "follower"). The follower controls its own decision variables and has its objective function to optimize. The follower's decision directly impacts into the leader's objective function or its decision space. This hierarchized problem appears under diverse maritime logistics situations involving different stakeholders. For example, suppose the case where a network of port terminal operators imposes prices of their transfer services aiming to maximize their profit. Hence, the shipping lines will decide whether to select a port terminal and use its services based on the imposed prices aiming to minimize their operational costs. Another example can consider the situation where a public agency or authority may define the construction of a dry port, aiming to minimize operation and maintenance infrastructure cost, while in the lower level, the follower, freight forwarders aim to decide their optimal shipping routes. This hierarchized situation has been addressed in the context of the policy-making process, the existing competition among ports, and the regulation activities of port authorities and their concessionaires or port terminal operators. In this research, each of these echelon or components of maritime supply chains have been identified. A systematic review is performed to compare the common consideration of leader and follower. Moreover, the developed solution methodology is identified, and the application of bilevel optimization models into case-studies is described. From this review, a detailed classification is done, and the main drawbacks for modelling and solving maritime logistics problems under a bilevel optimization framework are pointed out.

2 - An approach to the digital transformation process in the context of logistic chain port after the COVID-19 experience

Lorena Bearzotti, *Javier Maturana-Ross*, *Maria Isabel Vega*, *Nicolás Tapia Menares*

During the covid-19 pandemic, a series of disruptive events affected global supply chains. Additionally, an explosive increase in e-commerce occurred, approximately triplicating the amount of transactions in the early stages of the pandemic, and forcing logistics companies to adapt their processes to cope with the upcoming challenges. The resilience of the global supply chain was tested, and the digital transformation was the great ally to respond quickly and efficiently to the new scenario, where plans related with the digital transformation were accelerated or indicated as priority. In this study, we analyze the digital transformation in the context of supply chain with focus on the port logistics chain and classifying the best practices and learned lessons from their adaptation process, to propose an organizational strategy to implement the digital transformation process in organizations. In this context, the study looks for how the pandemic really affected different logistics organizations, using a series of questions corresponding to various topics, divided into 18 questions focusing on basic knowledge, pre-pandemic status, during the pandemic and post pandemic, and also seeking to collect data on problems during digital transformations. After applying the questionnaire, some preliminary

results can be presented; for example, 85% of the companies associated with logistics presented digital transformations and had a very good perception. There is still low automation, however; with only 29% of organizations confirming a good level of automation. On the other hand, most of them find improvements in the management of the already automated processes. An interesting result was the adaptability of the management seen in a good way, where 85% of the respondents see a good adaptability of their superiors. Finally, 92% believe a good digital transformation process is a good positive differentiation mechanism from competitors. Based on the above, a study model is created establishing good practices, such as a diagnosis of technological knowledge and leveling of knowledge. We intend to later apply a case study, with solutions to the problems exposed by the respondents, such as repositories, documentaries and data visualization.

3 - Review of port tariff literature
Alejandra Gomez_Padilla, *Rosa G. González-Ramírez*

In this research, we review port tariff literature, considering the main themes identified by Acciaro (2013): strategic pricing, port pricing and infrastructure cost recovery, port pricing and market conditions, pricing and external costs and empirical studies. We are interested in identifying optimization models and methods used to define tariff structures and their relation with strategies, infrastructure and the market. Strategic pricing schemes are based on various tariffs between cargo owners due to segment demand or freight traffic. Infrastructure tariffs are usually managed by the port authorities and may be influenced by policies and regulations; the market is influenced by the global supply chain. With this research, we identify the main elements mentioned in literature to decide pricing strategies, infrastructure and market characteristics, and we highlight as main themes the following: strategic pricing, port pricing and infrastructure cost recovery, and port pricing and market conditions. Mathematical modeling problems, as an issue identified, was not very popular with Acciaro (2013); nowadays, mathematical modeling has been one of the main tools to model and analyze situations.

Metaheuristics for Social Impact

Cluster: Metaheuristics
Invited session
Chair: *Helena Ramalhinho Lourenco*

1 - Heuristic-based decision-support system for integrated home care planning
Bruno Vieira, *Jésica de Armas*, *Helena Ramalhinho Lourenco*

With the continuous increase in longevity worldwide, the elderly population requiring home health and social care has been continuously growing over the years. Planning combined home health and social services has been shown to be a very difficult task for current decision-makers, not only due to the high number of working regulations and user-related necessities needing to be considered, but also due to the need for synchronizing both services.

The multi-objective and highly constrained nature of the home health and social care routing and scheduling problem (HHSCRSP) makes obtaining efficient solutions an extremely complex and time-consuming task for planners. Social and health care providers are not only interested in a decision support system (DSS), (partially) automating and accelerating the laborious planning process, but they are also keen to find answers to some logistical questions: What is the impact of including synchronization requirements and dependencies between services? What happens if we increase the break length duration? Should we hire more caregivers on a part-time or full-time contract?

Therefore, we propose two heuristic methods to find high-quality solutions for the HHSCRSP problem while optimizing for different objectives, such as minimizing non-effective working time and maximizing the continuity of service. These methods optimize towards several other secondary objectives, such as minimizing the number of unscheduled jobs, minimizing the workload differences between caregivers, and minimizing the deviation between services for the same user. This is the first attempt to solve this problem, including all the necessary working regulations, one-week time horizon, continuity of service during the time horizon and between time horizons, synchronizations and dependencies between jobs, and the previously-mentioned different objectives. The design of these heuristics was inspired by social and health care providers in the Barcelona area. Both methods can obtain efficient solutions with low computational times. We also provide insights into parameter tuning, the trade-off between objectives, and the impact of some features of the problem in its solution. The proposed system has been made available via the development of a web-based DSS planners can use to obtain an efficient solution in an intuitive manner.

2 - Sizing service areas and staff for home social care
Daniel López Badell, *Jesica de Armas*

Home social care services (HSCS) are emerging as a social pillar for the care of dependent people. The demand for these services is increasing, mainly due to the aging of the population, and the challenge of meeting this demand, while maintaining proximity to the user and quality of service, is growing. To meet this challenge, Barcelona City Council proposes a new organizational model for HSCS; it divides the city into areas and assigns a team of caregivers to cover its services. Each area is made up of one or more contiguous zones, called superblocks. This model introduces a new problem caused by the variability of demand, leading to teams being over- or under-staffed. Planners aim to keep teams as stable as possible, as long as demand can be met and costs are not driven up by overstaffing. The planner can address this tactical problem by taking three actions: sizing the number of superblocks per area, allocating the number of caregivers per team, and allocating the number of back-up caregivers - who can cover all areas at a higher cost. These actions can be taken on a monthly basis to provide stability for staff and users. We propose an innovative MILP model for this optimization problem with two objectives: minimizing the demand requiring external resources and minimizing total costs. In addition, the model prioritizes full-time workers over part-time workers, to improve the working conditions for the maximum number of caregivers. We used Monte Carlo simulation to generate different scenarios according to the set of superblocks and the demand in the planning horizon. We combined this simulation with optimisation to carry out a parametric analysis of the model and an analysis of solutions according to the variability of the demand. Considering the multi-objective nature of the problem, we provide Pareto front solutions for the decision-maker to choose, according to the period criterion. Moreover, we plan to implement metaheuristics to solve rapidly a wider variety of larger instances. The result of this research is a simulation tool for planners to meet demand at a lower cost and to mitigate the impact of demand variability. This decision support system improves the decision-making process, previously carried out manually, and allows us to analyze what-if scenarios. Consequently, we achieve a positive impact on the working lives of caregivers, a better quality of the HSCS, and a reduction of costs.

3 - A biased random-key genetic algorithm for the home health care problem
Mauricio Resende, *Alberto Kummer*, *Olinto Araújo*, *Luciana Buriol*

Home health care is a complex problem, involving the scheduling of visits to home patients by health professionals, while satisfying a series of requirements. In this work, we address the Home Health Care Routing and Scheduling Problem, a multi-attribute vehicle routing problem with soft time windows, including additional constraints related to route inter-dependency for patients requesting multiple visits, such as simultaneous visits or visits with precedence.

We propose a biased random-key genetic algorithm (BRKGA) to solve the problem, incorporating state-of-the-art components recently proposed in the literature; we also obtain lower bounds for the problem using a mathematical programming solver. To evaluate our approach, we conduct computational experiments on a publicly available benchmark dataset.

Our approach outperforms previous local search-based methods by up to 26.1%, and our proposed BRKGA with state-of-the-art components

achieves improvements from around 0.4% to 6.36%, compared to previous results from a similar genetic algorithm. These findings demonstrate the effectiveness of our approach in addressing the Home Health Care Routing and Scheduling Problem.

4 - Optimizing the door-to-door transport of people with reduced mobility in the city of Barcelona
Helena Ramalhinho Lourenco, *Laura Portell*

Dial-a-ride problems (DARP) involve designing routes for transporting people from a specific origin to a specific destination. In particular, we introduce the rich heterogeneous DARP (rHDARP), inspired by the daily door-to-door transport of people with reduced mobility in the city of Barcelona. The rHDARP considers multiple constraints, such as heterogeneous users and vehicles, time windows, maximum ride and waiting times, and the possibility of an accompanying staff member when required. We apply our metaheuristic based solution to a real-world case study of the Transport Service for People with Reduced Mobility in Barcelona and demonstrate the efficiency and cost-effectiveness of our method compared to the current routes being used. Our results show a significant improvement in the quality of service for users and highlight the potential of our approach for solving real-world transportation problems.

Recent Applications of Metaheuristics and Matheuristics in Industrial Engineering Problems

Cluster: Metaheuristics
Invited session
Chair: *Debora Ronconi*

1 - On the advances of metaheuristics for parallel machines scheduling: Computational evaluation and guidelines for efficiency.
Gustavo Alencar Rolim, *Marcelo Nagano*

Metaheuristics are vastly adopted solution techniques in discrete optimization, and they have attracted a special attention from both scientific and industrial communities. In the past few years, the number of these approaches has been continuously growing with the emergence of new algorithms inspired by various phenomena. Since the unrelated parallel machines scheduling problem with sequence-dependent setups has many practical applications, it has generated a great impact in the field, resulting in the publication of numerous metaheuristics over the last 20 years. Although this research leads to new insights, it unavoidably induces certain problems. First, most of the methods proposed for makespan minimization do not provide a proper consolidation of the existing knowledge, so it is impossible to determine the ones most efficient in terms of the solution quality and the computational effort required. Second, the proposed methods become also increasingly complex, making them more difficult to understand and apply. Third, the state-of-the-art remains unclear due to the absence of rigor and adequate formalism, as well as the lack of a homogeneous framework to conduct a fair comparison between methods. To avoid or at least alleviate these issues, we interpret and implement several metaheuristics not previously compared and conduct computational experiments in a standardized set of conditions. We comment on their performance and classify solution encoding schemes, neighborhood exploration structures, and acceleration procedures to determine key aspects for the design of efficient algorithms.

2 - The Capacitated Family Traveling Salesperson Problem
Saúl Domínguez-Casasola, *Jose Luis Gonzalez-Velarde*, *Yasmin Rios-solis*

Retail companies have increased their desire to fulfill their consumers' orders rapidly. The picker's itinerary problem in massive warehouses motivates the Capacitated Family Traveling Salesperson Problem (CFTSP), a Family Traveling Salesperson Problem variant. In the CFTSP, we consider a graph where the nodes are partitioned into disjoint families; the problem consists of selecting a given quantity of nodes per family and deciding the sequence the nodes will be visited by a set of capacitated agents to minimize the total distance traveled by the pickers. We propose an integer linear programming formulation for this problem. We develop five specific sub-tour inequalities sets, then experimentally tested with linear solvers and compared with the classical approaches. We also propose an alternative for large instances: a Biased Random-Key Genetic Algorithm with four decoder algorithms finding high-quality solutions in short computational times.

3 - An adaptive multi-objective Biased Random-Key Genetic Algorithm to schedule technicians and tasks
Debora Ronconi, *Ricardo Damm*, *Antonio Chaves*, *José Angel Riveaux*

This work addresses an enhanced Biased Random-Key Genetic Algorithm to solve a multi-objective version of the Service Technician Routing and Scheduling Problem, involving daily planning of technicians' tasks (such as installing a device or providing equipment maintenance to businesses). Each task has a priority level representing the importance of the customer. In addition, the time windows of each task are associated with customers' availability, technicians having the skills allowing them to perform each task, and technicians' working hours and lunch breaks must be respected.

Two goals are sought simultaneously in line with the demands and expectations of large cities' customers. On the one hand, we aim to maximize the sum of priority values associated with the tasks performed. On the other hand, we aim to serve priority customers, as soon as possible. For this problem, a bi-objective mixed integer programming model is proposed. Furthermore, a multi-objective version of the Biased Random-Key Genetic Algorithm (multiBRKGA) is also developed to explore the problem's characteristics and search space properly. BRKGA works with a population of solutions, making it a natural candidate to be applied to multi-objective problems. Besides, the practical application of BRKGA in several combinatorial optimization problems motivates this study. Moreover, we use the Q-Learning method to control the parameters of the multiBRKGA during the evolutionary process.

Extensive numerical experiments are presented, and a comparative study was conducted with Non-dominated Sorting Genetic Algorithm II and the Strength Pareto Evolutionary Algorithm 2 - widely used methods and particularly well-suited for many combinatorial problems. Both algorithms were adapted to use random keys for the solution representation and the same decoders proposed for the multiBRKGA-QL. While the considered methods have a similar performance in small-sized instances, the proposed multiBRKGA-QL outperforms the other approaches in large-sized instances with up to 200 tasks and 30 technicians, the size of the instances appearing in practice. In a comparison made with the optimal Pareto set for small problems, on average, the BRKGA found 96% of the Pareto-optimal solutions, achieving 99.8% of the optimal Hypervolume and 0.999 of the Epsilon Multiplicative Indicator.

Metaheuristics Applied to Problems in Natural, Industrial and Health Crises

Cluster: Metaheuristics
Invited session
Chair: *Andréa Cynthia Santos*

1 - A fix-and-optimize matheuristic to solve the location-allocation of vaccination facilities: the case of Jalisco, Mexico.
Marisol Sarai Romero Mancilla, *Jaime Mora Vargas*, *Angel Ruiz*

Since the start of the most recent pandemic of COVID-19, around 755 million cases and 7 million deaths have been reported (WHO, 2023). Based on the availability of vaccines to contain the spread of COVID-19, different vaccination plans have been implemented around the world - some being more effective than others, depending on the social, territorial, economic, and political circumstances of each country. In Mexico and other Latin American countries with similar situations, COVID-19 vaccination has almost exclusively relied on ephemeral mass vaccination facilities, together with existing healthcare infrastructure. Other countries (USA and Canada, for instance) have opted into Pharmacy-based Immunization (PBI), however, a strategy using community and/or chain pharmacies as vaccination facilities to provide more accessible immunization services to the population. This research evaluates the feasibility and the expected performance if PBI would have been used in Mexico. To this end, we propose a mathematical formulation to address the location-allocation problem underlying pharmacy selection and the assignment of individuals to them. Since commercial solvers are unable to tackle efficiently the resulting formulation for real-sized instances, however, the formulation is embedded into a heuristic fix-and-optimize scheme, allowing exploration of the solution space in a more efficient manner. The case of Jalisco, Mexico, illustrates the performance of the proposed approach.

2 - Drone fleet management for searching post-disaster victims

Christophe Duhamel, *Amadeu Almeida Coco*, *Andréa Cynthia Santos*

The post-disaster response phase is critical for mitigating the casualties in an impacted area. The rescue teams have to proceed as quickly as possible to search for the victims, assess their health, provide first aid and transfer them to facilities. Yet, in many cases, finding victims is complicated, due to poor ground conditions. Thus, deploying a fleet of flying drones is a valuable alternative. Identification by drone sensors may be difficult, however, due to several parameters, such as the flight conditions, the victims' location or the sensors' capacities. Thus, the time required to perform identification may vary.

Given a heatmap of the impacted area corresponding to the estimated number of victims in each zone, and a fleet of flying drones, we consider the Probabilistic Drone Routing Problem (PDRP); it consists of organizing the drones' routes and the time spent at each zone, to maximize the expected number of identifications. The drones are subjected to range constraints due to their battery, forcing them to recharge at their base. Moreover, anti-collision rules are set at each zone. The probability of identification in an observation is given for each individual. Correlation on successive observations is considered.

We propose an Adaptative Large Neighborhood Search (ALNS) for the PDRP. The initial solution is computed by a Greedy Constructive Heuristic (GCH). It first starts with an empty drone route. At each iteration, one operation is added to one drone: move to another zone, perform another observation or return to the base for recharging. The selection criterion depends on the energy left, the travel time, the energy consumption and the expected number of identifications of each possible operation. Six removal operators and five insertion operators are proposed for the ALNS. Each one relies on a specific rule for removing or adding nodes / observations from the drone routes. In addition, two shaking procedures are proposed.

The methods are evaluated on a set of grid instances with up to 900 nodes. A set of instances from the explosion on the port of Beirut (Lebanon, August 4th, 2020) with 1040 nodes is also proposed. GCH can provide high quality solutions in less than one second. Thus, it can be used to quickly assess configurations and scenarios just after the disaster. The ALNS improves upon GCH and can provide solutions in less than ten minutes for most instances.

3 - Learnheuristics in Health Informatics

Felipe Cisternas-Caneo, *Broderick Crawford*, *Ricardo Soto*, *Franklin Johnson*

There is a growing need in every field for access to accurate and quality information for decision-making. Health Informatics is already considered an interdisciplinary scientific discipline, comprising the convergence between Informatics and Applied Health Sciences, and has been rapidly being introduced into healthcare systems around the world. The scientific community has had great interest in applying it in the medical field for the following reasons: 1) access to large computational capacities and 2) large volumes of existing data. These techniques have been successfully applied to image analysis, natural language processing, sentiment analysis, and analysis of medical examinations. A practical application of machine learning techniques in the medical field is to predict a possible hypotension during the dialysis process, from exams and vital records. While these methods are effective, they have scalability issues and are sensitive to data change. The large volume of data available for processing may contain redundant or unnecessary variables for classification, however, decreasing the accuracy of the results and the performance of the predictive algorithms. Feature selection (FS), one of the most widely used preprocessing techniques, eliminates irrelevant and/or redundant information to keep only the most representative information of the dataset. FS is a combinatorial optimization problem, where we minimize the number of features and maximize the accuracy of classification or learning algorithms. Metaheuristics (MHs) are general-purpose algorithms, solving any complex optimization problems, with few modifications; various applications of continuous MHs solve the FS, with very good results. As the FS is a binary problem, these continuous MHs underwent a binarization process - complex and leading to errors. Therefore, there are proposals using reinforcement learning techniques to vary the binarization as the optimization is performed - "Learnheuristics". In this work, we apply a Learnheuristics based on Pendulum Search Algorithm as a MH and Q-Learning as a dynamic selector of binarization scheme to improve the efficiency, scalability and accuracy of the prediction of hypotension during the dialysis process in real patients. Our proposal will help medical staff to focus relevant attention.

4 - An Iterated Local Search metaheuristic applied to a particular scheduling problem found in technological disasters

Andréa Cynthia Santos, *Thiago Jobson Barbalho*, *Juan Luis Jiménez Laredo*

Residential areas have become closer to industrial ones due to the concentration of population in urban regions; some of these industries are classified as dangerous, according to the activities and hazardous materials required in their production or service processes. In spite of several regulations to reduce risks, technological accidents can happen, as was the case of the fire in a storage area of dangerous industrial products close to Rouen in France, 2019, and the Beirut port explosion in Lebanon, 2020. In this context, we investigate how to clean an area affected by a technological disaster to attenuate the impact over the population and environment; this issue is modeled as a Resource Constrained Project Scheduling Problem with Risk and Priorities (RCPSP-RP) policies. Depending on the extent of the area, the problem can also integrate a routing problem, where travel times are modeled as sequence-dependent setup times. Four scales of risk are applied (low, medium, high and critical), while three policies of priorities are considered (strict, moderate and none). The goal of RCPSP-RP is to define a schedule for cleaning nodes in a time horizon so the overall risk is minimized. The proposed mathematical formulations can solve small- to medium-size instances; an Iterated Local Search (ILS) metaheuristic is also proposed to solve large instances of RCPSP-RP. ILS is composed of three basic components: a heuristic to produce a feasible solution, a local search and a perturbation method. A randomized heuristic to produce feasible solutions, a first-improvement local search, and a perturbation using random swaps are applied in the proposed ILS. Extensive numerical experiments have been done to analyze several scenarios, producing insights for the application developed in this study.

Metaheuristics I

Cluster: Metaheuristics
Invited session
Chair: *Jiefeng Xu*

1 - Relaxed Models and Metaheuristic for Surgery multi-room planning and scheduling
Bruno Salezze Vieira, *Antonio Chaves*

This work proposes a mathematical model for surgery multi-room planning and scheduling and a metaheuristic approach to solve the problem. The problem was modeled using real-world data from a hospital and considered various factors, such as duration of each surgery step, surgeon availability, room availability and specialty, equipment requirements, and patient availability, to optimize the whole scheduling of surgeries across a planning horizon. The problem was approached as a flexible job shop scheduling (FJSS) problem, with rooms and surgeons as machines and surgery steps as jobs. The proposed models consider different room bottleneck premises to calculate strong bounds for the problem. The metaheuristic approach combines a well-known metaheuristic Biased Random Key Genetic Algorithm (BRKGA), with a machine learning technique to optimize the BRKGA parameters during execution, without calibration. The models and metaheuristic publicly available test instances from literature, and procedure generated one from statistical data. The results with the public instances outperformed previous results, and the calculated bounds proved one solution as optimal. Furthermore, the results with the new instances show small gaps for some instances and the metaheuristic computational efficiency solving large schedules previously scheduled by hand. This study provides a practical and effective solution to the challenging problem of surgery multi-room planning and scheduling, with potential implications for improving patient experience and hospital efficiency.

2 - Stochastic Network Design for Energy Transition
Umur Hasturk, *Albert Schrotenboer*

Hydrogen can be produced from water, using electricity. Unlike electricity, hydrogen can be stored in large amounts for future use, enabling solar and wind energy generation to occur asynchronously from its usage. Therefore, hydrogen is anticipated to play a vital role in achieving a climate-neutral economy. Nevertheless, managing the logistics for hydrogen is a challenging and intricate process.

We consider a hydrogen network of production/storage facilities and customers. In this network, the hydrogen is distributed by pipelines and trucks. We can build new infrastructure or convert the existing natural gas pipeline infrastructure for hydrogen; these are more suitable if the hydrogen volume is high. Otherwise, trucks are cheaper for short-term planning, and they also provide flexibility, in case of unforeseen shortages to customers. To address this, we assume the production and consumption levels are uncertain; this can also reflect uncertainty in when and how the hydrogen economy will emerge in society.

We consider this problem in a multiperiod setting, to answer the long-term decisions of a growing economy. Among the plans balancing production and consumption successfully, we provide a cost-efficient policy, by deciding when and at what capacity to build pipelines and utilize trucks.

We model this multiperiod stochastic network design problem as a two-stage recourse model, subject to sampled scenarios. The first stage includes decisions of opening pipeline infrastructure. Then, truck utilization, flow decisions, and inventory levels are given, after realizing a scenario for each commodity in the second stage. We implement a progressive hedging-based matheuristic to solve this problem to near optimal. As a benchmark, we employ sample average approximation on the basic two-stage recourse model.

3 - A New MIP/Tabu Search-Guided Method for Supply Chain Network Design
Jiefeng Xu, *Sai Rajesh Mahabhashyam*

We consider a practical capacitated fixed charge facility location problem in the design of a two-echelon supply chain network. Products are transported from supplier locations to a set of consolidation distribution centers (CDC) to consolidate and, then, are delivered from CDCs to downstream facilities (DF). Many proven benefits for using CDC consolidation make it important to develop an efficient optimization tool to help make optimal strategic decisions on locations/sizes of required CDCs. We address this challenge by an integration of modeling and solution approaches. We first formulate the problem as a mixed integer programming (MIP) model, where binary variables represent the decisions of using or not using specific CDC candidates, while continuous variables indicate the product flows from supplier locations to used CDCs and from used CDCs to DFs. The objective is to minimize the total costs (including fixed costs and variable operating costs for CDCs and inbound and outbound transportation costs through CDCs), subject to certain practical constraints. We must go beyond this formulation, however, because practical problems often require standard MIP solvers, such as Cplex, lengthy computation time to obtain an optimal solution. To overcome this limitation, we develop an efficient tabu search (TS) algorithm utilizing two MIP models: (1) a neighborhood search (NS) model representing an approximation to the original problem, aiming to find the best move for CDC selection from an approximate neighborhood space; and (2) a cost correction (CC) model to evaluate the actual cost of the original problem based on the given CDC selection. Our TS algorithm incorporates generic ejection chain neighborhood moves for selecting CDCs, guided by tabu restrictions and an aspiration rule based on a set of constraints supplementing the NS model at each iteration. The Cplex solver is used as a subroutine to solve the NS and CC models. At each iteration, only constraints w.r.t. tabu restrictions and the aspiration rule for the next iteration are altered, providing warm-starts for Cplex from the current CDC solution to expedite the solution time for the NS model. By running the NS model iteratively and calling CC model on-demand, our TS method yields the optimal solutions for several large real problems, using only a small fraction of the computational time required by Cplex. We also validate the contribution to overall efficacy provided by the various TS components.

4 - A Multi-objective Optimization Model for Outpatient Care Delivery with Service Fairness
Rohit Kapoor, *Soumyajyoti Datta*, *Peeyush Mehta*

Purpose - Outpatient care delivery is one of the key revenue sources of a hospital which plays a salient role in timely care delivery. The key purpose of the study is to propose a multi-objective simulation-based decision support model that considers the cost of care delivery and patient dissatisfaction as its two key conflicting objectives. Patient dissatisfaction considers service fairness. Patient idiosyncrasies, such as no-show, unpunctuality and balking, have been considered in the model involving multiple classes of patients.

Design/methodology/approach - A model has been designed using data collected from field investigations. In the first stage, a queuing theory based, discrete event simulation model has been developed. Genetic algorithm has been used to solve the scalarized problem and obtain actionable insights. In the second stage, non-dominated sorting genetic algorithm II (NSGA-II) has been involved to achieve the Pareto-optimal fronts considering equal priority of the two objectives.

Findings- The computational results considering various parameter settings can help in efficient resource planning, while ensuring better care delivery. Our model provides structural insights as to the business strategy of healthcare service providers on optimizing the dual goals of care delivery cost and service fairness.

Originality- The study is one of the early works that helps to improve the care delivery process by taking into consideration environmental factors as well as service fairness. The study demonstrates the usage of simulation-based multi-objective optimization to provide a more sustainable patient-centric care delivery.

Metaheuristics II

Cluster: Metaheuristics
Invited session
Chair: *Laura Mónica Escobar Vargas*

1 - A New Metaheuristic to GCOP
Bayron Fuentealba

This paper presents a two-phase local search to solve the Generalized Cluster Orientation Problem (GCOP); in this problem, different locations (nodes), not necessarily together, belong to a group or cluster K, where each node contributes a certain amount of benefits when visited. The goal is to maximize the benefits obtained by making a complete journey, visiting at least once each cluster without exceeding the budget B assigned for the trip. To solve the GCOP, a local search metaheuristic is proposed, divided into 2 phases: a constructive phase and a improvement phase. The first phase uses an NNH algorithm, generating the initial feasible solution to the problem - to this end, it meets the constraints set forth; starting from a random node, it looks for the next closest node not belonging to the clusters already selected. The initial solution will have a length equal to the number of clusters. The second phase uses different local search and exchanges algorithms, presenting modified and adapted algorithms to the problem, among which stand out: Greedy, 2OPT, and 3OPT. It also has node exchange and elimination algorithms, to replace high-cost edges with lower cost ones. These algorithms will be detailed in the next section. The following is the pseudo-code used for the proposed heuristic, performsing multiple iterations accessing different functions; they have the task of deepening and diversifying the space to find a solution comparable to the original paper. It begins with a function called Greedy, performing the initial solution, meeting the constraints of Budget(B) and Clustering (K). After creating the initial solution, a vector is generated, allowing storage of the 10 best partial solutions; if at any moment it is impossible to add more nodes to the solution, the local search can be started from one of these best solutions. A 3OPT is performed to decrease the cost (distances) of the proposed solution. Afterwards, Greedy2() function is used, to add all possible nodes not in the current solution, regardless of whether the insertion position is the least distance; if it is possible to make the insertion, it is performed.

2 - Generic Metaheuristic Solver for Problems with Permutative Representation

David Woller, *Miroslav Kulich*

We propose a novel formalism for a large class of problems with permutative representation and a generic metaheuristic solver for addressing these problems. Problems with permutative representation are defined as problems whose solution can be encoded as an ordered sequence. Individual elements may repeatedly occur in the sequence, as long as the number of occurrences stays within specified bounds; thus, the solution sequence does not have a fixed length. The objective function can be arbitrary, and a penalization mechanism treats additional constraints. The solver is intended to obtain good-quality suboptimal solutions, perform better in terms of scalability than commercial MIP solvers and, at the same time, save the user from the time-consuming development of custom metaheuristic algorithms. The only user requirement is to formulate the problem in the proposed formalism and provide the fitness and penalty functions. The proposed multipurpose solver is highly modular and implements several established metaheuristics, both local search-based and evolutionary. Several construction procedures and a large bank of perturbation, crossover, mutation, and local search operators are either adapted or newly proposed to address any problem with permutative representation. Finally, static and adaptive penalization mechanisms are incorporated, and the best configuration for each problem is obtained by an automatic algorithm configuration tool. The solver is extensively benchmarked against the Gurobi optimizer on three classical problems: Capacitated Vehicle Routing Problem, Quadratic Assignment Problem, and Non-Permutation Flowshop Scheduling Problem. In an experiment with a fixed computational budget, the proposed solver convincingly outperforms Gurobi in terms of scalability and solution quality. The solver is also deployed to real-world problems richer in constraints: Travelling Salesperson Problem with Traversal-Dependent Edge Deletion motivated by a mining application, Electric Vehicle Routing Problem, and Transmission Maintenance Scheduling Problem from ROADEF Challenge 2020 and benchmarked against problem-specific metaheuristic solvers in the latter two cases. Here, the generic approach's scalability limits and constraint satisfaction success rate are investigated in detail.

3 - VR-based Visualization tools to evaluate the results of Multiobjective Optimization applications to exterior and interior spaces

Magesh Chandramouli

This presentation will discuss two applications of genetic algorithm-based MOO (Multiobjective Optimization) - one for exterior space (urban land use) and another for interior (optimizing interior spatial configurations). In the face of increasing demands by population and several other factors, Urban spatial analysis has required multifaceted entailing multiobjective optimization tools. One study, the MOGA (Multi-objective Genetic Algorithm), designed to generate alternative land use scenarios, offers a visual evaluation tool for assessing Pareto solutions. Typically, when using GAs, planners, decision-makers, and administrators get multiple viable solutions as a Pareto set, from which to make a challenging selection, since all solutions are meant to be equally fit. Consequently, a visualization tool is employed here, so decision-makers can better evaluate alternative solutions from the Pareto set. The land use scenarios are modeled as an optimization problem with the goal of sustainable urban land use planning. The GA was implemented for multiple objectives, such as maximization of per capita green space, maximization of urban housing density, maximization of public service space, and conflict resolution among neighboring land uses. For the interior space problem, the presentation will focus on an earlier published study on the design and implementation of a Desktop VR (Virtual Reality) framework for generating and evaluating Pareto-optimal alternate 3D spatial configurations using GA (genetic algorithms). The 3-tier framework involves the generation of Pareto-optimal plans using GA, subsequently visualized - first, using a Java-based 2D Interface and, finally, in the form of a 3D VR scene. The interior space allocation problem is formulated and implemented as the "optimal configuration of artifacts". This study applies a tool to not only visually evaluate the plans, but also to interact with those plans to develop them further, if needed. Besides enabling the optimal spatial configuration of the scene elements, this framework also facilitates evaluation and interaction via 3D VR worlds.

4 - Impact of Work Shifts Scheduling for Maintenance Technicians in a Multiple Depot Maintenance Vehicle Scheduling Problem

Laura Mónica Escobar Vargas, *Rubén Iván Bolaños*, *Cesar Marin*, *Luis Miguel Escobar Falcón*

From a technical point of view, the operational planning of public transportation systems has its focus on the scheduling and rostering of work shifts, specifically for drivers. The optimal programming of preventive maintenance tasks, among other conditions, are not present in the scheduling programing and are usually found in separate analysis and mathematical models - primarily due to the increase in the computational effort and mathematical complexity, when considering the programming of preventive maintenance or the rostering of maintenance technicians. The main goal is to obtain the optimal solution of the problem in each case, which ensures the expected behavior of the cuts to preserve the optimality of the original problem. Although the model can improve the representation of the real-life problem, by adding specialized cuts based on interesting behaviors of the original rostering model, this can lead to increased computational effort, even when it can remove low-quality subspaces and in the end produce a decrease in the number of nodes analyzed, in a method such as Branch and Cut. To ensure the proposed model presents the expected calculation behavior, a set of equations are added to the original multiple depot maintenance vehicle scheduling problem, where the found solution will ensure the preventive maintenance tasks and the minimum number of maintenance technicians necessary for each task. In a first stage, the Genetic Algorithm of Chu-Beasley, which uses constructive heuristics, generates the initial solution considering the complete model. In the second stage, the solutions obtained through the genetic algorithm are refined by a Set Partitioning process (SP), whose variables (columns) correspond to the set of itineraries found in the entire final population; the analysis of the itineraries are used to find possible improvements in the incumbent of the Genetic Algorithm. Then, the new solution is used as a starting point of the proposed model with the deterministic method, and the initial solution is used in combination with the solver CPLEX, using the branch and cut algorithm. To test the model reliability, the new group of constraints are tested using instances generated with random structures, a relatively small number of technicians and the test system of interest: Integra S.A.

Metaheuristics and Machine Learning

Cluster: Metaheuristics
Invited session
Chair: *Simone de Lima Martins*

1 - Dynamic operator management in meta-heuristics using machine learning
Maryam Karimi Mamaghan, *Mehrdad Mohammadi*, *Wout Dullaert*

The performance of meta-heuristics highly depends on their search operators; it is critical to efficiently choose and manage the operators from a set of potential operators available in the literature (Karimi-Mamaghan et al., 2022). In this regard, we need to decide which subset of operators should be considered at each stage of the search and how an operator should be selected from the subset to be applied to the solution at each iteration; we call the former "portfolio selection" and the latter "operator selection". These decisions become more challenging as the number of available operators increases.

Contrary to classical methods constructing the operator portfolio offline (static) without changing it throughout the search, this study aims to construct an online portfolio evolving throughout the search. For this aim, this study develops a general framework to dynamically perform the portfolio selection, using tabu search concepts and Q-learning as a reinforcement learning algorithm to select operators. Because not all operators are useful at each point of the search process (Kheiri et al., 2016), our approach can add effective, and exclude ineffective, operators at different stages of the search to attain better algorithm performance without adding significant computational overhead. Based on this idea, the operators found to be inefficient at some stages of the search are removed from the portfolio for a fixed number of iterations (tabu list size), potentially to be added to the portfolio later in the search. Moreover, new operators might be invited to be included in the portfolio for only particular stages of the search. After the portfolio selection at each stage, Q-learning selects the most efficient operator at each iteration.

The applicability and the performance of the proposed framework are assessed by solving the permutation flowshop scheduling problem. Preliminary results show an improvement in terms of optimality gaps and convergence rate compared to the offline portfolio selection and state-of-the-art algorithms.

2 - Hybrid BRKGA and Q-Learning for dial-a-ride-problem with heterogeneous private fleet and common carrier
Antonio Chaves, *Cleder Schenekemberg*, *Leandro Coelho*, *Thiago Guimarães*

The Dial-a-Ride Problem (DARP) aims to optimize the cost of providing transportation services to individual users, while considering service constraints, such as time windows, service and route durations, and ride time. In some cases, the demand for transportation services exceeds the capacity of the provider's fleet, however, resulting in unmet user requests. To address this issue, we solve the Dial-a-Ride Problem with Heterogeneous Private Fleet and Common Carrier (DARP-HPFCC), allowing for outsourcing of unmet demand to mobility-on-demand services and taxis. In this context, all outsourced vehicles are assumed to have unlimited capacity and to be available at any time, ensuring the satisfaction of all user requests, particularly during peak times. To solve the DARP-HPFCC, we implement a parallel metaheuristic combining the Biased Random-key Genetic Algorithm and the Q-learning method. The BRKGA-QL learns the optimal parameter configuration throughout the evolutionary process. Q-Learning, a model-free reinforcement learning algorithm, has a set of states (parameters) and a set of actions representing a parameter value, with one state for each BRKGA parameter. The value function of the Q-Table is updated based on the Bellman equation. BRKGA-QL is flexible enough to solve the classical DARP, and our computational experiments demonstrate its efficiency. Additionally, we present a real case study to assess the effects of heterogeneous vehicle capacity on shared transportation, highlighting the benefits of combining heterogeneous private fleets and common carriers in dial-a-ride problems for both the provider and users.

3 - Reinforcement Learning for Multi-Neighborhood Local Search
Roberto Maria Rosati, *Sara Ceschia*, *Luca Di Gaspero*, *Andrea Schaerf*

In metaheuristics, it is challenging to determine a single best parameter configuration, especially when instances vary considerably in size or problem-specific characteristics, particularly in real-world scenarios. To address this issue in a multi-neighborhood search, we propose the use of reinforcement learning to adjust neighborhood probabilities, focusing on Simulated Annealing as an underlying metaheuristic. In Simulated Annealing, a move is chosen at random at every iteration, according to probabilities assigned to the neighborhoods. In the traditional setting, these probabilities are determined with an offline tuning procedure and remain unchanged during the search. We assign the same initial probabilities to the neighborhoods, and, then, we employ a reinforcement learning strategy at each cooling step to rebalance the weights of the neighborhoods, based on their performance during the last temperature batch. A reward system is used to quantify this performance and assign higher rewards to the neighborhoods contributing the most to improving the objective function. The computational time required for evaluating and performing different moves can vary, however, so neighborhoods consuming more time are penalized, enabling the metaheuristic to adjust its parameter values and to assign higher probabilities to neighborhoods providing better cost-time effectiveness in the specific stage of the search. To evaluate the effectiveness of our approach, we consider two case studies, namely the examination timetabling problem, proposed by Carter et al. (1996), and the sports timetabling problem, from the ITC2021 competition (Van Bulck and Goossens, 2022). Both problems have numerous algorithms developed, and multi-neighborhood Simulated Annealing has already achieved state-of-the-art results using offline tuning techniques. Our new Simulated Annealing method, with adaptive multi-neighborhood probabilities, improves upon already competitive results. In addition, it is rather robust with respect to learning hyperparameter configurations, requiring less parameters and much less tuning effort than traditional offline parameter tuning.

Multi-objective Metaheuristics for Healthcare and Location

Cluster: Metaheuristics
Invited session
Chair: *Benjamin Ivorra*

1 - Ant colony optimization of Pareto front approximation
Jaroslav Janacek, *Marek Kvet*

A Pareto front of multicriterial problem solutions represents the only one exact solution of the problem having two or more equivalent objectives. When the number of all problem solutions is finite, determination of the exact Pareto front is a very hard task; exact computational time demanded approaches are replaced by various metaheuristics, providing a good Pareto front approximation. The acceptable computational time of metaheuristic balances a declination of the obtained solution from the Pareto front. This contribution presents one of the spectrum of metaheuristics implemented to find non-dominated solutions of the public service system design problem with two conflicting criteria. The metaheuristic is based on the ant colony optimization principle applied to minimizing a difference between a current set of non-dominated solutions and the Pareto front. The efficiency of the proposed metaheuristic is tested by numerical experiments with benchmarks, having known exact Pareto fronts.

2 - Tabu search approach to multicriterial location problem
Marek Kvet, *Jaroslav Janacek*

Designing a good public service system, providing a geographical region with service via service centers, is a very complicated task, especially when several objectives are applied to its quality evaluation. A Pareto front of the public service system designs represents a very helpful tool for any designer needing to take into account various requests of public representatives. As the Pareto front determination is a computationally difficult task, a series of heuristic approaches has been developed. One of these approaches (called "gradual refinement") proved to be very promising, but its efficiency might be improved by not repeating some elementary swap routines. This contribution is focused on application of tabu search features to enhance the gradual refinement process and increase its efficiency by suspending the minimally useful applications of the routines. The resulting metaheuristic is verified by numerical experiments performed with benchmarks, and the resulting Pareto front approximations are compared to the exact Pareto fronts.

3 - A multi-objective approach to identify parameters of compartmental epidemiological models - Application to Ebola Virus Disease epidemics.
Benjamin Ivorra, *Miriam Ruiz Ferrández*, *Juana Lopez Redondo*, *Angel Manuel Ramos*, *Pilar M. Ortigosa*

In this work, we propose a novel methodology to identify parameters of compartmental epidemiological models, based on solving a multi-objective optimization problem by fitting some of the model outputs to real observations. First, according to available data from the considered epidemic, we define a multi-objective optimization problem, where the model parameters involve the optimization variables. Then, we solve this problem by considering a particular optimization algorithm called ParWASF-GA (Parallel Weighting Achievement Scalarizing Function Genetic Algorithm). Finally, the decision-maker chooses, within the set of possible solutions, the values of parameters better suiting their preferences. To illustrate the benefit of using our approach, we apply it to estimate the parameters of a deterministic epidemiological model, called Be-CoDiS (Between-Countries Disease Spread), used to forecast the possible spread of human diseases within and between countries, considering data from different Ebola outbreaks from 2014 to 2019. In all cases, the proposed methodology helps to obtain reasonable predictions of the epidemic magnitudes with the considered model.

Metaheuristics for Transportation and Routing I

Cluster: Metaheuristics
Invited session
Chair: *Cristian Oliva*

1 - Maritime SAR vessel allocation with cost-effectiveness trade-off
Ronald Pelot, *Alireza Forouzangohar*

Maritime incidents, whether commercial shipping, fishing or recreational boating, are often complex situations. Being on the water is of course a key risk in itself, but many other factors increase the urgency of response: the weather, condition of the vessel, status of the passengers, ocean conditions, etc. Fast and effective response is needed to mitigate the consequences following an incident. In this research, we propose a location-allocation model for optimizing maritime Search and Rescue (SAR) vessels, with a case study in the Atlantic region of Canada across two operational seasons. The region is gridded to allow for spatio-temporal analysis. A stochastic approach is used to address the uncertainty over incident occurrence (using historical data over the years 2014-2016 drawn from the Canadian Coast Guard's SISAR database) to obtain the probability distribution in each grid using Kernel Density estimation. A non-linear multi-criteria model optimizes insufficiency probability (related to the responders' capacity to cover all incidents), capital and operating costs for response vessels, primary and backup coverage, and effectiveness of a SAR response resource. A rating scale has also been defined based on expert opinion to reflect the capability of each response vessel class for dealing with each incident. The problem has been formulated with Dynamic programming for small scale examples, and metaheuristic approaches have been used to solve it for large scale. The results present the trade-off between cost, coverage, and response effectiveness. A comparison between the optimum solution and the current fleet configuration in the Atlantic region of Canada was made, and sensitivity analysis of different model parameters showed alternative arrangements along with different managerial insights.

2 - Toward better service quality with dynamic feeder service and maximum headway at mandatory stops
Bryan David Galarza Montenegro, *Kenneth Sörensen*, *Pieter Vansteenwegen*

Feeder bus services transport passengers from rural or suburban areas to areas with more public transportation options. On the one hand, fully flexible demand-responsive feeder services efficiently tailor their service to passengers' needs. Traditional feeder services, on the other hand, offer predictability and easier cost control. This paper considers a semi-flexible, demand-responsive feeder service combining positive characteristics of both traditional and fully flexible services. In this feeder service, mandatory bus stops have a maximum allowable headway for bus departures and optional stops are only visited with demand for transportation nearby. When new passenger requests arrive, performance of the feeder service is optimized in real-time. A metaheuristic with two phases is developed to optimize the service. An insertion algorithm generates an initial solution in the first phase. If possible, an improvement heuristic - a semi-random, greedy construction algorithm - improves the initial solution in the second phase. The dynamic optimization method is compared to a model optimizing the service in a static manner, i.e., when all requests are known beforehand; it performs well, with an average gap of 6.5% with respect to the static model and an average acceptance rate of 95.1%.

3 - The value of flexibility in periodic waste collection vehicle routing problems
Christina Hess, *Alina-Gabriela Dragomir*, *Karl Doerner*

In this work, we deal with a real-world inspired periodic vehicle routing problem with intermediate facilities (PVRPIF), arising in the field of solid waste collection in urban areas. The waste is collected with a fleet of vehicles located at a central depot and delivered to incinerators; trips to these intermediate facilities must be scheduled mid-route, when necessary, and at the end of the route, so the vehicles return to the depot empty. Since most locations do not have to be visited every day, a planning horizon of several days is considered. Based on real-world handling, in periodic routing problems one typically selects a visit schedule from a given set of possible alternatives; these sets contain schedule variations with a fixed number of visits per location, and the number of alternatives is usually small. In our work, we investigate the value of flexibility, by modifying the schedules to a varying extent using a set of real-world-inspired instances. We study the effects of different visit frequencies and more flexible schedules on the vehicle routes, with the goal of keeping the routes as short as possible, collecting the total amount of waste generated and avoiding overflowing bins. Additionally, we consider flexibility in the number of intermediate facilities and their assignment to vehicle routes, while observing capacity constraints and minimum quotas. We implement an adaptive large neighbourhood search algorithm (ALNS) to solve the PVRPIF and show its effectiveness on a set of small benchmark instances from the literature. The method uses several problem-specific operators to adapt visit frequencies and schedules and a heuristic procedure to insert the intermediate facilities. We solve realistic and real-world instances with up to several thousand collection locations.

4 - Vehicle Routing Problem with Time Windows and Scheduling for Loading Trucks (VRPTWSL) Solved with a Metaheuristic based on an Ant Colony Algorithm.
Cristian Oliva, *Manuel Cepeda*

We introduce a new model to represent a Vehicle Routing Problem with Time Windows, considering Scheduled Loading of a truck fleet from a depot (VRPTWSL: Vehicle Routing Problem with Time Windows and Scheduled Loading); this problem arises in a real world problem of distributing plants from a plant nursery to several fields of a forest company. A metaheuristic, combining an ant colony algorithm and a stochastic incorporation rule, allowing a truck to move back prematurely to the depot, instead of including a visit to a new customer on its route, is developed to solve this VRPTWSL problem. The results obtained with the metaheuristic procedure are compared to the manual solution obtained by the company in terms of the total kilometers traveled, of the number of vehicles used, and of the utilization rate of the carrying capacity of the truck fleet and indicate improvements over the manual solution.

Metaheuristics for Transportation and Routing II

Cluster: Metaheuristics
Invited session
Chair: *Michell Queiroz*

1 - A novel exact and heuristic solution for the Periodic Location-Routing Problem applied to Waste Collection
Daniel Norena, *Julian Restrepo*, *Daniel Morillo Torres*, *Gustavo Gatica*

In the development of Smart Cities, a waste collection network considering recycling is crucial. Over 8.3 billion tons of plastic have been produced in the last 65 years, and less than 9% is recycled. Hence, constructing more efficient routing and deposit locating techniques under a waste collection context needs to consider heterogenous cargo. This paper presents a three-level metaheuristic for the periodic location routing problem (PLRP) and a mathematical model based on mixed-integer linear programming, focused on waste collection in urban areas. The PLRP considers the classical vehicle routing problem throughout a defined time-period and includes the location problem for optimal transportation times and distances, addressing both problems as a whole. The objective is to create routes where each customer can be visited every planning day according to its waste demand frequency, collecting their waste while minimizing the distances and transportation costs. Differing from the problems in the literature, this approach characterizes each client considering five waste materials: organic, plastic, paper & cardboard, glass, and waste from electronic and electrical equipment (WEEE); they have been divided into two main categories: organic and not organic. There is homogeneous truck capacity; however, each car can only transport one category of waste between organic and not organic. Different customer categories were created based on their mixed waste demands, to design a list of visit frequencies. Furthermore, the opening of new deposits is allowed. The mathematical model considers these factors to establish constraints like subtour elimination, collection by category and sequence of visit. In addition, the algorithm proposed is based on concepts used in Variable Neighbourhood Search (VNS) algorithms and Local Search heuristics. This algorithm employs a three-level search: random key re-ordering for prioritizing customer visit sequences, an exchange sequence of visiting days, and a combinatorial opening of deposits. Computational experiments carried out on instances taken from the literature show promising results when the metaheuristic approach is used. The mathematical model had limitations, however, due to computational time proposed by the authors, not allowing results to be achieved.

2 - LNS-based approach to solve the very large scale Team Orienteering Problem in an industrial context
Charly Chaigneau, *Nathalie Bostel*, *Axel Grimault*

This paper is motivated by a vehicle routing problem, arising in the sub-ground analysis field, where the objective is to analyze the subground composition to better understand its properties. In this field, operations cover very wide areas, involving several thousands of points visited each day. To insure an efficient analysis, points can only be visited if they belong to a sensor-covered area, as sensors are needed to get the measures obtained while visiting a point. Since subground analysis operations can last for a very long duration (several months), it is not worth considering to place sensors on the whole area to study. The equipment is then progressively deployed based on the operation progress: when one of the equipment-covered areas is finished, sensors are redeployed on the next zone. Point disponibility, based on the sensor-covered area, depends on the period considered. The problem can be modelized as a Team Orienteering Problem, with mandatory and optional points. When every mandatory point of an area is visited, sensors are moved and the sets of mandatory and optional points are modified. The objective of the problem is to maximize the number of visited points, while respecting all field-specific constraints. Among others, vehicles need to be constantly geographically separated, and the mandatory area needs to be quickly covered. We present a LNS-based approach for this problem. The proposed algorithm consists of three phases aiming to get high-quality solutions in a reasonable computational time. First, a clustering algorithm based on k-medoids is applied to the problem, enabling an implicit management of some constraints. Then, several independent sub-problems , based on the initial clusters, are built and optimized simultaneously using a Large Neighborhood Search (LNS). Finally, when all sub-problems are optimized, the initial partitioning is reassessed by applying a local search on nearby routes, not belonging to the same sub-problem . The algorithm is tested on literature instances. On these instances, the proposed metaheuristic is relevant as it finds solutions of similar quality than state of the art algorithms in much less computational time, also improving three best known solutions. When applied to industrial instances, the LNS-based approach finds better solutions than the ones used by the company in a reasonable computational time, confirming the relevance of the proposed methodology.

3 - Multi-Depot Heterogeneous On-Demand Bus Routing Problem
Michell Queiroz, *Kenneth Sörensen*

This work presents a metaheuristic for the Multi-Depot Heterogeneous On-Demand Bus Routing Problem (MD-H-ODBRP), consisting of serving transportation requests in an urban environment. Passengers are picked up and dropped off by a bus at assigned stations near their origin and destination locations. A fleet of heterogeneous vehicles must serve the passengers within their time windows, and the objective function is to minimize the total user ride time (URT) of all passengers. We introduce the dynamic version of the problem and a simulated annealing algorithm to provide solutions. Computational experiments are performed on a new set of benchmark instances. We analyze the effect of instance properties, namely, size, dynamism, urgency, and geographic dispersion, on solution quality and the percentage of rejected requests. The correlation between dynamism, urgency, and those measures is different; the former has a minor influence, but it is shown to improve solution value and reduce the number of rejected requests as dynamism grows. Meanwhile, scenarios with higher urgency strongly negatively impact both solution value and the percentage of rejected requests.

OR for New Trends and Technologies in Urban Logistics

Cluster: Mobility and Transportation Systems
Invited session
Chair: *Mathias Klapp*

1 - Using Public Transport as first leg in Last-mile deliveries
Ricardo Giesen, *Irecis Ilazcuy*

The increasing demand for short deadlines in urban e-commerce deliveries is making the process less efficient, especially in congested cities where logistics facilities are often located outside the city center.

To address this challenge, a collaborative approach with public transport is proposed, where goods are transported first by public transport services and then by last-mile vehicles. This approach leverages the priority already given to public transport services in many cities, potentially reducing costs arising from e-commerce, urban congestion, and logistics centers outside urban areas. An integer linear programming model is presented to find transfer locations minimizing last-mile operating costs while considering uncertain aggregate demand, limited capacities of last-mile vehicles, and tight delivery deadlines. An experimental case is evaluated, and results show savings increase as delivery deadlines become tight in congested cities. The performance of this delivery system is fairly smooth to changes in public transport operations when delivery deadlines are flexible, but reacts accordingly to improvements or worsening when flexibility is lost.

2 - Revenue management of customer service offers in on-demand delivery distribution systems
Mathias Klapp, *Diego Mendieta*, *Felipe Lago*

We study revenue management decisions for a crowdsourced, on-demand grocery delivery service, with dynamic customer requests. Crowdsourced delivery platforms are asset-light services, using existing distribution capacity offered by people online to serve delivery requests (see, for example, Cornershop, Pedidos Ya and Rappi in Latin America, or Instacart in the US). A major challenge in these services is to promise delivery time windows to each arriving request, especially, when narrow windows are required.

In particular, we assume customers are offered a Delivery Service Time Window (DSTW) immediately after they place an order in the platform. If an offer meets the customer's preferences, they will accept service and the corresponding order must be picked up at a requested store and delivered to the desired location within the promised DSTW; otherwise, the order is canceled by the customer. Our goal is to dynamically design these DSTW offers to minimize the cost of canceled requests and overpromised services, ending up in late deliveries. A breach of promise to customers produces worse effects than canceled requests; we model these customer preferences via a discrete choice model.

We consider dynamic request arrivals and shoppers who randomly connect to the platform offering how long they are willing to work. In this context, the platform dispatcher has to anticipate future demand, shopper availability, adapt to newly revealed information to assign orders to shoppers, and assess the future quality of DSTW offers; for example, if too many attractive (i.e., very fast and narrow) DSTW offers are given to customers, then future workload will increase and could produce late deliveries.

We model our problem as a route-based MDP and design dynamic policies for it, via a parametric value function approximation (VFA). Our dynamic policy outperforms myopic benchmarks, reducing costs up to 47% and increasing the total number of accepted requests up to 20%.

3 - New developments in the long term IRP
Homero Larrain

Strategies for addressing Inventory Routing Problems (IRP) in real-life contexts tend to be based on methods optimizing the operation of a near horizon and applying the results in a "rolling horizon." Optimizing the operation of an immediate horizon makes sense, but it is only an approximation of the real objective of an operation - to minimize costs in the long term. There are opportunities to improve the performance of an IRP in the long term, by making simple modifications to the problem solved in the short term. This paper presents two new variations of the IRP, allowing for improvement of the long-term performance of the operation.

The first variation is the "IRP with relaxed periods" (IRP-RP), applying a linear relaxation to some of the last planning periods of an IRP. The IRP-RP is not only faster to solve than the IRP, but it also leads to better long-term performance, evaluated by simulating the rolling horizon. The IRP-RP proved to be on average three times faster to solve than the IRP and, under favorable conditions, it generated savings of around 13% in long-term costs.

The second variation is a simplified version of the IRP, where customers are visited at regular intervals, the "regular IRP" (or RIRP); this problem allows finding groups of customers to be synchronized to minimize long-term costs. A heuristic called "M-Sync" was developed, solving the RIRP by applying various indicators of the convenience of combining customers to form groups of customers synchronized with each other. These indicators could also be used to evaluate the future costs of a given state of an IRP, usable to enhance the IRP-RP. One interesting variant of the RIRP is the "1-Dimensional Inventory Routing Problem," able to be reduced to a linear problem, opening up new research possibilities.

4 - Solving a Dynamic and Stochastic Vehicle Routing Problem for a Liquefied Gas Company using Reinforcement Learning
Clemente Vial, *Felipe Lago*

Dynamic and Stochastic Vehicle Routing Problems (DVRP) have gained considerable attention in recent years; in our work, we study the DVRP arising in a liquefied gas distribution company. In this problem, a company distributes the gas (in various container options) to the customers' locations, who place their orders online throughout the day. As an important product for the company's customers, it delivers the gas orders in less than 30 minutes, with a fleet of vehicles having sufficient inventory to serve customers who order the service during the operating period. The company has the option to reject an order if its operation does not have the capacity to fulfill it.

We model this problem as a Markov Decision Process (MDP); each new request generates a system state. We have also included states generated after a predetermined time, so the policy can anticipate future events. Each state consists of the list of customers served, time of day, positions and routing plans of the vehicles, and the (possible) new order. The actions involve serving the new order and modifying the routing plan for the vehicles, with the objective of finding a decision policy maximizing the number of accepted orders minus any penalty cost.

To solve the MDP, we use an on-policy Monte Carlo control method, using a linear approximation for the value of the state-action. In this method, episodes generate from the process, using the on-policy for taking actions. This policy, starting out as arbitrary, improves by including values generated from episodes. For efficient and effective learning, we incorporate an epsilon-greedy strategy, i.e., a randomized mechanism for exploring new actions. We propose a strategy able to efficiently handle this routing problem. For the state-action value function approximation, by including several features (basis functions), our method can automatically detect features relevant to the problem.

In our computational study, we examine the performance of our proposed method and myopic policies. The myopic policies allow us to have a benchmark policy, but also to represent how the company currently operates. Using real data of the company, our method achieves a better customer service level than the benchmark policies, meeting the company's objectives.

Optimization of Transport Decisions Based on User Behavior

Cluster: Mobility and Transportation Systems
Invited session
Chair: *Bilge Atasoy*
Chair: *Adrien Nicolet*

1 - A Service Network Design and Pricing model considering Shippers' Behavior
Adrien Nicolet, *Bilge Atasoy*

Service Network Design (SND) problems are critical for intermodal transport planning; indeed, they cover most tactical decisions of a carrier, e.g. the itineraries to be served or the offered frequencies. In the existing SND literature, only a handful of works cover pricing decisions and preferences of shippers. With this work, we integrate these

two aspects within a cycle-based Service Network Design and Pricing (SNDP) problem, formulated as a bi-level optimization. The upper level represents an inland barge operator, whose objective is to maximize their profits under fleet size and capacity constraints. The lower level describes the utility maximization of shippers, having three transport alternatives: inland barge, train, or truck. The first one is related to the upper level, whereas the last two are competing options exogenous to the model. We estimated the utility functions for these three alternatives in a previous work, where a mixture formulation was introduced to represent the heterogeneous cost sensitivities of shippers. This bi-level SNDP problem can be reformulated into a single-level linear problem using the strong duality theorem, the big M technique and expressing frequencies as binary variables. The proposed model is compared to a benchmark where shippers are purely cost minimizers. While the latter generates higher profits, it also results in unrealistic mode shares, with road transport being negligible. On the other hand, the proposed formulation leads to mode shares considerably closer to reality. With the mixture formulation of utility functions, we can also introduce a stochastic version of the SNDP problem. In particular, the cost coefficient for intermodal alternatives (barge and train) is assumed to be randomly distributed among the population of shippers. The problem is then solved using Sample Average Approximation (SAA), and the obtained solution is assessed using an out-of-sample simulation, imitating the behavior of a "real population of shippers". The proposed SNDP problem allows us to design services and set prices accounting for the heterogeneous preferences of shippers. Thus, transport operators can respond more accurately to shippers' needs and gain a significant advantage against their competitors.

2 - A Logistics Provider's Profit Maximization Facility Location Problem with Random Utility Maximizing Followers
David Pinzon, *Emma Frejinger*, *Bernard Gendron*

We introduce a strategic decision-making problem faced by logistics providers (LPs) seeking facility location decisions, leading to profitable operations. The profitability depends on revenue generated through agreements with shippers and costs arising when satisfying those agreements; the latter depends, in turn, on service levels and on characteristics of the shippers' customers, but, at a strategic level, LP has imperfect information.

We propose a stochastic bilevel formulation where a given LP (leader) anticipates the decisions of shippers (followers) arising from a random utility maximization model. Using a sample average approximation and properties of the associated optimal solutions, we introduce a non-conventional single-level mixed integer linear programming formulation solvable by a general-purpose solver. We can quickly identify situations leading to zero expected profit for the LP. Experimental results show optimal expected profit is highly dependent on shippers' price sensitivity; under-estimating it can lead to an over-estimation of expected profits.

3 - Integrating passenger demand prediction in real-time rail traffic management
Bianca Pascariu, *Johan Victor Flensburg*, *Paola Pellegrini*, *Carlos Lima Azevedo*

In recent years, European and international transport policies focused on the transition to sustainable and intelligent mobility, aiming to foster a major modal shift to rail. The rail transport system is thus required to be more resilient and capable of self-adapting to an evolving environment, with respect to demand and in case of disturbances. This paper presents a novel approach to real-time rail traffic optimization, integrating passenger prediction. The proposed methodology is part of the SORTEDMOBILITY project, focused on developing optimized solutions for self-organizing management of public transport operations. By incorporating dynamic passenger information into the traffic management system, the proposed approach aims to improve the efficiency and effectiveness of rail transport systems, while meeting passenger needs. Specifically, we design a modelling framework for the traffic management system consisting of two modules: a demand prediction module provides information about upcoming origin-destination passenger flows, given a planned rail scheduled and past observed demand; a traffic control module optimizes rail traffic in real-time by taking into account this dynamic demand information. The demand prediction module relies on a deep learning prediction model, using updated train schedules and real-time tap-in and tap-out data as input, and a heuristic for assigning predicted demand to individual trains. In the traffic control module, we include these demand predictions in an existing mixed-integer linear programming-based algorithm for real-time traffic management, called RECIFE-MILP. The predicted train and passenger paths are then used in the traffic control module to minimize the weighted sum of train and passenger delays at destination. We validate our methodology, in terms of its ability to optimize traffic while capturing passenger demand, on a case study of a Copenhagen suburban rail network, considering the network around Hellerup station, for a total of 13 stations. The lines between stations are double-track with a one-way train direction; train reordering and rerouting are allowed in stations with more than two platforms. The methodology is validated using perturbed traffic and passenger demand scenarios occurring during a typical weekday. During peak hours, there are approximately 80 trains and 300 passengers, with 20% of the passengers requiring a transfer.

4 - Synchromodal Transport Planning with Shippers' Preference Learning
Bilge Atasoy, *Mingjia He*, *Yimeng Zhang*

A comprehensive understanding of shippers' preferences can help transport freight forwarders create targeted transport services and enhance long-term business relationships. Nevertheless, limited research has examined the benefit of considering shippers' preferences in the decision-making of synchromodal transport planning, and collection of relevant data is still not straightforward.

This research proposes an innovative framework to learn shippers' preferences in synchromodal transport operations and optimize transport services, accordingly. A preference learning method is developed to capture shippers' preferences through pairwise comparisons of transport plans. To model the underlying complex nonlinear relationships and detect heterogeneity in preferences, artificial neural networks (ANNs) are employed to approximate shippers' utility for a specific plan. Based on the learned preference information, a synchromodal transport planning model with shippers' preferences (STPM-SP) is proposed, with the objectives of minimizing total transportation cost and maximizing shippers' satisfaction. An Adaptive Large Neighborhood Search algorithm is developed for solving this optimization problem; it takes into account the two different objective functions and searches for Pareto solutions to the planning problem.

A case study is conducted based on the European Rhine-Alpine corridor to demonstrate the feasibility and effectiveness of the proposed methodological framework. Basic discrete choice models (DCMs) are used as benchmarks for preference learning, and the synchromodal transport planning model (STPM) without preferences is used as the benchmark for planning. The results show ANNs have better predictive power than DCMs for preference learning, achieving higher accuracy and lower variation. With the consideration of shippers' preferences, STPM-SP can significantly increase shippers' satisfaction with transport services. Scenarios with different preferences are tested and results show the highest improvement in satisfaction reached 34.19%. This research contributes to learning shippers' preferences in the transport operation process and highlights the importance of incorporating these preferences into the decision-making process of synchromodal transport planning.

Real Time Decisions for On-demand Systems

Cluster: Mobility and Transportation Systems
Invited session
Chair: *Shadi Sharif Azadeh*

1 - Data-driven real-time demand forecasting and dynamic hot spot clustering for an on-demand meal delivery platform
Shadi Sharif Azadeh

The on-demand meal delivery business has expanded to a billion dollar market; to improve delivery time efficiency, delivery platforms want to optimally operate their courier resources in real-time, based on their insights into the distributions of demand in the city. To generate short-term demand insights, we study data-driven approaches to predict the demands for different city areas for the next 15-minutes, and we investigate the use of predictive demand information to determine the future hot spots of the city. This research focuses on machine learning models' random forest regression and XGBoost for short-term demand forecasting. By including lagged dependent features, we extend the baseline random forest regression and XGBoost models to be adaptive predictors. Furthermore, we explore the potential gains in the performance of hot spot clustering via incorporating probabilistic predictions generated by quantile regression forest. All machine learning models outperform the conventional time series benchmark TBATS model in terms of prediction accuracy. In addition, the performance of hot spot clustering is improved by including lagged dependent features and probabilistic forecasting information. Through an empirical case study, we show on-demand delivery platforms can utilize the machine learning models we suggest to generate accurate predictions of demand and city hot spots in real-time. The data-driven short-term demand predictors can be incorporated into the system to assist operational decision-making for the meal delivery platform

2 - Steering benefits in On-demand Meal Delivery
Yousef Maknoon, *Alp Arslan*, *Martin Savelsbergh*, *Shadi Sharif Azadeh*

Managing an on-demand meal delivery service involves multiple interrelated tasks, e.g. recruiting couriers and coordinating courier activities. Many of the meal delivery platforms rely on ad-hoc crowdsourced delivery capacity, i.e., rely on individuals willing to make deliveries in their free time. Some platforms manage temporal and spatial imbalances between delivery capacity (supply) and order placements (demand) by adjusting compensation to attract or deter couriers (e.g. Uber Eats and Deliveroo). Because customers expect to pay only a small fee for delivery, however, adjustments in courier compensation cannot easily be passed on to the customers. Furthermore, regulatory changes related to crowdsourced delivery capacity, e.g. minimum payment guarantees and provision of benefits, have led platforms to switch to the use of advance scheduled couriers (e.g. JustEat and Takeaway.com). We focus on the latter model, where the couriers available to make deliveries during an operating period are scheduled in advance.

A major challenge for platforms is to effectively handle the spatial and temporal demand variations naturally occurring daily and from hour to hour. When a platform cannot dynamically adjust delivery capacity and cannot dynamically adjust delivery fees (and influence demand), other tools are necessary to manage the highly stochastic meal delivery demand, effectively. For that purpose, we introduce demand steering, i.e., adjusting delivery time promises, and supply steering, i.e., adjusting courier-order assignments, to increase customers' service quality, measured by delivery time promise delays and delivery time promise. Supply and demand steering mitigates the shortcomings of myopic dispatching policies by (i) proactively directing couriers toward areas requiring additional delivery capacity and (ii) temporally lowering service by displaying increased delivery time promises in certain areas.

We evaluate the efficacy of steering actions using public restaurant meal delivery problem instances, derived from our industry partner's historical transactions in the greater Berlin area. Our extensive computational study carefully assesses the benefits of the different steering actions, studies their sensitivity to modeling choices, e.g. the level of aggregation in the network used to determine steering actions, and characteristics of the environment, e.g. the available set of couriers with known blocks.

3 - Scalable policies for the dynamic traveling multi-maintainer problem with alerts
Peter Verleijsdonk

Downtime of industrial assets, such as wind turbines and medical imaging devices, is costly. To avoid these downtime costs, companies seek to initiate maintenance just before failure, challenging because: (i) asset failures are notoriously difficult to predict, even in the presence of real-time monitoring devices signaling degradation; and (ii) limited resources are available to serve a network of geographically dispersed assets. In this work, we study the dynamic traveling multi-maintainer problem with alerts (K-DTMPA) under perfect condition information with the objective to devise scalable solution approaches to maintain large networks with K maintenance engineers. Since these large-scale K-DTMPA instances are computationally intractable, we propose an iterative DRL algorithm optimizing long-term discounted maintenance costs, potentially improving upon any heuristic solution. To vastly reduce complexity, we approach the problem from a system-centric perspective. Specifically, we train neural network policies using a handcrafted feature vector design leveraging the available information to select actions for engineers sequentially in a fixed order. We extend existing heuristics to devise both quality benchmarks for tailored instances and suitable initial policies for the DRL algorithm. DRL can solve single maintainer instances up to optimality, regardless of the chosen initial solution. In addition, DRL can be successfully applied to improve state-of-the-art dispatching heuristics on large-scale instances and benefits from smart initialization to significantly reduce the number of iterations required to reach suboptimality. Studying the trained policies reveals DRL can improve these heuristics by, among others, learning a repositioning strategy to anticipate future alerts and failures. Experiments with hospital networks containing up to 35 assets show the proposed DRL algorithm is scalable, and it is cost-efficient to share resources over the network, as opposed to subdividing the network into smaller regions. A sensitivity analysis shows the trained policies are robust against removing an asset/engineer or yield suitable initial solutions to optimize these instances.

Shared Resources on the Last Mile

Cluster: Mobility and Transportation Systems
Invited session
Chair: *Margaretha Gansterer*

1 - A 2-Stage Stochastic Model for the Mitigation of the Occasional Drivers Absenteeism in the Last Mile Delivery
Chefi Triki, *Simona Mancini*, *Margaretha Gansterer*

E-commerce popularity has exponentially increased in the last decade; while e-commerce giants have their own established distribution network, fulfilling a high number of deliveries became a challenging issue for small and medium companies. Running an owned delivery fleet could be extremely costly for these companies, since very high fixed costs must be paid for drivers' salaries, and a large initial investment is required to purchase vehicles. Furthermore, in last mile delivery, demand is typically not constant, since a huge peak of demand is totally concentrated in time, e.g. Christmas; for this reason, maintaining a fixed fleet for the whole year, able to handle demand peaks, would be too costly. On the other hand, an undersized fleet would not allow fulfillment during a high peak of demands, forcing the company to reject several customers during peak seasons, generating a huge loss of profits for the company. One possible solution for reducing delivery cost is to make use of occasional drivers (ODs) - freelance drivers without a fixed contract. ODs are cheaper compared to traditional drivers because they do not imply any fixed costs - they are paid only for the performed deliveries. In this delivery system, the company establishes an online auction platform, where a set of bundled requests is to be fulfilled. Available ODs join the platform and bid for the bundles they are willing to serve. After receiving all the bids, the company decides the bids to accept and communicates it to the drivers through the platform, fixing the overall cost, given by the sum of the cost of accepted bids, plus penalty costs. The drawback of the system is the reliability of ODs; the absenteeism of ODs could potentially generate a huge loss of money for the company, potentially unable to fulfill all the requests. In this study, we propose a novel mitigation strategy, based on the concept of ODs reservation, to proactively hedge against possible ODs absenteeism. The absenteeism level will be represented as a discrete random variable, and the problem can be formulated as a two-stage stochastic model. We also propose a matheuristic to solve the resulting problem.

2 - Stochastic dynamic inventory routing problem with intra-period demand depletion.
Emilio Jose Alarcon Ortega, *Sebastian Malicki*, *Karl Doerner*, *Stefan Minner*

In this paper, we introduce a variant of the inventory routing problem focusing on the stochastic and dynamic nature of demands businesses, such as beverage, food, and retailer industries, face in real-world applications. Most research related to inventory routing reduces its complexity by considering aggregated per-period demand. In many real-life applications, the demands customers experience, however, differ on both a daily and an intra-day basis. The supplier must develop efficient replenishment and routing plans to minimize the transportation, inventory holding, and stockout costs, taking into account late deliveries can result in lost sales, not only at the end, but also within the periods. We present a mathematical formulation resembling the real-world problem related to replenishment decisions companies face, formulating the problem as a finite-horizon stochastic dynamic program, where each period during the planning horizon is divided into sub-periods with distinct demand distributions. This division helps the supplier create efficient replenishment plans and account for intra-day inventory levels. The modeled characteristics include routing, holding and stockout costs, inventory and vehicle capacities, and delivery time windows. The routes, replenishment quantities, and sub-periods, when each customer is visited, are planned at the beginning of each period and cannot be altered throughout the period (day of operation). To solve this problem, we propose an iterative look-ahead algorithm combining an adaptive large neighborhood search for the routing generation with a policy learning process for the replenishment decisions. In addition, we develop different sequential decision algorithms using order-up-to level and chance-constrained policies with different run-out times, and we evaluate the efficiency of the proposed iterative algorithm by comparing the results obtained by applying all methods. These computational experiments show the effectiveness of the proposed algorithm when considering different instance sizes, coefficients of variation, and holding costs. Furthermore, considering intra-day consumption of goods helps the central supplier reduce overall costs more than 20% when compared to planning for full periods.

3 - Anticipatory request acceptance in dynamic and collaborative vehicle routing
Margaretha Gansterer, *Yannick Scherr*, *Richard Hartl*

We consider the problem setting of a less-than-truckload carrier, serving stochastic customer requests; each request must be answered dynamically by accepting or rejecting it immediately. The next day, the accepted requests are served in routes using vehicles with limited load capacity and route duration; after the request acceptance phase and before the requests must be served, multiple carriers participate in a combinatorial auction to exchange a subset of requests. After carriers place bids on bundles of requests, an auctioneer allocates the bundles to carriers in a cost-minimizing way and distributes the auction profits. This horizontal collaboration provides cost savings to carriers and contributes to reducing negative impacts of transportation, such as emissions or traffic. Each carrier's optimization problem of maximizing profit can be modeled as a Markov decision process, comprising the sequential decisions in all phases, i.e., request acceptance, request selection for the auction, bidding, and routing. Heuristic approaches are proposed to generate preliminary route plans and to consider the options provided by the auction already, when making request acceptance decisions. We specifically consider overbooking policies, for accepting more requests than can be served before the auction takes place and the strategic rejection of requests in anticipation of more profitable upcoming requests. Carriers' request acceptance decisions impact their individual profits and overall collaboration savings; the largest benefits can be achieved with an overbooking policy applied by all carriers and considering the locations of both the request and the carriers' depots.

Air Transportation

Cluster: Mobility and Transportation Systems
Invited session
Chair: *Nahid Jafari*

1 - The chaos on U.S. domestic airline passenger demand forecasting caused by COVID-19
Nahid Jafari

Commercial aviation is a major contributor to the U.S. economy, directly or indirectly generating approximately US$ 680 billion, or 4% of GDP, and supporting millions of jobs. Approximately 965 million passengers flew to U.S. destinations in 2017 (https://rosap.ntl.bts.gov/view/dot/37861). Given the importance of the industry, accurate forecasting of air passenger demand is valuable, and the most sophisticated forecasting technologies can be applied to this endeavor.

The ongoing COVID-19 crisis has had an unprecedented impact on air traffic. Effective forecast of passenger demand would benefit airlines to develop adequate recovery plans and prevent (or minimize) any catastrophe in handling passengers during and post pandemic. The purpose of this study is to investigate COVID-19's impact on the U.S. domestic air passengers demand, identify the most influential features on air passenger demand, and design more accurate forecast models. In addition, we address a computational challenge in developing forecasting models due to the volatility of the recent data as a result of the COVID-19 crisis. We use both traditional and artificial intelligence methods and discuss their capabilities to handle the challenge.

2 - Air freight forwarder's allotment problem among heterogeneous flights under demand uncertainty
Kannapha Amaruchkul

A freight forwarder, one of the most important players in the air-cargo service chain, collects individual packages from shippers and transports the consolidated shipments to air carriers, some of which have long-term block space agreements (BSA) with the forwarder. Although the BSA imposes a minimum charge on the BSA space, often referred to as the allotment, it allows the forwarder to achieve lower freight rates and to guarantee some space on direct flights. Air shipments are time sensitive; thus, an indirect flight's long transit time is undesirable. If, on any day, the total demand from the consolidated shipment exceeds the allotment, the forwarder may purchase additional space from non-BSA carriers at higher spot rates, or indirect flights with longer transit times have to be used. On the other hand, if the total demand is less than the allotment, it needs to pay at least the minimum charge. For each destination and each day of the week, demand varies significantly week by week, but the allotment remains fixed over the contract duration. In the long-term problem, the forwarder needs to decide the allotment before knowing the random daily demand. In the short-term problem, it decides how to allocate the realized demand to multiple carriers with different freight rates and trip times - the actual flight times plus transit times. The objective of this study is to formulate a unified mathematical programming model for both short- and long-term problems and to apply the model in the case study of one of the largest forwarders in Thailand. The problem is formulated as a two-stage stochastic program, where, in the first stage, the long-term allotment is determined, and, in the second stage, the recourse function is the minimization of the daily cost. The short-term daily problem is formulated as a linear programming model, where the objective function includes both the freight cost and the cost of time, and the constraints include weight and volume limits of different flights and the nonanticipativity constraints. In the case study, daily demands of the top five destinations from April 2020 to July 2021 are used. The demand scenario is created from the empirical distribution. The average daily cost from using our approach is 344,577 THB, whereas that under the current policy is 609,822 THB and that with perfect hindsight is 319,606 THB. On average, the cost saving from the current policy is 118.72%, and the gap from perfect hindsight is 15.79%.

3 - Approximate Dynamic Programming Approach for the Airport Gate Assignment Problem
Hakyong Kim, *Junyoung Kim*, *Kyungsik Lee*

In airports, flights need to be assigned to gates to carry out ground operations. The airport gate assignment problem (AGAP) establishes an efficient flight-to-gate assignment plan, based on the planned schedules of flights. Each day's flight-to-gate assignment plan is established in advance; however, modifications may be necessary in response to unexpected changes in flight schedules on the day of actual operations. Therefore, an efficient solution approach for the AGAP is required in practice, while it is challenging due to the NP-hardness results and a large number of involved flights and gates. In this study, we propose an efficient approximate dynamic programming approach (ADP) for the AGAP based on integer programming (IP) models. Specifically, the underlying value function is approximated using bounds provided by an extended formulation for the AGAP, having exponentially many variables. The extended formulation provides tighter linear programming relaxation bound compared to the existing models; however, it is not straightforward to utilize the bound due to the huge number of variables. Therefore, we devise an efficient column generation method along with several acceleration techniques. Computational test results for real-world instances demonstrate the proposed ADP approach can provide a high-quality solution in a reasonable amount of time compared to the existing solution approaches for the AGAP.

Traffic Analysis

Cluster: Mobility and Transportation Systems
Invited session
Chair: *Maria A Wilches-Mogollon*

1 - Assessing factors influencing the occurrence of traffic conflicts: a novel vehicle-by-vehicle approach
Franco Basso, *Yanara Muñoz*, *Raul Pezoa*, *Mauricio Varas*

Traffic accidents are one of the leading causes of death in the world. In this context, analyzing traffic variables for crash and non-crash situations has been vital in understanding the underlying reasons for crashes' occurrence. Nevertheless, crashes are rare events, implying limited data availability, limiting analysis and conclusions. Thus, studying traffic conflicts has appeared to be an appealing option for understanding risky situations in recent years. This research analyzes the main factors leading to the occurrence of traffic conflicts on the urban highway Autopista Central in Santiago, Chile. Unlike previous contributions, we propose a vehicle-by-vehicle approach where we estimate the probability each vehicle, passing through each gate of Autopista Central, has a conflict. This approach allows us to study variables at an individual level, not analyzed before, using full real-world data, such as driver (age and sex) and vehicle information (model and age). We use Time to Collision (TTC) as a surrogate safety measure, defining different critical TTC thresholds for each gate to maximize the area under the ROC curve, considering conflicts as a prediction for crashes. Subsequently, a logistic regression model is built to understand the input variables' influence on the probability of conflict occurrence. Overall, men and young drivers are more likely to have a conflict, and the age of the car is negatively correlated with the occurrence of conflicts.

2 - Integrated model of urban freight and passenger trips to analyze parking and road usage
Facundo Sosa, *Germán Faller*, *Matías Gutierrez*, *Antonio Mauttone*, *Pedro Piñeyro*

The planning and management of public infrastructure used to provide support to mobility alternatives is a challenging task, given the restrictions of physical space and the variety and intensity of activities to be considered simultaneously. We present a model to evaluate different scenarios related to the use of public infrastructure. Vehicle flows, parking options and their interactions are modeled simultaneously for both passenger and freight trips, considering the old-town neighborhood of Montevideo, Uruguay, as a case study. Origins and destinations are assumed as known for each trip. Trips are divided into the following stages: First, the vehicle travels from the origin to a parking place. The vehicle is then parked in a public or private parking lot. Finally, the user walks from the parking spot to the final destination, incurring a cost as a function of distance to the destination. In the case of freight vehicles, the return trips from where they park to unload are also considered in the model. Each stage has an associated cost expressed in travel time. To model the study zone as a network, each road section was modeled with a representative street node. Then, parking nodes are connected with each street node (public, private and freight). Finally, edges connect the parking nodes with each destination node representing the walking stage of the trip. Given the network as described and the demand values for each destination node, the flow assignment can be solved as the User Equilibrium Problem. We solve this problem using the Frank-Wolfe algorithm since the cost function used is convex. While this is a standard approach to solve traffic equilibrium problems, our contribution is the modeling of the different problem features within this framework (road congestion, parking choice, walking time, car and freight vehicles interaction); a specific network structure and variants of the cost functions are proposed. The model is applied for a range of different inputs representing real life decisions, such as pedestrianization of streets and parking availability for freight and cars. These scenarios are evaluated with global and local metrics regarding the travel time for each user, providing urban planners useful information to support the decision-making process.

3 - An urban bicycle traffic assignment framework with preferences and congestion
Maria A Wilches-Mogollon, *Jorge E. Mendoza*, *Andres Medaglia*

Transportation agencies in cities worldwide have made significant efforts to increase the number of trips in active transportation modes, such as bicycles, aiming to reduce traffic congestion and air pollution. To implement these policies, these agencies need to plan interventions on the street network with new bicycle infrastructure, often limiting the space to motorized vehicles. To support these decisions, it is necessary to understand how bicycle users move throughout the city. Thus, we present a framework for estimating urban bicycle traffic assignment, explicitly accounting for commuters' preferences and bicycle congestion. This computational framework comprises three iterative steps: (i) a bi-objective optimization model unveiling efficient bicycle routes in terms of travel time and safety; (ii) a classification model assigning routes to cyclists based on their socio-demographic profiles; and (iii) a Jackson queueing network estimating bicycle congestion. We illustrate the framework on the Sioux-Falls city network and a scaled network of Bogotá, Colombia. The framework can predict traffic flows, considering Wardrop's principle for bicycle commuters.

Vehicle Routing

Cluster: Mobility and Transportation Systems
Invited session
Chair: *Hyunseop Uhm*

1 - Consistent Vehicle Routing Problem with Simultaneous Delivery and Pick-up and Time Windows
Diego Bravo, *Hernán Lespay*

This work proposes a Mixed-Integer Linear Programming (MILP) formulation for the Consistent Vehicle Routing Problem with Simultaneous Delivery and Pick-up and Time Windows (ConVRPSDPTW) for multi-periods. Besides standard VRPTW constraints, ConVRPSDPTW determines an efficient set of routes, where each customer has both a delivery and a pick-up demand to be satisfied, simultaneously. Moreover, the routes are constrained by vehicle capacity, time windows, and service consistency, meaning assigning each set of customers just one driver to fulfill their orders during the whole planning horizon and making it impossible to decompose the model into several independent one-period problems. The model is employed to minimize operational costs: number of vehicles and total travel time. The computational experiments were executed utilizing benchmark instances

constructed from Solomon's VRPTW instances and were solved by a commercial solver.

2 - Environmental aspects in supplier networks - A bi-objective just-in-time truck routing problem
Julian Baals

Freight transportation, including just-in-time (JIT) supplier networks, accounts for a substantial part of global carbon dioxide (CO2) emissions. The JIT truck routing problem (TRP-JIT), presented in the recent literature, consists of several suppliers serving a single original equipment manufacturer (OEM). A logistics provider organizes the milk-run routes; the shipments are available after their release dates at the suppliers and should be delivered on their due dates at the OEM, with minimal total earliness-tardiness penalties (first objective). Unlike previous research on the TRP-JIT, we focus on its environmental impact: 1) we include the weight-distance (second objective), depending on the truck's curb weight, the load, and the transportation distance; 2) we adapt a state-of-the-art, large neighbourhood search (LNS) from the literature considering both objectives; and 3) we embed the LNS in bi-criterial frameworks, i.e., varepsilon-constraint and weighted sum methods. Thereby, we estimate Pareto frontiers with at least 60 solutions in less than 25 minutes, for instances with 99 shipments. From a managerial perspective, increasing the difference between the release and due dates for a better JIT performance may worsen the environmental impact. Lighter trucks can reduce the environmental costs without affecting the JIT performance, while a smaller fleet negatively affects both objectives.

3 - Consistent Time Window Assignments for Stochastic Multi-Depot Multi-Commodity Pickup and Delivery
Shohre Zehtabian, *Marlin Wolf Ulmer*

In this paper, we present the problem of assigning consistent time windows for the collection of multiple fresh products from local farmers and delivering them to distribution centers for consolidation and further distribution in a short agri-food supply chain with stochastic demand. We formulate the problem as a two-stage stochastic program. In the first stage, the time windows are assigned from a set of discrete time windows to farmers and, in the second stage, after demand is realized, the collection routes are planned by solving a newly introduced multi-depot multi-commodity team orienteering problem with soft time windows. The objective is to minimize the overall travel time and the time window violations. To solve our problem, we design a (heuristic) progressive hedging algorithm to decompose the deterministic equivalent problem into subproblems for a sampled set of demand scenarios and guide the scenarios toward consensus time windows. Through numerical experiments, we show the value of considering demand uncertainty over solving the deterministic expected value problem and the superiority of our approach over benchmarks, when it comes to reducing routing cost, as well as inconvenience for farmers.

4 - Fleet-mix and multi-shift vehicle routing problem for the e-commerce delivery with truck electrification and off-hour delivery implementation
Hyunseop Uhm, *Abdelrahman Ismael*, *Natalia Zuniga*, *Olcay Sahin*, *Joshua Auld*, *Monique Stinson*

Freight truck electrification for last-mile delivery is one of the most important research topics to reduce the dependency of oil-based operations. Although a battery electric vehicle still has shorter driving ranges and less capacity than a conventional truck due to the heavy and large-sized battery in the truck, operations with electrified trucks reduce the total energy usage and driving noise on routes. In this paper, we focused on the last-mile e-commerce delivery systems, described as a fleet-mix and multi-shift vehicle routing problem. Every electrified truck can have two shifts for daytime and off-hour deliveries, while conventional trucks can operate during daytime only, because of the loud noise from the diesel engine. Also, all electrified trucks must recharge between their operations, using the assigned electric vehicle supply equipment at depots. A fleet owner decides the best electrification ratio of the fleet and a proper number of recharging equipment with the minimum total cost. The whole decision-making problem is described as a mixed-integer non-linear programming model, including common constraints for vehicle routing problems, recharging constraints with expected waiting time from queueing theory, and two-shift operation of electrified trucks. A two-stage VNS-TS heuristic is suggested to capture characteristics of both two-shift routing and recharging. The upper-level problem assigns trucks with certain engines and brief route information, using variable neighborhood search heuristic, and the lower-level problem finds the best route of each assigned truck using tabu search heuristic. All the algorithms are developed and collaborated with POLARIS, an agent-based transportation modelling framework, enabling realistic analysis on the regional traffic network.

Public Transportation Systems

Cluster: Mobility and Transportation Systems
Invited session
Chair: *Shuhei Konno*

1 - Designing Sustainable Transit Networks for Battery Electric Vehicles: An NSGA-II-based Approach
Daniel Martinez, *Marcela Munizaga*, *Cristian E. Cortes*

Electric transit networks, based on Battery Electric Vehicles (BEVs), have emerged as a promising solution to mitigate the impact of transportation on climate change; BEVs are a cleaner alternative to fossil fuel-based vehicles, as they produce zero emissions during their operation. Thus, adopting BEVs in public transportation systems can significantly reduce greenhouse gas emissions and improve air quality in urban areas. The widespread adoption of BEVs requires the development of efficient electric transit networks - meeting the demands of commuters, while ensuring cost-effectiveness, reliability, and sustainability. Therefore, the proposed solution method for transit network design can play a crucial role in promoting the adoption of BEVs and mitigating the impact of transportation on climate change. This paper presents a solution method for the Electric Transit Network Design and Frequency Setting Problems (E-TNDFSP) for BEVs. The proposed method integrates charging infrastructure location, route design, and frequency assignment to optimize the overall performance of the transit network, considering the limited autonomy of BEVs and the availability of different charging technologies, such as opportunity charging and overnight charging, for tackling this problem. Opportunity charging involves charging BEVs during short periods on stops along the route, and overnight charging involves charging vehicles in a depot. The method is based on the NSGA-II genetic algorithm for multi-objective optimization; it allows considering multiple performance criteria, such as operation cost, charging infrastructure cost, and user cost. We explore different tradeoffs between the performance metrics in both charging scenarios (opportunity and overnight charging), providing transportation planners with a holistic understanding of the effects of charging technologies on a public transport system. Developing efficient and sustainable electric transit networks based on BEVs is critical for achieving climate change mitigation goals. The proposed solution method for the E-TNDFSP represents a step toward this goal, by providing a tool for optimizing the design and operation of electric transit networks - promoting the adoption of BEVs and reducing the environmental impact of transportation.

2 - Spot fare inspections under non-adaptive opportunistic passengers and mass inspection policy
Enrique Simpson, *Pablo Escalona*, *Luce Brotcorne*, *Bernard Fortz*

This study addresses the operational implementation of a spot fare inspection strategy in public transportation networks, where opportunistic passengers can evade fare payment by the most convenient path and the transit authority implements a mass inspection policy. A spot fare inspection strategy defines the frequency when the transit authority should control each transit network location during a given time interval to inhibit the action of opportunistic passengers. Its operational implementation is done using an unpredictable inspection team's allocation, where the transit authority selects a collection of spatial locations to be controlled (one for each inspection team) each day with

some probability to induce uncertainty in transportation network users. The challenge is to determine the set of inspection teams' allocations and their respective probabilities of being selected whose systematic day-to-day application matches the inspection frequencies defined by the spot fare inspection strategy. The interaction between transit authority and opportunistic passengers is modeled as a Leader-Follower Stackelberg game, where the decision of opportunistic passengers to evade the fare payment and the path to take depends on the control frequencies set by the transit authority.

3 - Development of a Mathematical Model for Optimal Rail Grinding Schedules in Railway Track Maintenance
Shuhei Konno, *Mami Matsumoto*

On railway tracks, rail surface roughness increases due to repeated train runs; resulting vibration increases noise both inside cars and along railway lines and deteriorates track components. To reduce these problems, rail grinding operations are carried out by vehicle machinery equipped with multiple grinding wheels underneath. The grinding vehicle is operated by passing repeatedly while changing pressure and angle of the grinding wheels against the top of the rails, and the number of grinding passes is determined depending on the amount of roughness and wear generated on the rails. It is important to schedule grinding operations and vehicle turnaround efficiently, under the restrictions related to operation time and traffic.

In this study, we first show a summary of MIP modeling techniques applied to make yearly optimal grinding schedules, developed so far. The schedules obtained by our proposed model have been practically used in several railway companies in Japan. The model uses the railway track network, including depot locations, as input and decides where to locate a vehicle, then allocates the vehicle from each depot to locations to be grinded. The model obtains an optimal schedule maximizing the total improvement of rail surface irregularity on lines under several related constraints, such as the condition vehicles can only be operated within a limited distance from the depot. Since the model assumed the grinding distance per one operation was constant, however, the number of grinding passes in the operation could not be reflected; thus, the model is next modified in this study. With the recent development of sensing technology, it is becoming possible to periodically collect rail profile data from running train cars. The rail profiles are a very useful factor for deciding the number of grinding passes. We investigated a relationship between the measured rail profile and the appropriate number of grinding passes in our previous study. By utilizing this relationship, the proposed model was modified in this study so the grinding distance per one operation is variable, depending on the measured flatness of the rail head, contributing to reducing the cost of railway track maintenance by eliminating the surplus of grinding passes in the present schedules.

Electrified Transportation Systems

Cluster: Mobility and Transportation Systems
Invited session
Chair: *Aman Sharma*

1 - Optimization Framework for Concurrent Planning and Charging Scheduling Decisions for Battery Electric Buses
Pranav Gairola, *N. Nezamuddin*

Battery electric bus (BEB) operators are troubled by restricted range and lengthy charging periods. Thanks to fast-charging technology, the daily driving range of BEBs may be increased with a rise in electricity tariffs, a reduction in battery capacity, and a reduction in charging time. We first propose an integrated optimization framework for concurrent BEB planning, design, and operation decisions to aid BEB operators in selecting the optimal combinations of battery packs, charger locations, their quantities, and their sizes, as well as preparing BEB recharge schedules, accounting for demand charges and time-of-use energy tariffs. The model incorporates terminal-level resource sharing across BEBs on multiple routes, enhancing the possibility of decreasing demand charges and resource utilization. We've strengthened the deterministic optimization model by factoring in energy consumption uncertainty, using a budgeted uncertainty set. The model was then converted to its tractable robust equivalent, so it could be solved with off-the-shelf solvers. A comprehensive examination of the current public bus network in Delhi, India, was conducted to establish the viability of the proposed strategy. The results demonstrate the relationship between BEB planning and scheduling decisions, as well as the validity of a fair compromise within an integrated optimization framework. The proposed strategy was effective in resolving the combined planning and design challenge for a BEB system; it balanced costs by avoiding the acquisition of bigger battery and charger sizes and by assigning most recharging activities during off-peak hours. The sharing optimization model could reduce peak hour demand charges by approximately 480 % and increase resource utilization via optimization of the charger cost by around 780 % compared to the existing non-sharing optimization model. The comparison between the deterministic model and its corresponding robust model with varying levels of conservatism illustrates robust models can provide a robust solution to hedge against the uncertainties in energy consumption for BEBs under 5 % relative gap. Two extensions to this work look promising - 1) development of an improved heuristic or metaheuristic-based framework for using the smaller time-periods for scheduling framework, and 2) incorporation of queueing theory-based approach for charging delay modelling while scheduling charging activities.

2 - Delay Minimization for Uncertain Electric Bus Operations due to Charging Infrastructure Breakdown
Aman Sharma, *Pranav Gairola*, *N. Nezamuddin*

Electric Buses are an environmentally friendly alternative to the traditional Internal Combustion Engine buses and are, therefore, gaining worldwide attention. In an optimal opportunity charging system, the electric buses frequently require battery charging during their daily operation, due to their limited driving range. This makes the charging infrastructure a critical part of the system and, hence, it requires proper design to ensure a predefined transit schedule is adhered to. Due to the technology being new, however, there is a lack of data available regarding the reliability of the charging system; this introduces unpredictability into the system, making predefined transit schedule adherence a difficult task. This study proposes a method to minimize the delay in a cost-optimal electric bus system, considering the possibility of charging infrastructure breakdown. A stochastic model was developed utilizing input from a cost optimal deterministic model to incorporate the probability of charger breakdown up to a certain confidence level. The model is then applied to a city's General Transit Feed Specification (GTFS) bus network to determine the effects of charging infrastructure breakdown on the system, in terms of delay in the service. The model could minimize the delay due to charging infrastructure breakdown possibility, by making changes to the energy recharged at the terminals. The maximum amount of delay was observed to be within 10 minutes for 1% charging infrastructure breakdown probability, while accounting for 99% scenarios. Sensitivity analysis was conducted to determine the criticality of the infrastructure with change in possibility of charging infrastructure breakdown, leading to the determination of critical terminals in the network and their charging infrastructure characteristics. Common cost minimization practice of low number of higher-powered chargers was more critical than higher number of medium- or low-powered chargers when considering the possibility of breakdowns.

3 - Electric Rickshaw Charging Station Design for Urban Indian Areas
Sourav Das, *N. Nezamuddin*

The electric rickshaw (e-rickshaw) is a three-wheeled and demand-responsive informal public transport mode popular for last-mile connectivity and short trips in developing countries worldwide. In several semi-urban and rural parts of India, e-rickshaws fill the demand gap caused by inadequate or nonexistent public transit infrastructures; they act as a feeder to public transit systems in urban Indian areas, where they are sufficiently accessible (e.g. metros and buses). This paper contributes to the scarce empirical knowledge about e-rickshaw

drivers' charging preferences, and its impact on e-rickshaw charging infrastructure design. A primary survey of e-rickshaws in Karol Bagh, a municipality area in Delhi, India, indicates 93% of the drivers prefer charging during noon and afternoon. On average, they are willing to detour 0.32 kilometers for charging and wait up to 15 minutes in queue at charging stations. The drivers prefer initial and final state of charge (SoC) as 20 % and 80% before and after charging, respectively. We propose a Bi-objective Dynamic Probabilistic Maximal Covering Location-Allocation Model to design the charging stations with the objectives of maximizing charging demand coverage and minimizing charging station workload imbalance. The model uses gradual covering decay and cooperative coverage to find optimal locations for charging stations and assign charging demand. We incorporated the findings related to drivers' charging preferences in the developed model. A weight of 0.7 was assigned to the charging demand maximization objective, and 0.3 was given to the workload unbalance minimization objective. The gradual covering decay function was defined using the distribution of acceptable detour distance for charging. Number of charging stations, budget and maximum queue length at the charging stations were used as the model constraints. Bharat AC-001 and DC-001 chargers were considered, as recommended by the Ministry of Power, Government of India. The charging stations were modeled as M/M/c queueing systems. An extended network consisting of 34 nodes and 307 links, including the existing e-rickshaw routes, was constricted for the modeling purpose. Four charging stations with a total of 22 AC-001 and 10 DC-001 chargers can cover 75% of the charging demand, while maintaining the pre-specified upper limit of queue length for a specified percentage of time and utilizing the total budget.

Transportation System Analysis

Cluster: Mobility and Transportation Systems
Invited session
Chair: *Javier Durán-Micco*

1 - Using road grade and altitude information to estimate last mile distribution costs in strategic models.

Luz Flórez-Calderón, *Ricardo Giesen*, *Mathias Klapp*

We study the impact of using road grade and customer altitude information as input in aggregated models estimating urban last-mile distribution costs for strategic decisions. Specifically, we propose a model using aggregated information, such as service area size, customer spatial density over the service area, vehicle and engine characteristics, average payload weight per dispatch, average road grades within the service area, and the altitude difference between the depot and the service area. To improve our cost estimation, our model combines theoretical results, derived from continuous approximation approaches and statistical analysis. To do so, we start by constructing a lower bound on the fuel consumption cost spent by a truck, based on continuous approximation results and the fuel consumption formulas found in the literature. From this lower bound, we leverage a simple model estimating operating cost (i.e., fuel and salary cost) as a function of aggregated route information and calibrated parameters.

We calibrate the parameters of our model via regression techniques in a family of computer simulated instances representing a vast universe of potential real-world scenarios used as a calibration set. For each of these instances, the real operating cost is obtained by solving a detailed vehicle routing problem, specialized for instances with steep roads. We later compute and compare the estimation error of our model compared to a benchmark model proposed by the scientific literature in a different set of validation instances. In these experiments, our model yields a Mean Absolute Percentage Error (MAPE) 6.84% smaller than the benchmark model. MAPE decreases as the number of customers increases, and the performance of the proposed model improves in scenarios where the average road grade is equal to or higher than 4% and/or the average weight of the product demanded by customers is higher than 40 kg.

The results of this study are useful for strategic decision-making by logistics service providers in regions with steep roads. Understanding the impact of average road grades and customer altitude information on route costs should inform strategic decisions, such as the design of delivery districts, choice of vehicle model or size, and depot location.

2 - A simulation platform for sustainability assessment in urban transport

Laura M. Cardenas

A sustainable urban transport system is one involving social, economic, and environmental aspects in a balanced way, promoting accessibility, safety, equity, efficiency, and economic viability, and, additionally, minimizing its environmental impacts and emissions. The achievement of the previous goals in traditional urban transport models, however, requires the support of policies in an integrated and long-term manner. Therefore, the planning and decision-making processes around sustainable urban transport systems must be supported using tools facilitating the understanding of the transport system and its progress, as well as its evaluation. Sustainability Indicators currently represent the dominant system for evaluating sustainability in transport systems; however, many of these approaches ignore the global concept of sustainability and address social aspects in a limited way, resulting in incomplete and ambiguous evaluations of transportation systems. The need arises to implement evaluation tools facilitating the integration of sustainability indicators, while providing an integrated and holistic vision in the transport sector. This study presents a simulation platform allowing the user to evaluate the sustainability of Private Transport for a case study. This platform is made up of a system dynamics simulation model and an interface facilitating interaction with the user. The goal of the platform is to allow the user to evaluate the behavior of the private urban transport system against the implementation of policies, considering sustainability indicators. Within the environmental indicators are emissions, environmental impacts, and land use in transport infrastructure; within the social indicators are accessibility, quality and effects on health; and in terms of economic indicators are the use and consumption of energy, financial values and regulation and public policy aimed at transport.

3 - Assessing the impact of horizontal collaboration in logistic networks: a simulation-based approach

Javier Durán-Micco, *Shafagh Alaei Jordehi*, *Cathy Macharis*

The logistics industry is under pressure to reduce its environmental impact and achieve sustainability goals; in one potential solution, horizontal collaboration, logistics actors work together to optimize their operations. This approach is a key element of promising concepts, such as synchromodality and physical internet. For logistic service providers (LSPs), collaboration can help to optimize the routing and the utilization of assets by sharing information, resources, and capabilities. Implementing collaboration can be challenging, however, due to a lack of trust between players and their fear of losing competitiveness. To address these barriers, it is crucial to have tools to predict the performance of systems and estimate the impact of collaboration on the individual operations of different players.

To this end, we have developed an agent-based simulation model, evaluating the performance of a logistic network; it represents a large multimodal logistic network, where several LSPs satisfy transportation requests from external customers. LSPs can use their own fleet of trucks, outsource to external trucks, use previously reserved slots in train services, or buy train slots at the last minute, with different costs and environmental impacts for each option. Previous results show more flexible and collaborative operations lead to an overall reduction of costs and emissions of the system. In this research, we examine the impact of collaboration on individual LSPs in different scenarios; three basic alternatives are considered: LSPs only using their own resources, LSPs buying and selling services to each other at different cost margins, and a central operator assigning requests based on the benefits for the system as a whole. Additionally, we test different scenarios regarding the relative size of the players, such as cases where all LSPs are of similar size or where there are relevant disparities in their sizes.

The proposed model serves as a valuable instrument for assessing and examining the effects of introducing collaborative systems within a logistic network, with a focus on analyzing the impact on each individual participant. It can also provide input to design and test compensation schemes distributing the benefits of collaboration equitably between

actors. This is a critical aspect for LSPs to be interested in collaborating in these systems in the future.

Collaborative Transportation

Cluster: Mobility and Transportation Systems
Invited session
Chair: *Wouter van Heeswijk*

1 - Auction-based Exchanges in Last-Mile Parcel Logistics: The Issue of the Second Price
Christian Truden

The continuous shift of consumers towards e-commerce fuels a rise in global parcel volumes. The parcel business is often characterized by several carriers operating in the same geographical areas. Horizontal cooperation among carriers, i.e., the exchange of parcels, can be an effective means to reduce vehicle emissions while saving delivery costs. In general, carriers are somewhat averse when it comes to sharing business data with competitors to protect their competitiveness. Hence, smart mechanisms are needed to enable horizontal collaboration for parcel logistics, without requiring sensitive business data. We propose setting up a combinatorial auction organizing the exchange of parcels among carriers, so the overall vehicle emissions and delivery costs are reduced. To this end, we propose to run an adapted version of Vickrey-Clarke-Groves (VCG) auctions. The VCG mechanism is prone to overspending, however; i.e., paying the winning bidder significantly more than necessary, only limited by the second price. This property is potentially problematic for parcel auctions as the available amount of money is limited by the collected delivery fees. By conducting a numerical study, we quantify the premium of the VCG mechanism in a practical setting. First results, obtained from rather small test instances, are encouraging; the second price paid to the winning bidder is within an acceptable range of the first price. Results on larger instances will be presented at the conference.

2 - A carrier collaboration framework: collaborative vehicle utilization with routing decision
Sahand Asgharieh Ahari, Ilke Bakir, Kees Jan Roodbergen

Carriers are facing challenges with inefficient transport planning, resulting in increased delivery costs and negative environmental impacts, such as carbon emissions. Carriers can address these challenges through collaboration, where they can share their resources to make deliveries more efficiently. Within this context, we propose a collaborative setting where carriers collaborate by borrowing vehicles from each other to achieve higher network-level profits. When a carrier borrows a vehicle, it departs from the lender's depot to the borrower's depot. The borrowed vehicle is then loaded with goods, and deliveries are made based on optimal routing decisions. Each carrier can only visit its own customers. This collaborative setting, the "collaborative vehicle utilization"framework, decides the carriers borrowing vehicles and lending them, the number of borrowed vehicles, and the optimal delivery route for each vehicle in the setting. Next, a fair profit-sharing mechanism is considered to allocate the obtained network-level profit among collaborating carriers. We develop two integer-programming formulations for our "collaborative vehicle utilization" setting and solve them using exact branch-and-price algorithms. For profit sharing, an allocation mechanism from cooperative game theory is used. We compare our setting with a frequently studied collaboration setting from the literature, called "order sharing", where carriers can make deliveries on behalf of each other, by sharing customer orders instead of sharing vehicles. Thus, carriers must share their customer information with other carriers to enable delivery - a formidable barrier to forming these collaborations in practice. Our setting does not compromise the customers' privacy, has a shorter calculation time compared to "order sharing" and, typically, attains similar network-level profits.

3 - Learned bidding in freight transport with policy gradient methods
Wouter van Heeswijk

This study investigates the feasibility of multi-agent reinforcement learning to represent strategic bidding behavior in freight transport markets, without central control or communication between agents. The goals are to understand if feasible market equilibria can arise in these environments, serving as a stepping stone toward self-organizing logistics systems, like the Physical Internet, and to offer valuable insights for the design of contemporary transport brokerage platforms.

We model an agent-based environment, where shippers and carriers actively learn bidding strategies using policy gradient methods, posing bid- and ask-prices at the individual container level. Both agents learn the best response, given the expected behavior of the opposing agent. Inspired by financial markets, a neutral broker allocates jobs based on bid-ask spreads. From a game-theoretical perspective, the problem can be likened to a bargaining game, where agents pose bids and asks to share a surplus value, bounded by operational transportation costs of the carrier and maximum willingness to pay of the shipper. Our game-theoretical analysis and numerical experiments focus on behavioral insights, measuring adherence to Nash equilibria, fairness of reward division, and utilization of transport capacity to evaluate system performance. The results suggest a potential for full automation and decentralization of freight transport markets. The insights could ease the design of real-world market platforms, suggesting an innate tendency of markets to reach equilibria without behavioral models, information sharing, or explicit incentives.

Although observing some encouraging converging behaviors, overly aggressive strategies may easily destabilize the system. As the results also imply risk-seeking behavior tends to increase an agent's reward share, this indicates a need to curtail this impulse to safeguard system stability.

While self-organizing logistics systems are feasible, caution is necessary when designing automated platforms, to ensure they remain stable and do not lead to negative consequences.

Multiobjective Optimization Under Uncertainty

Cluster: Multi-Objective Optimization: Theory, Algorithms, and Applications
Invited session
Chair: *Margaret Wiecek*

1 - Parametric Multiobjective Optimization for Decision-Making under Conflict and Uncertainty
Margaret Wiecek

In some applications, decisions are made in the presence of multiple objectives, but also in continuously changing uncertain scenarios. For instance, a regional power grid must meet demand at all times, not just peak times, while power storage constraints render excess production impractical. In the petrochemical industry, uncertain proportions of chemical compounds are also controlled at all times, leading to an optimization problem with parameters in several locations.

Parametric multiobjective optimization (pMO) models decision-making problems with multiple objective functions and parameter uncertainty, allowing decision-makers to compute efficient and Pareto sets as functions of uncertainty. When additional parameters are included in a multiobjective optimization problem (MOP) to model uncertain data, the resulting parametric MOP (pMOP) is solved to obtain a parametrized collection of efficient sets, as opposed to a unique efficient set associated with a standard MOP. Because mpMOPs can be solved before their efficient sets are actually needed, in time-sensitive situations the only computations required are function evaluations at

the specific parameter values stemming from the situation. The numerical representation of the efficient sets depends on the approach used to their computation. Scalarization methods make up a common and well-established methodology for computing efficient sets to MOPs. When the scalarizing parameters remain unknown, the efficient set is parametrized and represented as a set of efficient functions of these parameters. This parametrization can naturally be combined with solving pMOPs because the algorithms performing the former can achieve the latter.

We first propose new formulations of scalarizations and then focus on algorithmic developments for multiobjective convex quadratic problems (pMOQPs) with parameters in general locations. We solve pMOQPs with linear constraints exactly and pMOQPs with quadratic constraints by approximation. In each case, we provide a closed form description of the efficient sets.

The performance of the algorithms is examined on synthetic instances. The algorithms are also applied to pMOQPs modeling decision-making problems in statistics, portfolio optimization, and engineering design. The real-life context reveals the interplay between the scalarizations and provides additional insight into the obtained parametric solution sets.

2 - Solving bi-objective robust mixed-integer linear optimization problems
Anita Schöbel, *Fabian Chlumsky-Harttmann*, *Marie Schmidt*

Multi-objective optimization concerns optimization under multiple (maybe conflicting) criteria, while robust optimization aims to find the best solutions in the worst case; in this talk, we combine both and consider robust multi-objective optimization. While there exist concepts on how to define robust Pareto solutions, algorithms for finding the solutions are scarce.

We develop algorithms for solving robust bi-objective mixed-integer linear optimization problems by combining dichotomic search from multi-objective optimization and cutting-plane approaches (also known as optimization-pessimization) from robust optimization. There are two possibilities for a combination:

One may interpret the robust multi-objective optimization problem as a deterministic problem. This brings us to a nonlinear problem, since the objectives to be minimized include a maximization over the scenario sets. Nevertheless, dichotomic search can be extended to this setting, where the resulting scalarized problems can be solved by cutting-plane approaches or by dualization, in the case of purely linear programs.

A second possibility is to handle the robust multi-objective problem directly as a robust problem. To this end, we generalize the known cutting plane approach for single-objective optimization to a multi-objective setting. The resulting subproblems are robust multi-objective problems with small scenario sets, solvable by dichotomic search

We implemented the algorithms and report on our numerical experiments on randomly generated instances, considering both finite and continuous uncertainty and considering finite and infinite feasible sets.

3 - Upper Bounds on Performance Indicators for Multi-Objective Stochastic Optimization
Susan Hunter, *Burla Ondes*

We discuss recent progress in deriving upper bounds on a few performance indicators for multi-objective stochastic optimization. We use a triangle inequality to bound the performance indicators by the sum of a deterministic error term plus a stochastic error term. Then, we explore recent advances in deriving upper bounds for each term and how they might be used for algorithmic advances.

4 - Efficient sets according to different preferences
Giacomo Biolghini, *Sergio Ortobelli Lozza*, *Riccardo Sorce*

In this paper, we identify the non dominated optimal choices, according to different preferences. In particular, we want to compare the different efficient sets obtained by the non dominated choices, with respect to stochastic dominance orderings with the non satiable and risk averse investor portfolios' Pareto optimal set. In this context, we also compare the different efficient sets with the classical mean variance efficient frontier. Finally, we also propose multi-parameter efficient sets, and we ex-post compare the optimal choices for different levels of risk aversion and prudence.

Recent Advances in Pure and Mixed Integer Multi-objective Optimization

Cluster: Multi-Objective Optimization: Theory, Algorithms, and Applications
Invited session
Chair: *Lavinia Amorosi*

1 - A two-phase algorithm for the bi-objective integer minimum cost flow problem
Matthias Ehrgott, *Lavinia Amorosi*, *Benjamin Weißing*

In this paper, we describe a new two-phase algorithm to generate a minimal complete set of efficient solutions for the bi-objective integer minimum cost flow (BIMCF) problem. For the first phase, we propose the adoption of the dual variant of Benson's algorithm, taking advantage of the total unimodularity of the coefficient matrix of this problem. The second phase consists in a new enumerative recursive procedure, based on increasing values of reduced costs of variables in associated weighted linear programs. With this procedure, it is possible to generate all integer feasible flows on a connected network. Combined with bounds for the costs of efficient flows, the two-phase method finds a minimal or maximal complete set of efficient solutions; the description of this procedure is accompanied by an illustrative example. We will also discuss issues caused by degeneracy and present the results of numerical experiments demonstrating the effectiveness of the method.

2 - A new criterion space search algorithm for bi-objective mixed integer linear programs
Lavinia Amorosi, *Marianna De Santis*

In this talk, we focus on bi-objective mixed integer linear programming problems (BOMILP), presenting a new algorithm to detect the complete non-dominated set. The algorithm works in the criterion space, alternating the resolution of single objective mixed integer linear problems and bi-objective linear problems. At each iteration, a filtering and storing procedure is adopted, based on a bi-objective tree; an in-order traversal of the tree produces a sorted list of all non-dominated points and segments of the problem. An illustrative example and experimental results on a testbed of instances will be presented.

3 - Branch and Bound and Branch and Cut approaches for bi-objective linear binary programming
Lucas Létocart, *Pierre Fouilhoux*, *Yue Zhang*

Many real-world combinatorial optimization problems actually involve multiple objectives; in multi-objective integer programming, there exists generally no solution optimizing every objective simultaneously. We are interested in the complete set of Pareto optimal ("efficient") solutions, so solutions cannot be improved in any objective without losing advantages in at least one of the other objectives. Moreover, there might be an exponential number of efficient solutions; this problem is generally NP-hard and intractable for large size instances. In this work, we propose branch and bound and branch and cut approaches for solving bi-objective linear binary problems and two branching strategies, on free variables and on objective space (Pareto branching) we could combine. We compute a lower bound set at each node of the tree by solving a biobjective linear relaxation, and we maintain a global upper bound set, storing the best solutions known so far and using bi-objective heuristics. To tighten the lower bound set, we could add valid inequalities (from a new multi-point cutting plane scheme and from a commercial solver). Our first preliminary experiments show the outstanding performance of our branch and bound and branch and cut methods on different problems and instances.

4 - On two methods of deriving interval representations of Pareto optimal outcomes for large-scale bi and three-criteria MIP problems
Janusz Miroforidis

Despite the rapid development of optimization techniques, there are still MIP problems for which the derivation of optimal solutions can be time-consuming, or even beyond allotted limits for top-class commercial MIP solvers. However, when there is, e.g., a time limit on optimization, and a MIP solver is not able to derive the optimal solution, it provides the MIP gap that gauges the quality of the approximate solution. In the case of multi-objective MIP problems, the Chebyshev scalarization and a MIP solver can be used to derive Pareto optimal outcomes. For a large-scale multi-objective MIP problem, its scalarization may not be solved to optimality under the assumed time limit. The decision maker (DM) then has the approximate Pareto optimal outcome and the MIP gap of the single-objective optimization problem. However, based on this information, the quality of the approximation of a single component of the Pareto optimal outcome cannot be shown to the DM. In my previous work, a general methodology for multi-objective optimization to provide lower and upper bounds on objective function values of a Pareto optimal solution designated by a vector of weights of the Chebyshev scalarization of a multi-objective MIP problem has been proposed. The bounds form the so-called interval representation of the Pareto optimal outcome. The DM can use interval representations to navigate the Pareto frontier. To derive them one needs the so-called lower and upper shells. However, in my previous work, there is a lack of an algorithmic method for deriving an upper shell that is necessary to calculate the interval representation of the Pareto optimal outcome. In this work, a time limit on the derivation of a Pareto optimal solution is assumed. The approximate solution derived within this limit forms a single-element lower shell. For multi-objective MIP problems with two and three objective functions, I propose two methods of deriving an upper shell that, together with the lower shell, can be used to calculate the interval representation of the Pareto optimal outcome. The methods are based on solving a series of single-objective optimization problems solved within another time limit on optimization. To illustrate the viability of the methods, I present results of several numerical experiments with selected large-scale instances of the multidimensional knapsack problem with two and three objective functions. I discuss the pros and cons of both methods.

Multiobjective Optimization Applications

Cluster: Multi-Objective Optimization: Theory, Algorithms, and Applications
Invited session
Chair: *Juan Carlos Pina Pardo*

1 - A scalable multi-objective maintenance optimization for multi-component systems over a finite horizon
İpek Kıvanç, *Claudia Fecarotti*, *NÉomie Raassens*, *Geert-Jan van Houtum*

Nowadays many original equipment manufacturers (OEM) not only provide innovative products, but also the related technical services, including repairs and warranty. Delivering the after-sales maintenance services is challenging as the importance of key performance indicators (e.g. costs of maintenance and downtime) differs for each customer. Unexpected failures and long downtimes can have significant consequences, thus cost-effective maintenance where both costs and system availability are optimized, is of great importance to ensure seamless performance of systems. We consider a system of multiple heterogeneous components under a mix of failure-based, age-based, and condition-based maintenance policies. Due to the heterogeneity of the components, coordinating maintenance actions, triggered by different policies for various components, is a challenge. To meet this challenge and based on the collaboration with an OEM manufacturing automation systems for the dairy industry, we present a bi-objective optimization model for developing efficient maintenance concepts minimizing both maintenance costs and system downtime. The resulting maintenance concept is defined by (i) frequency of scheduled downs, (ii) thresholds triggering maintenance for age and condition-based maintenance components, and (iii) grouping of components to be repaired, simultaneously. We use a two-stage bottom-up approach where we iteratively optimize the maintenance thresholds at component level and the frequency of scheduled downs at system level. At component level, we formulate a single-unit replacement model and derive a control limit replacement policy for components subject to either age-based or condition-based maintenance. At system level, coordination of maintenance activities entails determining a fixed time interval for scheduled downs for the machine as a whole and the grouping policy for clustering maintenance activities. We formulate the decision-making process at component level as a Markov decision process (MDP) to get optimal policies for a given interval of scheduled downs. Then, we utilize an iterative procedure to optimize the interval of scheduled downs at the system level. We present a real case study to demonstrate how the proposed maintenance model can be used to derive optimal maintenance policies, tailored to different customer needs. We also investigate the performance of the solution algorithm in terms of computational efficiency.

2 - Multi-Objective Optimization Methods for the Green Inventory Routing Problem
Maristela Santos, *Arianne Mundim*, *Reinaldo Morabito*

This work presents the results of two exact multi-objective optimization methods applied to a green logistics problem, the green Inventory Routing Problem (green IRP), simultaneously considering inventory management decisions, vehicle routing, and product delivery scheduling and aiming to minimize CO2 emissions. The goal is to obtain a set of solutions corresponding to different trade-offs, allowing the manager to select the best option, according to current demands. Two methods were used - the e-GIRP and the TA-GIRP. The former uses the augmented e-constraint method to avoid weakly efficient solutions; in contrast, the latter uses the augmented Tchebycheff metric, one of the most powerful and efficient for integer problems, without modifying the criterion space. Two metrics were applied to evaluate and compare the methods: the sum of the trapezoid areas metric and the cardinality metric. Computational experiments were conducted on 75 instances with three planning periods, three vehicle models, and 5 to 15 customers. Regarding efficient solutions, the TA-GIRP found an average of 4.63 strongly efficient solutions, while the e-GIRP obtained an average of 4.59 solutions. Regarding the metrics used, the TA-GIRP was better in 63 instances in the sum of trapezoid areas metric and in 13 instances in the cardinality metric, being equal in several instances and worse in others. Both multi-objective approaches are competitive for the GIRP and can solve the addressed problem. The TA-GIRP was slightly better in terms of solutions and computational time.

Heuristic Solution Methods for Multiobjective Optimization

Cluster: Multi-Objective Optimization: Theory, Algorithms, and Applications
Invited session
Chair: *Giovanni Misitano*

1 - Using the Pareto Surface navigation method to extend the local search algorithm in MO-DAO in radiotherapy
Mauricio Moyano, *Guillermo Cabrera-Guerrero*, *Nicolle Ojeda Ortega*, *Liany Lizeth Tobón Castro*

Radiotherapy is a cancer treatment using high doses of radiation to destroy cancerous cells and shrink tumors, while sparing surrounding organs at risk; one of the most common techniques within radiotherapy is Intensity Modulated Radiation Therapy (IMRT). Given the complexity of the IMRT problem, it is usually approached sequentially. First,

we need to determine the beam angles where radiation will be delivered. Then, the radiation intensities for each selected beam angle are computed. Finally, the sequence of aperture shapes we need to use to deliver the computed treatment plan is generated. Unfortunately, the treatment plans generated by this sequential approach have many apertures, leading to longer treatment times. Unlike the sequential approach, in the Direct Aperture Optimization (DAO) problem, the constraints associated with the number of deliverable aperture shapes and the machines' physical constraints are considered during the intensities optimization process. The DAO problem has been studied more and more in recent years, as it can produce treatment plans comparable to plans produced using the traditional inverse planning approach, while using significantly fewer apertures. Although IMRT is inherently a multi-objective optimization problem, where irradiating the tumor while sparing surrounding organs at risk are two compromised criteria, most of the algorithms proposed in the literature consider only the single objective version of this problem. For this reason, we extend a local search algorithm proposed in the literature, adapting the Pareto surface navigation method to solve the multi-objective DAO. We apply our proposed local search algorithm to a set of prostate cases and compare it with the single objective local search algorithms.

2 - Adapting NSGA-II algorithm for Bi-objective Composite Retrieval
Nicolle Ojeda Ortega, *Mauricio Moyano*, *Liany Lizeth Tobón Castro*, *Guillermo Cabrera-Guerrero*

Traditional search strategies in information retrieval consider only one attribute to build up a ranking list, depending exclusively on the considered attribute, often neglecting the relationships between other attributes. As a result, users may need to rethink the original query to accomplish the right solution, as these search strategies do not consider the existing relations among all the other attributes. Composite retrieval (CR) of diverse and complementary bundles has been proposed to respond to this behavior; it's objective is to group elements into bundles, with the items related under both criteria: similarity and complementarity of bundles. These bundles should satisfy users' expectations without needing a new intervention, improving the search experience. Despite the inherent multi-objective nature of the CR problem, only single-objective models, mainly based on the weighted sum of each criterion, have been proposed in the literature. In this work, we present a novel bi-objective Composite Retrieval model, considering the existing trade-off between the diversity and complementarity of each set of bundles. Given the excellent performance of multi-objective evolutionary algorithms in combinatorial problems, we implement the NSGA-II algorithm to evaluate our model; further, we propose some modifications to improve the algorithm's search strategy. Finally, we compare the results with those obtained by the single objective model previously proposed in the literature.

3 - A Hierarchical Approach to a Tri-objective Portfolio Optimization Problem Considering an ESG Index
Carlos Ignacio Hernández Castellanos, *Yeudiel Moreno*

The Markowitz covariance model is the classical approach to portfolio optimization, a bi-objective optimization problem aiming to minimize the variance and maximize the expected return. In recent years, there has been an interest in including several other objectives to better capture the preferences of investors, such as 12-month performance, 3-year performance, annual dividend, volatility, environmental, social, and corporate governance (ESG).

In this work, we focus on the last one (ESG); more companies and individuals are starting to look at the social and environmental commitment of the companies they invest in, besides the potential profit. As important as ESG is, it is still considered a secondary objective since most people would not consider portfolios with low expected returns or high variance even if the portfolio maximizes ESG.

Thus, we propose a hierarchical approach. First, the investor decides on allowed deterioration for the expected return and the variance (i.e., the points the investor is willing to sacrifice to look for solutions with better ESG). With this information, we compute the set of approximate solutions considering only the classical bi-objective problem with constraints by means of specialized evolutionary algorithms. Next, we integrate the third objective - the ESG index. Finally, we filter any dominated solution using the three objectives.

We tested our approach with data from 40 ETFs extracted from Yahoo finance over the last year (2021-2022). The approach found solutions having a good ESG compromise, offering options to potential investors beyond the classical bi-objective approach. In future work, we plan to compare our formulation with the one from the state-of-the-art, to better understand the advantages and disadvantages of the proposed model.

4 - Comparing interactive multiobjective optimization methods with artificial decision-makers based on computational rationality
Giovanni Misitano, *Bekir Afsar*, *Jussi Jokinen*, *Kaisa Miettinen*

Multiobjective optimization (MOO) problems are pervasive across many disciplines. In these problems, multiple conflicting objective functions are optimized simultaneously, usually with no single best solution. Instead, there are multiple mathematically incomparable so-called Pareto optimal solutions. A decision maker (DM) is needed to provide their preferences to find the best solution.

To solve MOO problems, different methods exist, which are classified based on when the DM provides preferences. In interactive methods, the DM provides preferences iteratively during the optimization process guiding the search towards preferred solutions. Thus, a DM learns about the problem and the feasibility of their preferences during the optimization process.

Choosing an interactive MOO method that best supports a DM for a given problem is challenging. So-called artificial decision makers (ADMs) have been developed to make inexpensive and reproducible comparisons. ADMs can provide preference information so that interactive methods can be applied without human involvement. However, current ADMs do not adequately model the cognitive aspects of DMs, such as learning and memory.

We propose to utilize computational rationality, an approach that optimizes ADM actions while accounting for limitations in computational resources such as memory and processing. Computational rationality has been applied successfully in the past to model human behavior from a cognitive perspective, e.g., driving cars, and typing on on-screen keyboards of smart devices, without assuming any behavior a priori, but rather focusing on modeling the task environment and computational resources limiting the behavior.

We combine computational rationality with ADMs, which enables us to predict how human DMs adapt to interactive MOO methods and cognitive constraints, providing a more accurate prediction of human behavior. We employ reinforcement learning to derive optimal policies for ADMs based on computational rationality. Optimal policies describe how an ADM, that has adapted to cognitive constraints and the environment, interacts with interactive methods. By studying the found optimal policies, we gain insights on what kind of demands different interactive methods can exert from a human DM in terms of computational resources. Based on these different demands, our work provides a new way of comparing interactive methods in a reproducible manner and without human involvement.

Optimization Under Uncertainty in Routing, Inventory, and Planning

Cluster: Multilevel and Stochastic Optimization Methods
Invited session
Chair: *Edilson Arruda*

1 - An Interval-based Stochastic Unit Commitment Model Under Demand Uncertainty
Hojin Jung, *Jongheon Lee*, *Kyungsik Lee*

The unit commitment problem finds a minimum-cost on/off status and amount of generation for each generator while satisfying electricity demand and operational requirements. In this talk, we address the stochastic unit commitment problem, where a demand forecast during a given planning horizon is given and the period-wise independent prediction error follows a given distribution. In this situation, the standard two-stage stochastic optimization models with a finite number of demand scenarios can be used, where the on/off status is decided in the first stage and the amount of generation in the second stage. They often suffer from excessive computational burden, however, as the number of scenarios increases. In addition, operations based on the solutions from the models may be ineffective when uncertain demand is sequentially realized. To overcome these drawbacks, we propose an interval-based stochastic unit commitment model, where a range of the amount of generation, called "interval", is determined in advance for the purpose of reliable operation. The proposed model can avoid the use of a large number of scenarios by using the upper and lower bounds on the expected second-stage cost. We show the effectiveness and efficiency of the proposed model through computational experiments in the context of the actual operation, where uncertain demand is sequentially realized.

2 - A two-echelon multi-trip vehicle routing problem with synchronization under delays

Cigdem Karademir, *Breno Alves Beirigo*, *Bilge Atasoy*

With growing urbanization, cities have been increasingly challenged by rising congestion and infrastructural damage due to their heavy reliance on road transportation. Advanced technologies, like electric vehicles, autonomous cars, unmanned vessels, and drones, can help mitigate these issues as they entail a more sustainable use of the whole transportation network. However, they require the development of advanced logistics systems that can integrate the different technologies and vehicles, allowing them to work together in synchronization in time, space, and cargo flow. We propose an Integrated Water- and Land-based Transportation (IWLT) system that utilizes autonomous vessels as mobile depots for Light Electric Freight Vehicles (LEFVs) to address the congestion-related issues in cities. However, delays can occur and quickly propagate on the network, and their impact on the integrated and synchronized systems has not yet been adequately researched in the literature. The IWLT system is modeled as a two-echelon vehicle routing with time windows, multi-trips, and satellite synchronization (2E-MVPRTW-SS) under delays. We propose a two-stage recourse model to identify optimal decisions in the face of delay uncertainty. Recourse is defined as the cost of lateness at demand nodes. A Logic-based Benders Decomposition (LBBD) is developed to solve each sub-problem representing the scenarios. The proposed flexible system where vessels navigate freely between satellites as mobile depots is compared to a stationary system where vessels are located at best satellites as temporary fixed depots. Preliminary results on small-sized test instances, considering delays in transfer operations at the satellites, show that the flexible system achieves fewer vehicles and trips on the roads. Moreover, it has greater flexibility in recovering the system's efficiency and feasibility by re-organizing water logistics with synchronized sailing vessels in case of delays. Besides the reduced risk of lateness at demand nodes for a reliable integrated system, it also leads to fairer mode shares between roads and inland waterways. To further analyze the cost-efficiency of such sustainable logistics solutions in urban areas, different delay sources will be studied.

3 - On the application of state space decomposition and time aggregation to solve Markov decision processes

Edilson Arruda, *Rodrigo Alexandre*, *Marcelo Fragoso*

Markov decision processes (MDP) are an elegant and powerful tool to tackle optimisation under uncertainty, with a wide range of applications in diverse fields that span from logistics management to healthcare optimisation. However, solving large-scale MDPs remains a challenging task, despite intensive research in the area and in the correlated fields of reinforcement learning and stochastic optimisation. This is due to the so-called (Bellman's) curse of dimensionality, which still eludes a satisfactory mathematical and computational solution for all but a few very specific instances of large-scale MDPs.

To tackle the curse of dimensionality, we introduce a decomposition approach for large-scale MDPs that hinges on a new state-space-decomposition technique, underpinned by time aggregation (aka Markov chain state space embedding) techniques. By introducing control, i.e. optimisation under uncertainty, the approach extends and generalises a multi-subset decomposition technique recently introduced for Markov chains. The approach allows us to design a two-phase time aggregation approach by performing absorption analysis at the small subset of states with certain communication properties that emerge from the very design of the partitioning scheme. Such properties allow us to design efficient algorithms that make use of the communication properties emerging from the partitioning scheme. The algorithms derive a distributed approach for value function evaluation that iterates on a single subset of the state partitioning at a time.

We validate the approach in the light of an inventory management problem. The results are promising and suggest that the proposed algorithms are capable of converging in a very small fraction of the time required by the classical value and policy iteration algorithms, with guaranteed convergence to an optimal policy.

Bilevel Programming and Applications

Cluster: Multilevel and Stochastic Optimization Methods
Invited session

Chair: *Margarida Carvalho*

1 - Exact Algorithm for Multicommodity Network Design under Stochastic Interdictions

Shabnam Mahmoudzadeh Vaziri, *Onur Kuzgunkaya*, *Navneet Vidyarthi*

Multicommodity network design problems have applications in transportation, logistics, and telecommunication networks, all based on the premise of undisrupted functioning with minimal redundancy in their structure. Given the importance of supply chains, it is essential to ensure these systems are resilient and able to withstand disruptions. Recent deliberate attacks and major natural disasters created the need to examine worst-case conditions more carefully in the design and operation of these networks. To achieve this objective, we use an important class of problems known as network interdiction and fortification planning problems, leading to multi-level optimization problems. In this research, we present a novel approach for designing resilient multicommodity networks, by considering the effects of worst-case disruptions and associated uncertainty, in a tri-level mathematical problem formulation. In the first level, the designer selects the design decisions and the flow decisions in normal conditions, by considering the effects of worst-case disruptions. Next, the interdictor interdicts the arcs of the network to cause maximum damage. At the third level, the designer reallocates the flow of commodities on the residual network, by minimizing the post-interdiction flow costs. Since it is unlikely the designer is aware of the number of attacks, we incorporate a stochastic number of attacks in the problem formulation. To solve the proposed tri-level stochastic mathematical model, we transform the tri-level formulation into bi-level using duality, then solved by using Branch-and-Benders-Cut algorithm. To improve the computational performance, we implement enhancement techniques, such as Pareto-optimal cuts, penalty reformulation, valid inequalities, warm start, and variable fixing. We compare the efficiency of the enhancement techniques on "r" multicommodity benchmarks from the literature. Enhancement techniques improve the computation time of the Branch-and-Benders-Cut algorithm by 51% on average. Through our numerical experiments, we demonstrate the benefits of the proposed stochastic formulation over the deterministic one in achieving resilient multicommodity network design.

2 - Two-Stage Stochastic Program with Mixed-Integer Recourse for Relay-Based Network Design

Onkar Kulkarni, *Mathieu Dahan*, *Benoit Montreuil*

The trucking industry majorly relies on long haul to maximize truck utilization and consolidation opportunities; this generates long delivery trips for truck drivers, recently leading the industry to face truck driver shortages and retention issues. Relay-based transportation serves as a

pragmatic solution, where a truck driver can actively advance a load for half of their daily driving limit and can return home daily, while the shipments travel toward their final destinations. In this work, we provide an optimization-based methodology to design a relay-based transportation network by strategically locating relay hubs. We formulate the problem as a two-stage stochastic program, where we position and size the hubs in the first stage. In the second stage, upon realization of the demand uncertainty, we decide the frequency of trucks on the transportation links for transporting commodities through consolidation plan considerations and potential back-haul opportunities. Due to the integral nature of the second stage decision variables and problem size, the program becomes difficult to solve exactly, via off-the-shelf solvers. We leverage the block-angular structure of the problem and employ a scalable two-phase Branch-and-Benders-decomposition-based algorithm to solve it exactly. In the first phase, we branch on the first-stage variables, add Benders feedback cuts at each node of the tree and employ a heuristic to prune non-promising solutions from the feasible solution set. In the second phase, we rank the promising solutions by solving them exactly to find an optimal solution. Next, we depict the applicability of our solution approach through designing a large-scale relay-hub network for a major car manufacturing company to be used for car deliveries in the South-East region of the USA. We show the importance of uncertainty consideration through evaluating the performance of the designed network against what is obtained in a deterministic setting in various demand scenario realizations. Finally, we also show the value of back-haul and consolidation consideration at the network design stage as well.

3 - Cutting-plane algorithms for the stochastic diversion path problem
Cole Smith, *Di Nguyen*, *Orkun Baycik*

This talk examines a problem taking place on a directed network, with a specified "diversion path" and a set of nonnegative arc lengths. The goal of the deterministic diversion path problem being to minimally adjust the arc lengths, so the given diversion path is optimal. In the stochastic diversion path problem, the arc lengths are independent uniformly distributed random variables, and the goal then becomes to guarantee the diversion path is optimal with a sufficiently high probability. In one problem, we model uncertainty in the stochastic network diversion path problem by drawing outcomes from randomly sampled scenarios; this framework allows us to uncover a fairly simple model, where more complex joint distribution functions describing the arc lengths can be considered. In the latter case, we consider an exact formulation of the problem without approximating stochasticity by sampled scenarios. For this more challenging problem, we prescribe an algorithm leveraging bounding and partitioning schemes to converge to an optimal solution. We demonstrate the efficacy of our procedures on a set of randomly generated instances.

Recent Advances in Network Interdiction, Network Resilience, and Bilevel Optimization

Cluster: Multilevel and Stochastic Optimization Methods
Invited session
Chair: *Yongjia Song*

1 - Distributionally Robust Two-Stage Convex Quadratic Programming
Dave Morton, *Nazlican Arslan*

Distributionally robust optimization (DRO) allows us to model stochastic optimization problems, with uncertain distribution of random parameters, but belonging to an ambiguity set. These models give rise to a bi-level optimization model via a game against "nature." We study a two-stage DRO stochastic program with convex quadratic recourse, consider data-driven distributional ambiguity sets based on the Wasserstein distance and discuss two decomposition algorithms.

2 - Strong bilevel feasibility for the network pricing problem
Margarida Carvalho, *Quang Minh Bui*, *José Neto*

The network pricing problem (NPP), a classical bilevel program, has a leader that controls the price of a subset of arcs (tolled-arcs) and a set of commodities, the followers, which aimto use the most economic path between their origin and destination. The leader seeks to maximize the revenue associated with the demand of the tolled arcs. In this work, we provide a novel approach demonstrating that, if the number of tolled-arcs is fixed, then the problem is solvable in polynomial-time. This is in contrast to the case where the number of commodities is fixed, which is NP-hard. We exploit this asymmetry in the computational complexity of the problem, which leads us to the concept of strong bilevel feasibility. We show computationally that cutting weak bilevel feasible solutions can enable solution approaches to scale to instances with many followers.

3 - Designing Resilient Distribution Networks Using k-Shortest Paths
Mathieu Dahan, *Onkar Kulkarni*, *Benoit Montreuil*

The recent surge in e-commerce and world trade has led the parcel delivery industry to be one of the fastest growing industries. In addition, fierce competition among courier companies motivates the need for fast, convenient, and resilient delivery of parcels to customers' doorsteps. All logistics networks face disruptions caused by frequent events, such as power outages, major traffic jams, natural disasters, pandemics, and deliberate attacks - leading to delayed parcel deliveries, increased delivery costs, and excess pressure on functional network components. Hence, there is an ever-increasing need to embed resilience, while designing these logistics networks; network structure has a significant impact on network resilience. Consequently, considerable efforts have been devoted to gauge the resilience of various logistics networks through structural properties of the networks. Topology-based resilience measures have rarely been used, however, at the network design level.

The objective of this research is to design resilient logistics networks by selecting hub locations and transportation edges to minimize the total demand-weighted distance of the k-shortest paths between each origin-destination pair. We derive two alternative mixed-integer programming formulations of the problem, based on path and edge decisions, respectively. We leverage their structures to devise and to accelerate three solution methodologies based on Benders decomposition, branch-and-price, and branch-and-Benders-cut utilizing k-shortest-path subroutines. We next showcase the applicability of the developed model and solution methodologies in designing large-scale resilient intercity parcel-delivery networks across Central China. Importantly, we evaluate and compare the resilience of the designed distribution networks to stochastic hub and edge disruptions, and we analyze the impact of the number of hubs and number of shortest paths k on the networks' resilience. Interestingly, the designed networks significantly outperform classical lean network designs when facing disruptions, while operating almost as efficiently as lean networks in nominal situations. This study demonstrates the value of accounting for resilience at the network design stage.

4 - A Bilevel Network Interdiction Problem with Applications in Human-trafficking Disruption
Yongjia Song, *Daniel Silva*, *Thomas Sharkey*

Motivated by applications in human-trafficking (HT) network interdiction problems, we study a special case of a bilevel network interdiction problem; the network operator's objective is to maximize the flow through the network after interdiction, but the attacker's objective is to minimize the number of arcs from a critical set with flow on them. For both the optimistic and the pessimistic version of the problem, we study their theoretical computational complexity, develop single-level reformulations, and perform a set of computational experiments for special cases of networks arising in HT applications, as well as for general network instances.

Multilevel and Stochastic Optimization

Cluster: Multilevel and Stochastic Optimization Methods
Invited session
Chair: *Camilo Gomez*

1 - Incorporating Service Reliability in Multi-depot Vehicle Scheduling: A Chance-Constrained Approach
Margarita Castro, *Merve Bodur*, *Yongjia Song*

The multi-depot vehicle scheduling problem (MDVSP) is one of the main planning problems for transit agencies. Only a few works in the literature consider travel time uncertainty, however, and its impact on the service quality for the users. We present a novel stochastic variant of the MDVSP guaranteeing service reliability, measured by on-time performance (OTP) at route terminals. We propose a chance-constrained programming model for this problem and two different optimization approaches to solve it. The first one is an exact approach based on a branch-and-cut procedure. The second approach is a heuristic algorithm based on Lagrangian decomposition utilizing our exact methodology to solve each sub-problem. We test our procedure on randomly generated and real-world instances based on the city of Halifax, Canada. Our experimental evaluation shows the value of our stochastic variant to achieve OTP, compared to alternatives currently used by practitioners, as well as the computational advantages of our methodologies and their theoretical guarantees.

2 - Addressing multi-actor decision-making problems under uncertainty: an application on public private partnerships for infrastructure projects
Samuel Rodriguez Gonzalez, *Juan Beltrán*, *Santiago Bobadilla*, *Andres Gonzalez*, *Carlos Lozano*, *Camilo Gomez*

Multi-actor decision-making problems are pervasive in practice, where individuals interact with each other (supply chains, energy systems, finance). Modeling decisions anticipating the reactions of others is challenging for practitioners, especially when considering combinatorial problems and non-deterministic behaviors.

The principal-agent problem is an instance of these problems, occurring when an agent, hired by the principal to perform a task, takes advantage of asymmetries of information to pursue its own goals, potentially in detriment to the principal's. Public-private-partnerships (PPPs) are prone to these behaviors, as governments rely on contractors to provide goods and services where their supervision capacity is limited. We explore an infrastructure maintenance problem in the context of a PPP to analyze the decision strategies of the involved 'players' under diverging objectives. Strategies and outcomes for both 'players' being affected by uncertainty and the other player's decisions is a key challenge for this analysis: the contractor's cashflows are affected by the government's inspection policies, while the societal benefit of the system is affected by stochastic deterioration and the contractor's maintenance policy.

We adopt an approximate dynamic programming approach allowing us to integrate different modeling and solution approaches into a unified framework. The latter is achieved through the implementation of a computational environment based on Markov Decision Processes capturing the decisions of both players and the stochastic deterioration process of the system. The environment provides a general representation of the problem; with it, we can evaluate and compare different mechanisms to generate decision strategies for players (i.e., policies). We evaluate policies based on the following: rules-of-thumb, mixed-integer stochastic bilevel linear programming, and math-heuristic approaches tailored for bilevel problems.

Our contribution is twofold: first, the proposed environment provides the basis for a simulator enabling PPP participants and regulators in assessing the potential outcomes of a specific PPP project (including the evaluation of players' likely strategies); and, second, the set of policy generating techniques shed light about key tradeoffs in PPP projects and may provide decision-support tools for PPP participants with varying levels of complexity.

3 - A computational environment for policy evaluation for the dynamic-stochastic purchasing inventory routing problem in agri-food supply networks
Camilo Gomez, *Juan Betancourt*, *Ariel Rojas*, *Daniel Cuellar-Usaquen*, *Sonja Rohmer*, *Marlin Wolf Ulmer*, *David Álvarez-Martínez*

Reconnecting consumers and producers, local food chains have received growing attention over recent years, offering more transparency and fairer prices to producers. In this context, online platforms play an important role by reducing intermediaries and creating new marketplaces for small suppliers. These newly established marketplaces are often highly dynamic, however, and volatile to changes in demand as well as the availability of products. Making good procurement and inventory decisions (balancing existing trade-offs between costs, service levels and the freshness of products) is, thus, extremely challenging within this uncertain context. This research addresses this problem under consideration of uncertain demand and supply of perishable products, by integrating purchasing, first-mile routing and inventory decisions. To solve this problem, we adopt an approximate dynamic programming framework allowing integration of several modeling and solution approaches into one computational environment. Our contribution is twofold: 1) the environment includes a stochastic instance generator based on Colombian agriculture information systems, providing a baseline for comparisons for the integrated decision problem, and 2) this environment is used to test and compare decision policies based on exact and approximate optimization models, relying on stochastic lookahead approximations. For this purpose, we propose a two-stage decision approach - an all-encompassing model is impractical and separate decision models do not capture the problem's complexity. We first focus on purchase and inventory decisions, using a stochastic mixed-integer program accounting for the quality loss of perishable products throughout sample paths, capturing variability of unknown information. In the second stage, we then tackle the induced Capacitated Vehicle Routing Problem with exact and heuristic strategies, identifying high-quality feasible routes providing feedback to the first stage. Our instance generator emulates the main agricultural supply network of Bogotá and is used to tune and validate the proposed methodology. The implementation of our virtual environment allows for policy evaluation - providing insights regarding key performance metrics such as profit, costs, product waste and service levels. Finally, we present a sensitivity analysis on how various product quality loss functions affect replenishment and demand compliance decisions.

Scheduling and Planning Under Uncertainty

Cluster: Multilevel and Stochastic Optimization Methods
Invited session
Chair: *Patricio Lamas*

1 - Dynamic Resource Sharing in Private 5G Networks with Slicing
Demet Batur, *Jennifer Ryan*, *Mehmet C Vuran*

A Markov Decision Process (MDP) model is proposed to study the decision problem faced by the operator of a private 5G network, known as a private cell, who must allocate available capacity to meet the resource needs of the primary user of the network, but who may also make excess capacity available to external secondary users to generate additional revenue. Private cells are privately-owned wireless networks independent of commercial or public 5G networks. Recently, these networks have been implemented in several settings, including factories, warehouses, hospitals, ports, and campuses. Private cells provide dedicated wireless connectivity, enabling enhanced security, reliability, and cost-effectiveness. Industries, such as manufacturing and transportation, can utilize private networks to prevent downtime for their automated operations. Private cells make use of network slicing, a technological advancement made available by 5G, to meet differentiated needs across applications; through slicing, the network and

its resources can be segmented to support specific services, applications, or devices. Further, the slices can be dynamic, changing as the needs of the primary user change, and it allows private cell operators to share their private wireless infrastructure more easily with external entities. Thus, resource capacity not currently in use by the primary user of the cell can potentially be leased to secondary users, such as brokers or mobile virtual network operators. Given this practical setting, we study the problem faced by a private cell operator whose main responsibility is to serve the slice instances of the private cell's primary user, but who can also lease excess resources to a secondary user to generate revenue. Slice instances are units of demand from the primary user, requiring a slice with a specific combination of resources, such as spectrum, computation, or storage. The operator must manage the network's operations to determine the instances admitted to the network for service and the resources leased to the secondary user. We use an MDP model to formulate this problem and characterize the optimal admission and leasing decisions, made in real-time and based on the private cell's current state. We develop and test an efficient approximate dynamic programming approach to obtain policies performing close to optimal, when the state space is large.

2 - A times-windows technique for underground mine scheduling under uncertainty
Patricio Lamas, *Marcos Goycoolea*, *Bernardo Pagnoncelli*, *Alexandra Newman*, *Andrea Brickey*

Underground mine schedules determine start dates for activities related to the extraction of ore, often with an objective of maximizing net present value; constraints enforce geotechnical precedence between activities, and restrict resource consumption on a per-time-period basis, e.g. development footage and extracted tons. Moreover, in the mining industry, schedules are executed under high levels of uncertainty, due to geological and geotechnical uncertainty and equipment breakdowns. Unfortunately, the underground mine scheduling literature is dominated by a deterministic treatment of the problem, usually modeled as a Resource Constrained Project Scheduling Problem (RCPSP), generating initial schedules (potentially) widely deviating from the actual executed schedules.

We propose an approach overcoming the drawbacks of the traditional deterministic treatment of the problem and having the following features: (i) it assumes uncertainty in durations and values of the activities of the mine, by modeling these parameters as random variables with known probability distributions; (ii) it assigns an initial time window to each activity of the mine, corresponding to a range of time periods when the corresponding activity must start (this feature allows better adaptability of the schedule to future uncertainty); and (iii) the width of each time window is a parameter of the problem and, therefore, can be freely chosen by the decision-maker.

Our technique generates schedules dominating those generated by the traditional deterministic approaches. Moreover, it took less than 10 hours of computation time to generate a solution in a real-case experiment.

3 - Parametric distributionally robust optimisation for resource planning problems
Christopher Kirkbride, *Trivikram Dokka*

In stochastic optimisation models, parametric probability distributions are commonly used to represent random phenomena in the system - especially useful when the nature of these phenomena is well understood. In distributionally robust optimisation, when the distribution is not known exactly, this ambiguity can be represented by a candidate set of probability distributions. The objective is to optimize, with respect to the worst-case, under probability distributions from this set; it can include (non-parametric) distributions, however - a poor representation of the phenomena's actual behavior. We overview a novel approach for solving optimisation problems representing this distributional uncertainty, but preserving information about the parametric family of the phenomena's distribution. Rather than construct an ambiguity set for the true distribution, we build an ambiguity set for the true distribution's parameters. Hence, each distribution considered will be a member of the same parametric family. We will introduce the framework in a motivating workforce planning problem with binomial demands, solved by a fast cutting surface algorithm. Our numerical experiments show comparatively fast run times with small loss in solution quality. We will briefly comment on extensions to a News-vendor problem, with Poisson and normal demands, and robust Markov decision problems - the latter solved by a projection-based bisection search algorithm.

Advances in Multiple Criteria Decision Analysis I

Cluster: Multiple Criteria Decision Analysis
Invited session
Chair: *Ta-Chung Chu*

1 - Designing a new approach for lot determination based on multiple quality characteristics
Shih-Wen Liu

In recent years, the design of products has focused on incorporating sophisticated functionalities and extending their lifespans; as a result, product yield evaluation now typically involves multiple quality criteria, rather than a single characteristic. This paper proposes a new sampling strategy, based on the designated process capability index, to estimate the product yield of submissions with multiple quality characteristics - an aid in making further lot decisions. The proposed method's operating characteristic function is derived using the Markov chain technique, and the corresponding probabilities are calculated based on the sampling distribution of the used index. To ensure the lot decision meets the desired quality conditions and tolerable sampling risks from both suppliers and customers under economic operation, the plan parameters of the proposed method are determined by solving a formulated minimization model. The proposed plan's performance is compared with conventional approaches to demonstrate its superiority. The plan parameters are solved under commonly used quality requirements and presented in tables for easy implementation.

2 - Drug discovery with decision rules
Grzegorz Miebs, *Miłosz Kadziński*, *Rafał Bachorz*, *Adam Mielniczuk*

Drug discovery is a complex and expensive process; many experiments end up with a negative result, proving a given molecule is not a promising candidate to be a biologically active agent and, therefore, should not be further considered. Reducing the number of these failures potentially saves time and resources available for more promising cases. To this end, we introduced a dominance-based rough set approach usable as a first filter, replacing well-known rules like the already classical Lipinski "rule-of-five" or Ghose filter. First, noisy data from real experiments are preprocessed and cleaned by finding consistent lower approximations for each decision class. Then, the clean data are used to build a decision model based on decision rules, decision trees, neural networks, or support vector machines. The models are validated and tested by domain experts, using real data. Finally, the best model is used to determine the molecules having the highest potential to be biologically active and, therefore, continuing as the focus of experimental verification.

3 - Modeling and Optimization of Generalized Redundancy Allocation Problem under Uncertain Component Reliability and Complex Network Topology
Yuan-Yuan Liu

As production lines in manufacturing systems are becoming increasingly complicated, the challenge of maintaining reliability is growing. Some manufacturers may prepare more redundant components to reduce the probability of system failures happening. This problem can be abstracted as a generalized redundancy allocation problem in complex networks (GRAPCN). Most related studies on redundancy allocation problems (RAP) are considered in series-parallel, where the reliability of each component is assumed a known constant. In reality, the component reliability may exhibit quality variations, however, and the reliability of each component shall be better considered stochastic. This

motivates this paper to extend the RAP to a more realistic situation where the reliability of each component is stochastic in nature and the system can have a complex network structure; the system components are connected with each other neither in series nor in parallel, but in some logical relationship. Due to the complex network structure and aggregated profound stochasticity, the overall system reliability is not analytically available, but instead has to rely on simulation for estimation. We, therefore, develop a Particle-Swarm-based simulation optimization method (PSSO) to enable the optimal solution to be identified efficiently. An extensive numerical study verifies the efficacy and efficiency of our proposed method in realistic settings and is worth further investigation.

4 - Study on Center of Area and Its Application to Fuzzy TOPSIS
Ta-Chung Chu

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), developed by Hwang and Yoon (1981), an effective multiple criteria decision analysis (MCDA) technique, chooses the alternative having the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution. In many TOPSIS problems, exact numerical values are inadequate to assess ratings of alternatives, however, and human linguistic evaluations are often ambiguous, often extending TOPSIS research to fuzzy TOPSIS. Fuzzy set theory by Zadeh (1965) provides a tool to quantify linguistic terms using fuzzy numbers. In the proposed fuzzy TOPSIS, ratings of alternatives and criteria weights are assessed in linguistic terms, represented by trapezoidal fuzzy numbers. To complete the fuzzy TOPSIS model, a ranking method must defuzzify the fuzzy weighted rankings; numerous methods have been studied. This paper uses center of area (COA) to defuzzy the ratings and linguistic weights to convert fuzzy TOPSIS to a crisp TOPSIS - helping decision-makers to efficiently execute decision-making. The COA concept for defuzzification, found in Tong (1978), chooses the value of a fuzzy number, dividing the area under the membership function of the fuzzy number into two equal areas. Chu and Varma (2012) presented formulas for defuzzifying triangular fuzzy numbers by COA. In this paper, COA formulas for defuzzifying trapezoidal fuzzy numbers will be applied. Comparisons between triangular and trapezoidal fuzzy numbers based on the COA will be conducted, and properties on COA for the defuzzification between triangular and trapezoidal fuzzy numbers will be investigated. The applied formulas will be used in the fuzzy TOPSIS to complete the proposed TOPSIS method, and a numerical example will be used to demonstrate its feasibility. Finally, a numerical comparison with relevant ranking methods will be conducted to display the advantage of the proposed method. (Acknowledgments: This paper was supported in part by the National Science and Technology Council, Taiwan, under Grant MOST 111-2410-H-218-004-)

Advances in Multiple Criteria Decision Analysis II

Cluster: Multiple Criteria Decision Analysis
Invited session
Chair: *Chen-Tung Chen*

1 - A group multiple-criteria decision-making method based on linguistic Z-numbers and VIKOR
Chen-Tung Chen

In general, group multiple-criteria decision-making (GMCDM) is the main process for organizations to evaluate the alternatives with respect to multiple criteria by multiple experts or decision-makers. Due to the different knowledge, experience and expertise of experts, they usually express different opinions and their opinions are fuzziness and uncertainty, with difficult to use crisp values to indicate the real opinions of decision-makers. Under this situation, experts use linguistic variables to express their subjective opinions in the decision-making process. Therefore, it is an important issue to reach group consensus of linguistic opinions of experts in a group multiple-criteria decision-making process. Z-numbers extended from the concept of fuzzy sets, with fuzzy assessments, and their reliability to represent the opinions of experts. Therefore, linguistic Z-numbers are an effective way to extract subjective cognition and opinions of experts in a group multiple-criteria decision-making process,since the use of linguistic variables will enable experts to express their subjective cognitive assessment information more flexibly and adequately. Z-numbers will express fuzzy assessments of experts and measure the reliability of their opinions. In addition, VIKOR is one of the famous MCDM methods to deal with decision-making problems. Therefore, this paper will combine Z-numbers, fuzzy Delphi, with VIKOR based linguistic variables to construct a linguistic group decision-making model. First, this paper will present the transformation and integration methods for linguistic Z-numbers. Second, the fuzzy Delphi method will be used to reach the consensus of group opinions in this paper. And then, this paper will propose a linguistic Z-numbers VIKOR algorithm (LZ-VIKOR) to solve the group multi-criteria decision-making problems. Finally, an example will be presented in accordance with the LZ-VIKOR algorithm to illustrate the effectiveness of the proposed method.

2 - Developing the robust non-radial DEA model to measure the operating efficiency of Taiwan's hydropower systems with non-positive sediment variation and evaporation losses
Li-Ting Yeh

Hydropower, an important renewable energy source to meet a growing demand for energy, faces increasing frequency of droughts, high-intensity rainfall and fragile geology in Taiwan's hydroelectric reservoirs and dams, making sediment and evaporation losses increasingly serious and greatly reducing the amount of water usable for power generation. Thus, evaporation losses and sediment variation, considered bad variables, could be non-positive values. When measuring the operating efficiency of systems, a non-radial data envelopment analysis (DEA) model has better ability to handle bad variables, but it cannot handle non-positive data. Thus, this paper develops a robust non-radial DEA model able to handle non-positive good outputs and bad output data. To illustrate the proposed model, we solve numerical examples and compare the obtained efficiency results with those of other models. Finally, the proposed model measures the operating efficiency of Taiwan's hydropower systems.

3 - The construction of a new product development model for consumer artificial intelligence product
Amy H. I. Lee, He-Yau Kang

In a highly competitive global market and a rapidly evolving technological environment, firms need to respond spontaneously to market changes and the uncertainty of customer needs if they want to survive and succeed. Therefore, new product development (NPD) is extremely important to the survival of a business. Artificial intelligence (AI) has been gradually penetrating into people's lives, and consumers' demand for AI products is increasing. Firms need to understand the development trend of AI and consider consumers' preferences for AI-related products under social changes to correctly select and develop AI products suitable for consumers. This study investigates a consumer AI product development problem, and combines expert opinions, technical requirement and consumer needs to construct a model facilitating consumer AI product development decisions. Evaluation factors are first listed through literature review and expert interviews. Since the number of factors under consideration can be very large, only the important factors should be selected. These factors are extracted based on the opinions of experts through the fuzzy Delphi method (FDM). Because the factors can be positively or negatively related to each other, the fuzzy decision-making trial and evaluation laboratory (Fuzzy DEMATEL) is applied to understand the relationship between these extracted factors. A consumer AI product development network is constructed, and the fuzzy analytic network process (FANP) is used to prioritize factors and rank consumer AI product alternatives.

AHP/ANP and Extensions I

Cluster: Multiple Criteria Decision Analysis
Invited session
Chair: *Birsen Karpak*
Chair: *Claudio Garuti*
Chair: *Antonella Petrillo*

1 - Manipulation-resistant ranking aggregation method for the pairwise-comparisons method
Konrad Kułakowski, *Jacek Szybowski*, *Jiri Mazurek*, *Sebastian Ernst*

Most decision-making methods assume experts and decision-makers are honest, including comparing alternatives in pairs; their opinions expressed during the decision-making process should correspond to the best knowledge of the problem. Thus, all inaccuracies in their judgments result from their mistakes, not intentional actions. But what if one or more experts do not act in good faith? Their opinions are strategic and are intended to push through a specific view. In the presented work, we give two useful heuristics allowing us to mitigate the negative effect of manipulation in the case of the pairwise comparison method. Based on these heuristics, we propose three modified ranking aggregation methods. Finally, we test the effectiveness of the proposed solutions based on Montecarlo experiments. The presented analysis concerns the resistance of the modified ranking method to a simulated manipulation situation and the impact of modified aggregation methods in a case of no manipulation.

2 - Why We Need Desirable Properties in AHP?
Radomir Perzina, *Jaroslav Ramik*

Pairwise comparisons matrices (PCMs) are inevitable tools in some important multiple criteria decision-making methods, e.g. AHP, TOPSIS and PROMETHEE. In this paper, we investigate some important properties of PCMs influencing the generated priority vectors for final ranking the given alternatives. The main sub-problem of the Analytic Hierarchy Process (AHP) is to calculate the priority vectors, i.e., the weights assigned to the elements of the hierarchy (criteria, sub-criteria, and/or alternatives or variants), by using the information provided in the form of a pairwise comparison matrix- given a set of elements and corresponding pairwise comparison matrix, whose entries evaluate the relative importance of the elements with respect to a given criterion. In this paper, we investigate some important and natural properties of PCMs, called the desirable properties - particularly, non-dominance, consistency, intensity and coherence, influencing the generated priority vectors for final ranking of the given alternatives. Usually, the priority vector is calculated based on some given method, e.g. Saaty's Eigenvector Method, the Arithmetic Mean Method, Geometric Mean Method and Least Square Method. This approach is novel, since the priority vector is calculated as the solution of an optimization problem, where a special error objective function is minimized subject to constraints given by the desirable properties. The properties of the optimal solution are discussed and some illustrating examples are presented. The corresponding software tool has been developed and demonstrated on some examples.

3 - A Set Theory Justification of Garuti's Compatibility Index (G)
Claudio Garuti

This paper increases certainty and reliability of the compatibility index G through different examples and shows the G index can be reached by two different paths - first, using vector algebra as a weighted vector projection applying the concept of inner vector product and, next, using concepts of set theory. Finally, we compare G index with other known compatibility indices and, using set theory, show the G index is a generalization of the Jaccard (J) index considering the weights of the elements of two different sets. We make it applicable in the decision-making domain to measure similarity (compatibility or closeness) between priority vectors, system values and recognition of behavioral patterns among other features.

AHP/ANP and Extensions II

Cluster: Multiple Criteria Decision Analysis
Invited session
Chair: *Birsen Karpak*
Chair: *Claudio Garuti*
Chair: *Antonella Petrillo*

1 - The best approximation of an additive pairwise comparisons matrix equating two given alternatives
Jacek Szybowski

The problem of selecting the best alternative out of the final set can be solved by the pairwise comparisons method. Each comparison is presented as one element of a pairwise comparisons matrix (PCM). The resulting ranking vector can be obtained, for example, by means of the Eigenvalue Method or the Geometric Mean Method.

Sometimes little changes in the input PCM, no matter if introduced by mistake or intentionally, may make two or more alternatives equal or even can reverse their positions in a ranking. If we focus on two given alternatives, we may wonder what is the closest PCM to a given one, equating them in a ranking and how their changed weights will appear.

To answer these questions, we consider the additive form of PCMs to use their linear structure. We present an algorithm of finding the best approximation of a given PCM, equating two alternatives in a ranking. Then, we state a theorem, characterizing the weights of alternatives after the transformation. We illustrate the theory by an example.

2 - A Web Application for Group Decision Analytic Hierarchy Process
Rafael Verão Françozo, *Mischel Carmen N. Belderrain*, *Luiz Urquiza*

The Analytic Hierarchy Process (AHP) is a multi-criteria decision support method introduced into the literature in the 1970s by Thomas L. Saaty and is widely applied in areas such as education, manufacturing, industry, health, conflict resolution and government. The AHP is based on pairwise judgments in which a decision maker (or stakeholder) compares the performance (or priority) of a given alternative over others with respect to a criterion. The AHP original method proposed by Saaty, needs (n'-n)/2 comparisons. The number of required comparisons may make it challenging to use the method to maintain consistent judgments in problems involving many criteria and/or alternatives. Furthermore, the available softwares are platform-dependent and generally do not support group decision-making. Facing these issues, a Web application was developed to use the AHP; it demands n-1 comparisons. The stakeholder selects one criterion or alternative and conducts the comparisons with respect to the others. The remaining judgments are calculated by the software considering an inconsistency in the judgments as 0. The automatic judgments can be modified at the stakeholder's discretion, so that they consciously and optionally make inconsistent comparisons. Additionally, the software supports group decision making using individual aggregation of priorities with arithmetic and geometric means. It is possible to define weights for the stakeholders through comparisons in a similar way as for criteria and alternatives. The system is available (free of charge) at http://ahpweb.net/ and is accessible from any internet-connected device. It currently has more than 100 users and dozens of decision problems in various areas.

3 - Assessing Environmental Impacts of Large-Scale Development Projects: Two Case Studies Utilizing Pólya's Plausible Reasoning and Saaty's AHP/ANP
Luis Antonio Bojórquez-Tapia

The impacts of large-scale development projects have been a long-standing concern for environmental and social justice advocates worldwide; we present two case studies demonstrating the use of Pólya's plausible reasoning and Saaty's AHP/ANP in environmental impact assessment. The paper discusses the legal and methodological challenges of resolving environmental impacts caused by large-scale development projects, emphasizing the importance of assessing both tangible and intangible impacts. The first case study applies Bayesian modeling and decision theory techniques to measure the worth of expert judgment in cases of environmental tortious conduct; the AHP is used to obtain the prior probabilities and the ANP to obtain posterior probabilities. The second case study employs the Sustainable Livelihoods Approach, using ANP to assess both intangible and tangible vulnerability indicators, in identifying compensation measures for biocultural heritage losses suffered by indigenous and tribal peoples. These case studies highlight the suitability of the ANP for integrating the materialist and hermeneutic aspects of environmental impacts in a systematic manner. Overall, this presentation contributes to ongoing discussions on the need for more systematic and accurate (scientific) treatment of the relationship between the objective (logical) and subjective (psychological) dimensions of sociocultural impacts.

AHP/ANP and Extensions III

Cluster: Multiple Criteria Decision Analysis
Invited session
Chair: *Birsen Karpak*
Chair: *Claudio Garuti*
Chair: *Antonella Petrillo*

1 - A hybrid fuzzy Multi-Attribute Decision-Making (MADM) method for the evaluation of in-situ resource utilization (ISRU) technologies.

Alberto Maulu

At the start of the millennium, private company efforts to privatize spaceflight pushed unprecedented technological advancements necessary to create a new commercial space industry. The reduced size and cost of equipment, and the introduction of reusable launch systems, expanded access to space beyond governments and large companies. Today, the satellites sector represents the main commercial space market, together with the launch and ground support sector. At the same time, a new space market is rising, ignited by the resurgent global interest in space exploration. The objective is to establish a long-term, sustainable human presence on the Moon and beyond. To enable this vision, the shared strategy of the international space actors appeal to the utilization of resources in space, namely, In-situ Space Resource Utilisation (ISRU). The use of in-space resources to sustain human life and activities on the moon and other planets, by providing water, oxygen, fuel and construction feedstocks, is meant to significantly increase missions' life extension and enable mission capabilities, currently impossible without ISRU. By being a disruptive capability, the ISRU requires the systems to be designed around it from the concept phase to be incorporated into mission architectures. By doing so, several technology gaps need to be addressed with breakthrough innovations along the entire ISRU value chain. In this landscape, the technology roadmaps of major space agencies are dominated by competing technologies, in most cases not yet tested in the relevant environment and frequently at low technology readiness levels. This scenario encompasses extremely challenging decision problems, with uncertain data and strongly interrelated evaluation criteria. In the work here presented, a dedicated hybrid Multi-Attribute Decision-Making (MADM) method combining the Weighted Influence Non-linear Gauge System (WINGS) and The Analytic Hierarchy Process (AHP) method, is provided to support the decision-makers on the evaluation of ISRU-enabling technologies in a fuzzy environment. This method is then applied to two case studies for the production of oxygen on the Moon using lunar regolith. The case studies address two mission scenarios planned by ESA, where 8 technologies are compared and ranked based on a set of 10 mission criteria.

2 - Multi-Criteria Maritime Incident Response Tool

Danijela Tuljak-Suban, *Valter Suban*, *Urban Pegan*

When oil is transported by sea, serious accidents can occur where oil spills and subsequently pollutes the coastline. Knowing the importance of involved sensitivity aspects can help the first team responders decide where to place oil booms to protect the most vulnerable part of the coast. Therefore, they should have pre-prepared intervention scenarios supported by multi-criteria decision-making models, regardless of external pressures by various groups of interest. The deployment scenarios need to be supported by decision models based on measurable quantitative data and not on subjective assessments by the involved interest groups. In practice, various multi-criteria decision models are used; one of them is PAWSA, based on the proven Delphi method of systematic decision-making, where the opinions of experts with local knowledge are transformed into quantified results. The risk assessment model presented in this article enables the assessment of the general context, the identification of vulnerable areas, the consideration of shipping traffic and an overview of shipping accidents and possible scenarios of shipping accidents with oil pollution in the analysed area. The multi-criteria decision-making model presented in this article upgrades the Delphi approach used in the PAWSA model with Fuzzy AHP to arrange the criteria in a hierarchical structure and set the weights using a verbal rating scale, more confidential for the experts. The data for the calculation were collected in workshops organised by experts in the field as part of the NAMIRS project. Statistical analysis of the data was also carried out to ensure consistency of the questionnaire and responses and to increase confidence in the decision. The weights obtained with Fuzzy AHP are also used in a hybrid DEA-TOPSIS method, where the idea of an ideal/proper solution used in the TOPSIS method is combined with the concept of efficient decision units, the basic idea of the DEA method. In this way, specific scenarios can be defined to decide the part of the coastline in the area concerned needing to be protected first. The results obtained are then compared and validated with the PAWSA results. The defined method can significantly reduce the impact of oil spills in sensitive marine areas and their consequences for the economy and the lives of the people living on the coast under investigation.

3 - A Comparative Study of AHP and ANP with Best Worst Method

Natalia Karstegl

In this paper, a comparative study between AHP and ANP is conducted, using the Best Worst Method (BWM) as a benchmark. BWM is a relatively new method used to determine the relative importance of criteria by comparing them to their best and worst alternatives. The study aims to identify the strengths and weaknesses of AHP and ANP and determine the method performing best under different scenarios.

Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP) are two popular multi-criteria decision-making (MCDM) methods used for decision-making and problem-solving. Both methods have been widely applied in various fields, including finance, engineering, healthcare, and environmental management. There is a lack of research, however, comparing the performance of AHP and ANP with other MCDM methods.

First, this research provides with an overview of AHP, ANP, and BWM, including their mathematical foundations, advantages, and limitations. Next, the methodology used to conduct the comparative study is presented, including the selection of criteria, the definition of decision scenarios, and the evaluation metrics. Finally, the results of the study, including the comparison of AHP and ANP with BWM under different decision scenarios.

AHP performs better than ANP and BWM in scenarios with a limited number of criteria and alternatives. ANP performs better than AHP and BWM, however, in scenarios with a large number of criteria and alternatives. Furthermore, BWM is a promising method for assessing the robustness and sensitivity of AHP and ANP to changes in the decision-making environment.

In conclusion, this study contributes to the ongoing debate on the best MCDM method for decision-making and provides decision-makers with a comprehensive understanding of the strengths and weaknesses of AHP and ANP.

Methodological Improvements and Innovative Applications of Multiple Criteria Decision Analysis I

Cluster: Multiple Criteria Decision Analysis
Invited session
Chair: *Caroline Mota*
Chair: *Mischel Carmen N. Belderrain*
Chair: *Sarah Ben Amor*

1 - Insights on weight subspace reduction from FITradeoff method elicitation analysis

Jonatas A. de Almeida, *Eduarda Frej*, *Adiel Teixeira de Almeida*

Decision-making is one of the most important activities, not only in the organizational context, but also in the personal context, and defines the position of an individual or an organization in the future. Decision problems can be particularly challenging when the decision-maker has multiple objectives, and judgments are needed to express the importance of each objective and how much the decision-maker accepts losing in one of them to increase the advantage in another. The literature presents several methods dedicated to obtaining information about the decision-maker's preferences through their judgments, mainly from a context of compensatory rationality. The FITradeoff method, based on the tradeoff procedure and belonging to the set of MAVT methods, analyzes how the subspace of weights limited by partial information defines values and preference relationships between the alternatives building the recommendation. Methodological improvements to FITradeoff and applications have been published in various journals and conferences. Thus, this study seeks to present some analytical aspects about the FITradeoff method and how the partial information, obtained from the decision-maker through the decomposition process and through the holistic evaluation, is used to build the recommendation. Aspects related to the mathematical structure of the method are presented and discussed. The analysis will help researchers and practitioners better understand how the method works and how it reduces the number of questions and speeds up the elicitation process.

2 - Suitability analysis for wind farms projects: the case of Rio Grande do Norte, Brazil.

Ciro Figueiredo, *Marcio Dantas*, *Caroline Mota*, *Duan Vilela*

The growing number of renewable energy projects in Brazil, mainly in the northeast, requires support of spatial models to minimize impacts on several aspects, such as technical, social, economic and environmental to enhance the solutions achieved. The state of Rio Grande do Norte has around 174 wind farms deployed and the power generation capacity has grown rapidly. Since 2021, the Rio Grande do Norte stands out in installed capacity, having more than 5gW and prospects for expansion comprising offshore projects. The expansion perspective demands further suitability analysis for wind farm deployment, with strong impact in terms of plant efficiency, investments and expected returns, in addition to social and environmental consequences. Therefore, the analysis can be performed by integrating Geographic Information Systems and Multiple-criteria Decision Making, aiming to obtain a suitability index of the evaluated area. In this regard, seven criteria were selected: speed wind; power stations distance; highways/roads; slope; rural zones; urban zones; and exclusionary zones. With exception of the speed wind criterion, the other criteria were available on the shapefile format; they were converted to raster format, with width (1445 pixels) and height (867 pixels) and cell size of approximately 2.5 x 10-3. To perform the evaluation, the overlay raster combination was used (raster calculator tool), taking the same importance for the criteria was considered. We had some limitations to obtain these data, mainly because these are stored in distinct sources and have different file formats, making it difficult to obtain and process. Although there is a Brazilian government organization with assignments in the area of studies and research aimed at supporting energy sector planning, the available information has links with several matrices: hydropower, solar, wind and thermal. Next, exclusionary zones were applied, eliminating urban and rural, bodies of water, environmental protection areas and highway buffers, making 50,580 square kilometers suitable for new wind farm projects. A Weighted Linear Combination was carried out in the overlay analysis. There were still no studies considering several criteria for suitability analysis related to wind farm projects. In terms of suitability index, 31,000 square kilometers can be considered highly adequate for wind farm project development.

3 - Multi-Criteria Decision Analysis Methods: A Comparative Study of Compensatory and Non-compensatory Approaches under Uncertainty

Sarah Ben Amor, *Betania Campello*, *Leonardo T. Duarte*, *Joao Romano*

Multi-criteria decision analysis (MCDA) is often used to rank a set of alternatives, based on a set of criteria and, typically, utilizing a decision matrix as input data. The rows of the matrix represent the alternatives, while the columns correspond to the criteria; each element of the matrix indicates the evaluation of an alternative on a certain criterion. A fundamental aspect of MCDA, known as matrix aggregation, involves the application of a technique transforming the decision matrix into a scoring vector; when sorting this vector, the ranking of alternatives is obtained. Aggregation methods in MCDA can be classified as compensatory and non-compensatory. Compensatory techniques allow for full compensation among the criteria, meaning poor performance in one criterion can be offset by high performance in another criterion. In contrast, non-compensatory techniques do not permit these trade-offs between criteria. As a result, each criterion plays a more independent role in the ranking. TOPSIS is an example of a compensatory method, while PROMETHEE II is a non-compensatory one. MCDA data can be either deterministic or probabilistic. In probabilistic data, it is crucial to account for uncertainties that may impact the ranking; they may arise due to several factors, including situations where the criteria values are obtained from estimation methods, such as prediction methods. In this case, the criteria values are the actual future value, plus a prediction error. To better comprehend the previous statement, consider two decision matrices. The first matrix contains values obtained through some prediction methods, while the second matrix comprises elements representing the actual future values, assuming they are known. The actual future values can be expressed as the estimated value plus a prediction error. Applying an aggregation technique to the decision matrices results in a predicted ranking and a target ranking (i.e., the actual ranking); a desirable outcome is for the predicted ranking to closely match the target ranking. The aim of this study is to analyze how MCDA methods can help reduce the impact of prediction errors on the predicted ranking, and identify the most effective MCDA method in this regard. We performed initial computational tests employing both compensatory and non-compensatory methods, specifically, TOPSIS and PROMETHEE II. Our preliminary findings suggest that PROMETHEE II is more effective.

4 - Approach to Group Decision-Making with Alternatives Ranked by Categories

José Francisco Zanazzi, *José Luis Zanazzi*, *Daniel Pontelli*

In various organizations, it is necessary to promote group decision-making, because joint analysis facilitates the management of the intrinsic complexity of problems. Frequently, the structure of the decision problem allows the application of multicriteria methods, where the preferences and priorities of the work team members are expressed through cardinal-type utilities. Depending on the characteristics of the group, different scenarios may arise. First, the members share interests and objectives; second, the interests are different and it is necessary to negotiate; and, third, a compromise solution is adopted because it is not feasible to negotiate. The groups sharing objectives present heterogeneity, however, in their knowledge, priorities and preferences. These differences can cause divergences in the behavior of the members of the work team generating the need to discuss perspectives. These possibilities of exchange through decision-making processes allow the development of learning instances, where experiences and knowledge are shared. These processes offer advantages: collaborative learning, convergence of priorities and behaviors, and commitment to agreed actions. On the other hand, they require time and can be tedious,

when decisions are systematic and must be made frequently. They can also be affected by group pressure, inhibiting individual contributions and making it difficult to build commitments, or by disturbances in the available information (imprecision, uncertainty, or lack of some data). For this reason, the work presents a method structuring a problem with a finite number of criteria and adopting for each one a set of categories, allowing classification of the analyzed alternatives. The priorities of the criteria and the preferences of the categories are represented by subjective cardinal utilities. The proposal includes dynamics to reduce group pressure, disturbances and necessary time. The document includes an application to the treatment of non-conformities, in a production process. The participants adopted the methodology without problems and managed to agree on the categories, and they agreed the proposal significantly reduces analysis times.

Methodological Improvements and Innovative Applications of Multiple Criteria Decision Analysis II

Cluster: Multiple Criteria Decision Analysis
Invited session
Chair: *Caroline Mota*
Chair: *Mischel Carmen N. Belderrain*
Chair: *Sajid Siraj*

1 - Investment Portfolio Construction Using Multi-Criteria Methodology
Mariana Funes, *Hernan Guevel*, *José M. Vargas*, *Josefina Racagni*

To support the investment decision analysis process on listed companies of the Buenos Aires Stock Market, we constructed medium- to long-term portfolios, using ratios constructed from the final financial statements published by the companies for the year 2018. The procedure consisted of classifying companies according to their investment attractiveness into three categories, using the Basic Additive Model (DEA) in two stages. The given categories were modeled as a pre-order by applying the Additive Utility Discriminant Method (UTADIS), obtaining a piecewise linear additive utility function. Through a cross-validation procedure leaving 10% of the firms out, we were allowed to assign the firms to classes in a more robust way. Finally, considering the best-practice firms, we constructed investment portfolios with different numbers of assets, using the additive utility function to determine each firm share. Once the portfolios were constructed, their average annual returns were compared with those of the most important stock market indices in the local capital market: S&P Merval and S&P/BYMA Argentina General. The portfolio returns are higher than those of the general indices in all cases.

2 - Integrating soft and hard operational research to select the target market to define the internationalization strategy of a service company
Yadira Diaz Galeano, *Mauri Aparecido de Oliveira*

When an entrepreneur decides to take a company to the international market, it can be a smart business move, but with challenges. With all the potential benefits of expanding globally, to compliantly sell a product or service in a new international market, it will need to put together an international strategy. First, the company will have many possible countries where viable opportunities to offer its products and services are foreseen; later, to taper these sets of countries, the company will proceed with a preliminary selection, ignoring ones offering less potential and identifying countries with high potential and promising opportunities. To define target markets, aligned with the reality of each candidate country, crucial aspects must be considered, such as market behavior, competition positioning and economic risks and opportunities. The present abstract integrates soft and hard operational research with SODA (Strategic Options Development and Analysis) and AHP (Analytic Hierarchy Process) to the target market selection aiming for business plan development, allowing the international sales of a provided service, where the issue is an efficient strategy under the leadership of high administration and involving the commitment of the CEO, directors and employees. To achieve the main goal and help with the best decision-making support strategy, initially we used PSM (Problem Structuring Methods) for the problem formulation, players involved in the decision process and the problem scope definition. The SWOT matrix was used for the following: (1) problem definition and preliminary strength diagnosis, improvement opportunities, weaknesses and threats, (2) document analysis and enabling problem situation modeling, (3) allowing the SODA map creation and internal and external items identification with greater influence, and (4) defining the decision process criteria of the problem set. The method AHP was chosen for definition of the target market and the company business segments. The choice was made by its easiness to make available the decision problem decomposition in a rank of subproblems, ease of understanding by the decider, and the method capability of ranking the alternatives.

3 - Hybrid Talent Mapping
Sofia Carla Cortaberria, *Miguel Angel Curchod*

This work presents a hybrid methodological proposal for talent mapping, using the nine box matrix and the multi-criteria decision making method TOPSIS (technique for order preference by similarity to ideal solution). Talent management is a strategic function aligned with a company's business planning and whose objective is to attract, develop and retain talented employees. Talent mapping is a frequent practice in companies interested in identifying employees who add critical value and formulate talent management policies aligned with the company's strategic priorities. Nine Box Matrix provides companies knowledge about their talent availability. The nine-box grid consists of two axes: X and Y. The X axis represents performance divided in three categories: under, effective and outstanding performance. The Y axis represents potential, divided in three categories: high, medium, and low potential. The result is a matrix of nine boxes combining both variables defined in the axes. The matrix helps to apply best practices for talent development and management processes: training, salary raises, reassignments, promotions, or dismissals. Despite the wealth of information the matrix provides, it is insufficient when you need to decide inside the same category. To have a complete assessment, the evaluation process was improved by applying TOPSIS. TOPSIS is a practical and useful technique for ranking and selecting externally determined alternatives through distance measures. The main concept of the TOPSIS method is the best alternative should have the shortest distance from the ideal solution and the longest distance from the negative-ideal solution, in a geometrical sense. TOPSIS' decision matrix refers to n alternatives, evaluated in terms of m criteria. In this case, the alternatives are employees and the criteria are the intrinsic components of performance and potential. Both methodologies provide complementary insights. The matrix groups employees according to a category, enables general interventions and offers a comprehensive view of talent. The multicriteria method facilitates specific decisions, helping to prioritize those employees who are located in the same box, in case of scarcity of resources or opportunities. For these reasons, the use of both tools is recommended as complementary to improve the decision-making process.

Foundation Issues and Paradigm Shifts in Multiple Criteria Decision Aiding I

Cluster: Multiple Criteria Decision Analysis
Invited session
Chair: *Adel Guitouni*

1 - Multi-Attribute Utility Deep Reinforcement Learning Algorithm
Adel Guitouni

Deep Reinforcement Learning (DRL) evolved from traditional Reinforcement Learning and Deep Learning techniques to solve complex sequential decision-making problems. Despite the significant advances in DRL, little attention has been paid to developing DRL algorithms to solve sequential multi-criteria decision (SMCD) problems, usually involving conflicting and non-commensurable attributes. Drawing from these converging bodies of knowledge, we propose a Multi-Attribute Utility DRL (MAUDRL) algorithm to solve SMCD and make three significant contributions. First, we contribute to the operational research field by integrating DRL and Multi-Criteria Decision Analysis (MCDA) methods to enable more effective decision support for solving SMCD problems with high dimensionality. Second, we contribute to explainable analytics and artificial intelligence (AI) by proposing a tractable and explainable MAUDRL model with multiple sources of reward explicitly incorporating the preferences and risk attitudes of a decision-agent. Third, we contribute to the sustainability literature by applying MAUDRL to sustainable human resource planning in blueberry farming in British Columbia, Canada. We study different decision-making profiles representing farmers with varying sustainability preferences and risk attitudes. MAUDRL solves complex SMCD problems and contributes to explainable analytics and AI. We also discuss the contribution of sustainable decision-making behaviour of the decision-agent on the quality of human resource planning policies in blueberry farming. We discuss the implications for theory and practice.

2 - Machine learning for decision support: the case of supply chains
Loubna Benabbou

Machine learning is increasingly applied to assist the decision-making process. This application can take several forms, including the following: (i) to leverage large amounts of data, beyond the cognitive limits of decision-makers; (ii) to provide valuable assistance to multiple criteria decision supporting (MCDS), to gain accuracy; and (iii) to help ensure the scalability of solutions proposed classically, by adapting to the needs of organizations. The conjunction of machine learning with MCDS is necessary to face complex problems; indeed, MCDS is used, on the one hand, to integer decision-maker preferences in machine learning algorithms and, on the other, to operationalize the (passive) prediction results of the algorithms, by providing decision processes with the ability to identify actionable decision variables. This presentation will illustrate the contribution of machine learning to decision support systems in supply chains; we will particularly consider the case of improving the planning of operations in ports in an uncertain environment. The aim is to predict the arrival times and speeds of vessels with better accuracy using machine learning models.

3 - Structuring the Performance Assessment Context of a Nucleus of Legal Practice using the Methodology Multicriteria Decision Aid - Constructivist
Maria do Socorro dos Santos Giffhorn, *Edilson Giffhorn*

This paper proposes structuring the context of a multi-criteria assessment to improve the performance of a Nucleus of Legal Practice course by using the Methodology Multi-criteria Decision Aid - Constructivist to identify, organize and propose ordinal scales, allowing the decision-maker to increase understanding of the course's context of action at the Brazilian university where they work. As results, a means-ends relationship map was built, and clusters and areas of concern were identified. In this way, it was possible to build, in a personalized way for the decision-maker, scales directing the creation of improvement actions to the mentioned Nucleus, according to their value system.

4 - Development of strategic map (BSC) with fuzzy logic and multi-criteria optimization
Armando Meza, *Juan Perez*, *Luis Quezada*

The most relevant task for the implementation of the Balanced Scorecard (BSC) is the mapping of strategies. It provides a structure to demonstrate how strategies link intangible properties of an organization with the value creation process, in turn; and, it shows how the objectives of the different perspectives are related to achieve the vision. The main objective of this research proposal is to contribute to models and cutting-edge methodologies in the context of the systematic development of strategic maps of organizations, through the creation of a framework to help in decision-making. Our objective is the design of a methodology supporting the construction of BSC strategic maps in organizations, through the implementation of multicriteria decision making (MCDM) and optimization methods that allow establishing and reducing causal relationships between the strategic objectives of the four perspectives of the BSC (Learning and Growth,Internal Processes,Customers and Financial) and the selection of the most representative for the fulfillment of the strategy. We propose a framework to analyze the strategy mapping problem faced by organizations, which could allow clarity in planning and could indicate where efforts and resources should be concentrated to achieve goals generating the greatest impact and value in strategic management and to have better decision making. The MCDM method used to meet the objective of this work was DEMATEL, which determines the causal relationships and the effects of the variables of the strategic map with the information obtained from a group of experts. A linear programming optimization model that was applied is based on reducing arcs (causal relationships) within the strategic map, eliminating the objectives with the lowest rating in expert consultation, maximizing the selected financial objectives and maximizing the levels of fulfillment ni of the objectives. The objective functions are (2+3n), as many en's as objectives are. To fulfill this function, an optimization model is designed that has 3 objectives at the same time and the sum of the weights w must be equal to 1. As this is a convex problem, the weighted sum technique can be used, in which the 3 normalized objectives are weighted. These optimization problems do not have a single optimum, but instead have a frontier called the frontier of optima. The mathematical model proposed is in Python.

Foundation Issues and Paradigm Shifts in Multiple Criteria Decision Aiding II

Cluster: Multiple Criteria Decision Analysis
Invited session
Chair: *Adel Guitouni*

1 - Quasi-Experimental Approach to Compare Three SMAA-Based Multi-Criteria Methods
Javier Pereira, *Pedro Contreras*, *Danielle Morais*

Stochastic Multiobjective Acceptability Analysis (SMAA), an approach used as a stochastic wrapper on different multi-criteria decision analysis methods, is often used as a robustness analysis alternative to evaluate the stability of a solution built by an MCDA method. There is no research contribution, however, comparing solutions built by different methods using this approach. In this contribution, three SMAA-based multi-criteria decision analysis methods are compared by using a quasi-experimental approach; an airport-parcel logistics hub multi-criteria location problem is solved applying SMAA-2, SMAA-PROMETHEE and SMAA-TODIM methods. Treatments in experiments are modeled with the following independent variables: problem-size represented by the number of alternatives; uncertainty in evaluations; uncertainty of criteria weights; and three scenarios, representing different decision-making perspectives. A solution built by each method is presented in the form of a ranking; thus, the Kendall tau correlation between pairs of solutions is computed to compare rankings built in the experimental designs - to know how the solutions built by these methods are similar. Correlation between solutions increases with the number of alternatives, but potentially decreases with uncertainty on evaluations. In some scenarios, uncertainty on criteria weights lowers the correlation between solutions, somehow independently from the problem-size (number of alternatives). In these scenarios, uncertainty strongly decreases the correlation. In one of the scenarios, however, uncertainty on the criteria weights slightly increases correlation.

Preliminary conclusions obtained from the experiments are as follows: (1) In contexts where the number of alternatives is high, any of these methods could be used. (2) The more the uncertainty on evaluations

increases, deciding the methods to choose by the analysis becomes a delicate issue. (3) The same could be said for scenarios exhibiting uncertainty on criteria weights, except for "favorable scenarios" where a high correlation between solutions built by these methods exists, even if high uncertainty is observed on evaluations and criteria weights. Theoretical research is needed to verify whether favorable scenarios exist, however, helping to determine conditions to select a specific method.

2 - How does influencer marketing affect consumer purchase behavior on social media in the fashion industry
Vassilis Kostoglou, *Theodore Tarnanidis*, *Jason Papathanasiou*

Fashion companies have long established the practice of using people with a reputation, media exposure, and influence to promote their brands and products. By transferring the positive image and characteristics of a celebrity to a brand, companies aim to attract customers - a practice proven effective.

This research study analyzes the impact of influencer marketing on consumer behavior in the fashion industry, by examining various communication parameters on social media; we administered an online survey among social media users, who followed an influencer in the fashion and clothing industry. Consumers ranked and assessed the impact of the influencer on the criteria of brand awareness, expertise, informativeness and similarity behavior by producing valuable content on various social media platforms (Facebook, Instragram, Twitter, YouTube, Pinterest and Twitch). Data was analyzed with the use of multicriteria decision analysis and the methodology of PROMETHEE II. The best platforms, producing viable content to followers, are Facebook, Pinterest and YouTube, where influencers act as opinion leaders based on their credibility and trustworthiness; they deliver informative and enjoyable advertized content for brands and products. We see a shift in the use of social media, by creating new ways for consumers to absorb and share information; current platforms create the opportunity for regular people to act as digital celebrities, who share their thoughts and feelings with a wider audience of followers in the sector.

3 - Robust Determination of Risk Aversion
Bernhard Nietert, *Sarah Alexandra Jayme*

Risk aversion is a core concept in Finance/Economics. Nevertheless, its experimental detection, as outlined in Holt/Laury (2002) and ensuing publications, is not robust: it consists of a one-off choice between a risky lottery and a riskless payoff and does not take into account further conditions exerting influence. Consequently, the results regarding risk aversion are rather random and definitely not reliable enough, given its role as a core concept. This paper derives robust risk aversion results; to that end, it uses, on the one hand, the PEST procedure advocated by Luce. PEST analyzes repeated (and not just one-off) choices and determines risk aversion from the steady state, i.e., when decision-makers no longer switch between the riskless payoff and the risky lottery. On the other hand, conditions are specified as: (i) expected value is given as additional information, next to the state-dependent outcomes of the risky lottery; and (ii) lotteries' outcomes are made more extreme (including losses) than the ones of the literature's standard lottery. Finally, the test person's eye movements and reaction times are measured. This paper finds: (i) The condition "expected value" leads to higher average reaction times and requires more trials in the PEST procedure, compared to the benchmark case "only state-dependent outcomes". The test persons' certainty equivalents, however, are more similar in the expected value case than in the benchmark case. (ii) The starting value of the riskless payoff in the PEST procedure exerts a massive influence on the certainty equivalent: the certainty equivalents for lotteries with starting values of expected value plus 10% is 25% higher than the one for lotteries with starting value of expected value minus 10%. (iii) The certainty equivalents of the literature's standard lottery (good outcome: 60; bad outcome: 40) vary less across test persons, compared to the certainty equivalents of lotteries with more extreme outcomes or even losses: extreme outcomes obviously create heterogeneity, meaning the evaluation of these lotteries differs across test persons. In summary, certainty equivalents and, hence, risk aversions crucially depend on the exact con-ditions (information provided and lotteries' ranges of outcomes); these conditions must be carefully chosen to achieve reliable specifications of risk aversion parameters.

4 - Multi-criteria decision-making via multivariate quantiles
Daniel Kostner

A novel approach for solving a multiple judge, multiple criteria decision-making (MCDM) problem is proposed; the presence of multiple criteria leads to a non-total order relation. The ranking of the alternatives in this framework is done by reinterpreting the MCDM problem as a multivariate statistics one and by applying the concepts in Hamel and Kostner (J Multivar Anal 167:97-113, 2018). A function ranking alternative, as well as additional functions categorizing alternatives into sets of "good" and "bad" choices, are presented. The properties of these functions ensure a reasonable decision-making process.

Capacity Expansion Planning and Reliability

Cluster: Optimization of Power Systems
Invited session
Chair: *Ricardo Pinto de Lima*
Chair: *Ignacio Grossmann*

1 - Optimization model for expansion planning of reliable and resilient power systems under extreme scenarios
Ignacio Grossmann, *Seolhee Cho*

Reliability is the ability of power systems to satisfy power demands, and resilience is their ability to quickly recover normal operating conditions after the occurrence of disruptions. Resilience is related to low probability and high impact (LPHI) events, such as natural disasters and/or extreme weather conditions. In contrast, reliability involves high probability and low impact (HPLI) events, such as equipment failures. Power system reliability can be enhanced by installing sufficient back-up generators, and reliable power systems can produce power and satisfy demand with little interruption. On the other hand, power system resilience analyzes recovery after a power outage. The ultimate goal of power systems is to improve their reliability while ensuring resiliency, given the higher share of variable generation systems, such as wind turbines and solar panels.

In this work, we develop an optimization model for expansion planning of reliable and resilient power generation and transmission systems - extending our previous work [1]. The model is formulated using Generalized Disjunctive Programming (GDP), involving Boolean and continuous variables, algebraic equations, and logic propositions. The proposed model can decompose into a reliability-constrained expansion planning model and a scenario-based resilient evaluation model. The reliability-constrained expansion planning model first determines the optimal number of back-up units and maintenance/inspection schedules to maximize power system reliability, while satisfying electricity demand over the planning horizon. In detail, the model explicitly considers the impact of operational strategies of parallel generators (i.e., participating in electricity production vs. remaining idle units during operation) on power system reliability. Probabilities of equipment failures and capacity failure states estimate power system reliability. We then evaluate the resilience of the design and operation obtained from the expansion planning model by solving multiple contingency scenarios with different extreme weather conditions. The proposed model is tested with a 5-year planning example of two regions and three cases: i) deterministic case (without reliability and resilience constraints), ii) reliability-constrained case, and iii) reliability and resilience-constrained case. [1] Cho,S., Grossmann,I.E.,Computer Aided Chemical Engineering 51, 841-846 (2022).

2 - A two-timescale decision-hazard-decision formulation for prospective studies in energy systems under uncertainties
Camila Martinez Parra, *Michel De Lara*, *Jean-Philippe Chancelier*, *Pierre Carpentier*, *Manuel Ruiz*, *Jean-Marc Janin*

The energy landscape is changing; the penetration of renewable energy will require a large number of storage facilities and the introduction of new storage, such as batteries and hydrogen tanks or caverns, to complement the traditional hydroelectric reservoirs. As a result, there is an increasing interest in usage value calculation for stored energy - a calculation formulated as the result of a stochastic multistage optimization problem, as the stock evolution equations introduce time coupling constraints. This is the case for RTE, the French transmission system operator, conducting prospective studies on energy transition over dozens of years where, on the horizon, the uncertainties are high. Nowadays, RTE considers a weekly anticipative information structure to solve the problem using a stochastic dynamic programming algorithm and wants to explore alternative structures to improve uncertainty disclosure modeling. For this purpose, we consider stochastic multistage optimization problems with two timescales: a slow timescale (weekly), when we want to obtain usage values and coordinate decisions, and a fast timescale (hourly), needed to model physical constraints and variable decision granularity. Then, we study how to model the available information at each moment of the sequential decision-making process and the respective multistage stochastic optimization approaches. We start by presenting problem formulations considering a timeline with two timescales and two adapted classical information structures: the decision-hazard framework and the hazard-decision framework. While the decision-hazard structure cannot guarantee feasibility due to balance constraints in the presence of uncertainties, the hazard-decision structure assumes the following uncertainties are known before making a decision. We acknowledge the need to study new information structures; therefore, we introduce the decision-hazard-decision information structure in a two timescales setting. In this structure, we consider nonanticipative controls taken in the decision-hazard framework and recourse controls taken in the hazard-decision framework, but with possible alternative formulations, due to the existence of two timescales.

Electricity Markets and Power Systems Operations

Cluster: Optimization of Power Systems
Invited session
Chair: *Ricardo Pinto de Lima*
Chair: *Ignacio Grossmann*

1 - Managing energy real options: New dual reoptimization strategies and bounds
Alessio Trivella, *Selvaprabu Nadarajah*

Energy operations and investments are managed with real option models, embedding timing and/or switching decisions, where the former and latter decisions change irreversibly and reversibly, respectively, the status of the real asset. Optimizing flexibility in these models under realistic state-variable dynamics is typically intractable and requires heuristic approaches. Least squares Monte Carlo (LSM) is popular, while a known forecast-based re-optimization heuristic (FRH) is not well suited to handle timing decisions. We develop a network dual re-optimization framework, leveraging network flow algorithms and employing a novel class of partial information relaxations to overcome this shortcoming. Our framework provides both a new policy and a dual bound, provably tighter than a known penalized perfect information bound. Our network-dual re-optimization policy outperforms both FRH and LSM on two energy real option problems concerning commodity and energy production (a compound timing and switching option) and the electrification of a vehicle fleet (a pure timing option).

2 - Peer-to-Peer Transactions and Energy Consumption Decisions: An Equilibrium Analysis
Felipe Pulido-Prada, *Ariadna De Ávila*, *Alejandra Tabares*, *Seyed Farhad Zandrazavi*, *John Fredy Franco*

This work proposes an Equilibrium Analysis approach to address the problem of a microgrid with Peer-to-Peer Transactions, comprising a group of prosumers equipped with photovoltaic units for energy generation and batteries for storage. Traditional approaches to this problem involve nonlinear models, such as Quadratic Programs or Mixed Integer Linear Programs (MILP), generally solved using expensive commercial solvers; in contrast, our proposed methodology results in a fully linear equation system, named Equilibrium Model. Initially, we modeled the original problem using a MILP and transformed it into a Linear Program (LP) using McCormick Envelopes and reasonable assumptions based on the literature; from the LP, also referred to as Primal Problem (PP), we deduced the associated Dual Problem (DP), using Duality Theory, and combined the PP and the DP, into an Equilibrium Model. The resulting system of equations imposes both the Primal and Dual Constraints and ensures the Primal Objective Function is equal to the Dual Objective Function; due to Strong Duality, the Equilibrium Model is equivalent to the initial MILP. Ultimately, the Equilibrium Model ceases to be an optimization problem and transforms into an easily solvable linear equation system. We implemented the transformations and verified the objective functions obtained from the MILP, LP (PP), DP, and Equilibrium Model are identical, thus validating the correctness and the advantages of our approach.

3 - Integrating Automatic and Manual Reserves in Optimal Power Flow via Chance Constraints
Álvaro Porras Cabrera, *Line Roald*, *Juan Miguel Morales*, *Salvador Pineda Morente*

Many methods have been proposed in the technical literature to cope with the uncertainty of weather-driven renewable energy sources in power system operations. They either tend to be overly conservative, leading to higher costs, however, or leave the system vulnerable to unlikely but high-impact scenarios. To tackle this problem, we suggest a new approach to stochastic optimal power flow distinguishing between "normal operation," where automatic generation control (AGC) is sufficient to ensure system security, and "adverse operation," where the system operator must take additional actions. Our formulation combines a joint chance-constrained problem (JCCP) to enforce the use of AGC with specific treatment of large disturbance scenarios allowing for more complex redispatch actions. Since JCCPs are difficult to solve, we use a mixed-integer data-driven approximation combined with constraint screening and valid inequalities to find a solution. Our new method has been compared to classical approaches in a case study on the IEEE-118 bus system, and we have observed that our method, considering extreme scenarios, can produce solutions more secure than typical chance-constrained formulations, but less expensive than solutions guaranteeing robust feasibility with only AGC.

Power Systems Operations Under Uncertainty

Cluster: Optimization of Power Systems
Invited session
Chair: *Ricardo Pinto de Lima*
Chair: *Ignacio Grossmann*

1 - Stochastic Programming Applied to the Optimal Power Flow Problem
Mariane Bispo, *Aurelio Oliveira*, *Camila Zeller*

In mathematical programming, the modeled problem can often have difficulties with its data. Sometimes, the entries are constructed from statistical estimates taking into account only a small sample of the real data observed, causing bias in the final results. For instance, in problems of demand, price, among other things, changes over time. To avoid this bias, we can approach the problem using stochastic programming. In this perspective, we adopt a two stage problem, where, in the first stage, we solve the problem only for the variables considered deterministic, while, in the second stage, we solve the problem

for random variables taking into account the result obtained in the first stage. To solve a problem with this formulation, we will use an interior point method; we approach a linear programming problem with a stochastic perspective using an interior-point method for its solution. Application to the optimal power flow problem with demand uncertainty is considered.

2 - A hybrid Benders decomposition to solve the network-constrained unit commitment problem
Ricardo Pinto de Lima, *Gonzalo Constante-Flores*, *Antonio Conejo*, *Omar Knio*

We propose a novel hybrid decomposition method to solve network-constrained stochastic unit commitment (SNCUC) problems. We target large-scale instances of the SNCUC problem, involving stochastic renewable generation units, hundreds of thermal generation units, thousands of transmission lines and nodes, and uncertain demand. The problem is formulated as a two-stage stochastic program with continuous and binary variables in the first stage and only continuous variables in the second stage. We develop a solution method based on Benders decomposition recasting the original SNCUC problem into a novel master problem and subproblems. In this work, the master problem includes the typical first-stage unit commitment decisions and dispatch decisions over all scenarios (excluding transmission variables and constraints). The proposed decomposition embeds a column-and-constraint generation step at each iteration, to add specific transmission variables and constraints per scenario to the master problem, selected by comparing the solution of the master problem and subproblems. The performance of the proposed decomposition is contrasted with solving the extensive formulation via branch-and-cut and Benders decomposition available in commercial solvers, and with traditional Benders decomposition variants. The proposed method generates bounds of superior quality and finds solutions for instances where other approaches fail.

3 - An Exact Tri-Level Approach for Robust AC-OPF
Jorge Weston, *Kevin-Martin Aigner*, *Martin Schmidt*, *Frauke Liers*

Recently, increased supply with renewable energy and the growth of self-generation have increased the uncertainty of power demand and generation, needing to be taken into consideration in the operation of the power system to ensure proper functioning of the transmission grids. In this work, we will focus on a robust approach considering uncertainty of power loads in the alternating current optimal power flow model (ACOPF). Much of the current work related to the robust ACOPF makes use of convex relaxations or linear approximations to reduce the complexity of the optimization problems. Moreover, many studies assume a feasible network response exists for the whole uncertainty set studied. Both approaches can translate into solutions not robust feasible, however; there may exist some uncertainty realizations so the network cannot be operated properly. In this work we present an approach modeling the robust ACOPF as a min-max-min optimization problem to (i) identify the AC robust feasibility under power load uncertainty (discrete or continuous), and (ii) find the best linear decision rule to model how the network can be adapted, once the uncertainty manifests itself. We solve the min-max-min problem by solving the inner max-min with a spatial-branching approach, together with cutting planes for the outer minimization problem. With this approach, we can obtain, if it exists, a feasible robust solution. The spatial-branching algorithm has a finite termination, depending on the size of the uncertainty set and the given robust feasibility tolerance. We present preliminary computational results for small test cases of the IEEE library; the approach can detect robust infeasibility with a small number of iterations. On the other hand, solution times are larger in the case of robustness. From our results, using affine decision rules and box-type uncertainty sets, we notice protection against the extreme points of the uncertainty set leads to a feasible solution, robust for the whole uncertainty set, if it exists.

Community and Micro-grid Power Systems

Cluster: Optimization of Power Systems
Invited session
Chair: *Ricardo Pinto de Lima*
Chair: *Ignacio Grossmann*

1 - State Estimation on Power Systems with Branch flow model using Successive Linear Programing
Jefferson Javier Chavez Arias

Power system state estimation (PSSE) plays a crucial role in the operation and management of power networks; it serves as a reliable basis for the energy management system (EMS) infrastructure. A key challenge for accurate PSSE is the inherent nonlinearity of SCADA measurements in the system states. State estimation (SE) is usually mathematically formalized as a Weighted Least Square (WLS) or Weighted Least Absolute Value (WLAV) problem and solved by Newton's method. Although Newton's method is computationally tractable, it is highly sensitive at the initial point, as it is essentially a local search algorithm. This work shows SE based on mathematical programming, such as nonlinear (NL) models, and proposes a linear programming (LP) model. The LP model is based on the Successive Linear Programming (SLP) solution strategy for the linearized model, using Taylor's first order approximations for all nonlinear terms of the branch flow model to contour nonlinearities, by improving the local optimum feasible solution close to the optimal solution. The models were implemented using the AMPL algebraic modeling language and solved through commercial solvers. The results are shown on the IEEE 14-bus, the IEEE 30-bus system (in the presence of bad data), the IEEE 57-bus and the Polish 2383wp. Additionally, the proposed LP model is more robust than the WLS estimator and the WLAV estimator.

2 - Scalable optimization models and methods for microgrid operation under uncertainty
Jongheon Lee, *Seulgi Joung*, *Kyungsik Lee*

A microgrid is a localized power system with various distributed energy resources, usually connected to the main grid, but having the distinguishing feature it can also operate in an islanded mode. In this talk, we focus on operating microgrids efficiently and reliably under two stochastic factors - the net load demand and islanding events. First, increasing penetration of renewable generation makes the net load demand volatile and hard to predict. Next, islanding events, each corresponding to the periods a microgrid disconnects from and cannot rely on the main grid, need to be considered, since a reliable energy supply may be impossible if not prepared in advance. Although the standard multistage optimization model can address those uncertain factors sequentially realized, it suffers from the "curse of dimensionality"; the size of the model exponentially grows with the number of periods. Thus, in this talk, we propose efficient optimization models and methods to operate microgrids under stochastic net load and islanding uncertainty. To handle the net load demand, we propose an optimization model growing linearly with regard to the number of periods. In addition, to efficiently address the islanding uncertainty, we propose a heuristic procedure sequentially solving scalable optimization models. Numerical experiments demonstrate practical-sized instances can be solved using the proposed models; they cannot be solved using the standard multistage optimization model. One can effectively operate a microgrid with the proposed models.

OR and Food Sourcing

Cluster: OR and Food Sourcing and Distribution
Invited session
Chair: *Juan G. Villegas*

1 - Competitive Facility Location model for food distribution design through nano-stores
Agatha Clarice da Silva-Ovando, *Gonzalo Enrique Mejia Delgadillo*, *Christopher Mejía-Argueta*

Neighborhood stores are small businesses established as family's businesses (a.k.a. mom & pop, corner shop, convenience store, bodegas, etc.), normally started to contribute to the family income, for which reason there is little or no study for their opening planning. Store owners prefer to sell processed and packaged products, rather than fresh and healthy food, which limits the variety and quality of food offered. In this study, the Competitive Facility Location model has been applied to determine the location of a network of nano-stores offering both processed and fresh products, and, thus, to cover a demand neglected by other channels. With this, it ensures not only where a store should be located, but also ensures the operations of this network are sustainable over time. This model is fed with a nested logistic regression, with data from a survey providing information on purchasing behavior and retail channel preferences by the local population. The case study is applied in the Sabana Central region of Colombia, more specifically in the municipalities of Chía and Cajicá - very representative due to their population density, proximity to the capital, and mixed landscape between an urban region and rural.

2 - Analyzing the sustainability of intermodal transportation in Hass avocado exportation through multiobjective optimization models
Juan G. Villegas, *Germán Alvarez-Tobon*, *Paula A. Nisperuza*

In recent years, there has been an increasing awareness of fruits and vegetables deterioration in the distribution process; according to the Food and Agriculture Organization (FAO), one-third of the food produced globally is wasted. Hass avocados are no exception, making conservation and transportation alternatives necessary throughout the supply chain from harvesting to final consumers. In this work, we propose a decision support tool for the sustainable planning of the Hass avocado postharvest distribution network in Colombia supported by intermodal transport, when necessary; it is based on a multi-objective optimization model. The proposed model seeks three fundamental objectives within the distribution systems. First, it seeks to minimize the logistical costs associated with the distribution process. Secondly, from an environmental perspective, the aim is to minimize the carbon footprint generated in this process. Finally, the minimization of product losses is included to achieve the United Nations Sustainable Development Goal (SDG12) of responsible production and consumption. The proposed model can be seen as a multi-period multi-objective minimum cost flow problem with arc and storage losses, modelled using mixed integer linear programming. As a case study, we use the planning of the exportation process from the main region dedicated to Avocado Hass production in Colombia, where promising intermodal transportation alternatives (train and river) have not been explored yet. Using the proposed model, we evaluate the economic-environmental-social trade-off attained, if these transportation alternatives are used in the supply chain.

3 - Cooperative value chain design for Fine Flavor Cocoa
Karla Parra, *Andres Medaglia*, *Maria Fernanda Cortes*, *Daniela Rodriguez*, *Carlos Ardila*, *Sebastian Escobar*, *Bart Van Hoof*, *Ivan Mura*, *Jader Rodriguez*

The cocoa market classifies cocoa beans into two main categories: fine flavor cocoa (FFC) and bulk; FFC is considered a highly specialized market, where farmers have access to better prices. Despite the potential and interest of Colombia to produce FFC, currently, postharvest practices in farms lack standardized protocols and processes preventing small farmers from accessing high-value markets. This work presents the design of a cooperative model for the large-scale production of cocoa beans with fine sensory attributes. The transformation process of this cocoa agri-food chain is based on a centralized postharvest facility with standardized production methods, allowing the farmers' cooperative to reach the FFC market. The proposed three-stage methodology involves cocoa sourcing from farms, transformation at the postharvest facility, and sales planning. To model this agri-food chain, our work analyzes the transportation of cocoa pods from small farms to the processing plant by using transport routing and allocation optimization models. The transformation processes at the plant - classification, fermentation, and drying - are modeled via discrete-event simulation. Finally, the sales planning and profit analysis for FFC and bulk cocoa is modeled via mixed-integer linear optimization. We illustrate the methodology in a case study in Arauca, Colombia.

4 - Proximity centers to optimize last-mile logistics by analyzing household preferences and neighborhood store profile in Cochabamba
Abigail Aranibar Luján, *Jennifer Loayza Baldellon*, *Dayana Yugar Quiroz*, *Johan Rojas*

The traditional distribution channel is very important in emerging markets, such as Bolivia, where small "nanostore" retailers are the direct relationship between manufacturing companies and end customers. They have limited resources and are informal, however, a challenge in distribution due to the fragmentation of demand and the high density of stores in a neighborhood. The objective of the study was to propose the application of proximity points for household preferences and the needs of the "nanostores" to reduce costs and maximize distribution coverage. Firstly, data collection through surveys and geo-referencing was performed. Subsequently, the square kilometer methodology was applied to identify representative zones; the referential location for the proximity points was established using the gravity point method and clustering. The points obtained were evaluated using two route optimization models considering the various proximity points proposed as the origin of the routes; the first one, as a solution to the traveling salesman problem, was applied to determine the total distance traveled on an optimal route, allowing the minimum distance and cost associated to be determined. Secondly, coverage was evaluated considering the truck capacity, the demand of the nanostores, and the time occupied for loading and unloading. Thus, the time required for the execution of an optimal route was calculated, and the shorter time was associated with the achievement of greater coverage. Therefore, based on the location of the center of gravity and the two centroids, five alternatives were obtained. After prioritization analysis, the first and second alternatives are the most outstanding. On the one hand, the first alternative shows proximity to the centroid concerning the nanostores, while the second is to both the center of gravity and the centroid of the nanostores. Nevertheless, the sensitivity analysis prioritizes the lowest cost and highest coverage and proposes the second alternative as the best. In conclusion, the study proposes a logistic solution to the determination of proximity centers for soft drink manufacturing companies and suggests considering location characteristics to reduce variation in transportation cost and coverage. Additionally, integration of more complex location models is recommended in the study, as a methodological basis, without suppressing other variables greatly influencing the result of proximity centers.

Active Learning Strategies and Best Practices in Teaching Analytics

Cluster: OR Education
Invited session
Chair: *Hulya Julie Yazici*
Chair: *Erin Garcia*

1 - Project based learning approach in teaching analytics
Hulya Julie Yazici

Increasing demand in dealing with massive data and shortage of data scientists require effective teaching strategies for analytics. Furthermore, accreditation bodies, such as ABET, AACSB and SACS, emphasize the assessment of transferable skills and the ability to identify problems and to analyze and interpret data. Analytics is challenging to teach, due to inadequacies in learners' backgrounds and in resources and technologies. Usually, fear of statistics is real for students who were not exposed to it. This study presents an experiential project-based learning(PjBL) approach benefiting engineering, business and multi-disciplinary students. By having student groups collecting data

around a research question of their choosing and using descriptive and predictive analytics, an increased understanding of the data-driven decision-making process can be achieved; examples of this approach and assessment method are presented. Benefits and challenges of this methodology are discussed, with further improvement ideas from the IFORS Audience.

2 - Using student selected projects with multiple submissions in undergraduate linear programming
Erin Garcia

In this talk, we discuss the structure of a large project assigned in an undergraduate linear programming course, initially incorporated into the course in response to consistently low exam scores on modeling questions. Students work in assigned groups for the entire semester to complete the project and are responsible for all of the components, from initial topic selection to modeling, solving, and finally analyzing the results. Each of the four project submissions requires a revision of their existing work based on peer and instructor feedback, as well as the addition of another technical component. Through this structured submission approach, students are encouraged to change how they think about their modeling work. Instead of looking at modeling problems as something they attempt only one time and either have a correct or incorrect answer, they can understand modeling work often requires a revision process and there is often not a single correct way to approach a scenario.

3 - Get in the Game: Learning Inventory Management Through AI tools
Maria Trindade, *Gihan Edirisinghe*, *Lan Luo*, *Micah Logan*

The use of Artificial Intelligence (AI) in teaching Operations Research (OR) is becoming increasingly popular (Sollosy & McInerney, 2022). A recent survey conducted by McKinsey & Company found growing excitement among students and faculty about the use of technology in the classroom. Specifically, the survey revealed that over 30 percent of students expressed excitement for augmented reality and virtual reality-based classroom interactions. In comparison, more than 60 percent of faculty were excited about machine learning-powered tools and AI technology (Mckinsey & Company, 2022). This study aims to present a broadly accessible discovery-based teaching activity using ChatGPT helpful in teaching OR concepts. The proposed classroom game seeks to facilitate students' understanding of inventory management concepts, focusing on the Economic Order Quantity and how the number of orders and the average inventory levels affect total inventory costs. ChatGPT roleplays as a purchasing manager to simulate realistic data and associated inventory cost calculations as it supports student groups in discovering the optimal order quantity. An instructor-designed Google Sheet supplements ChatGPT's role in the activity by serving as a real-time dashboard of each group's performance. Despite the focus on OR learning, we ran this activity to raise the students' awareness of the ChatGPT limitations, namely concerning the lack of control over the answers provided, which may not always be accurate. To do so, the activity is preceded by a validation phase of the results and guidance on handling situations in which ChatGPT provides incorrect results. The activity is currently being implemented in two universities, one in Europe and one in the USA, in face-to-face environments. The activity has the potential to be used online and has the advantage of being very simple and inexpensive, which makes it broadly accessible to instructors from different backgrounds. The activity can be adapted for training and professional development programs and integrated into existing OR curricula or used as a standalone teaching module.

Panel: The Role and Recognition of Teaching Faculty in Operational Research

Cluster: OR Education
Invited session
Chair: *Ken Murphy*
Chair: *Alexander Vinel*

1 - The Emerging Role of Teaching Faculty in Operational Research
Ken Murphy, *Erin Garcia*, *Diana Prieto*, *Stefan Voss*

Operational Research (OR) is a discipline focused on problem-solving methods and their application in business and society. Operational Researchers engage at the intersection of mathematics, engineering, statistics, and computer science, with an emphasis on research. With the growth of business analytics practice, there is clear movement towards disseminating the OR skill-set with a much broader constituency. This has increased the importance of teaching OR methods effectively to broader audiences and in the growing array of academic programs.

In recognition of the importance of pedagogy, institutions of higher education have been adding long-term and even tenure-track faculty positions with teaching as the central focus. These faculty, with titles like clinical faculty, professor of practice, or lecturer, are assigned a larger teaching load relative to their research colleagues. They may also serve a significant service role at their institutions, including leading academic programs or other strategic initiatives.

The growing commitment to long- or longer-term teaching faculty also increases operational complexity at these institutions. For example, while most universities have well-established standards for tenure and promotion for research faculty, have they also developed similar standards for their teaching colleagues? Has this issue been fully addressed by the tenured faculty and/or university leadership?

This panel will focus on the topic, addressing these questions from the OR perspective: • To what extent are institutions implementing or considering long-term commitments to OR teaching faculty? What do existing faculty and university leaders think about the role of teaching faculty at their institutions? • Should teaching faculty receive tenure? How can one demonstrate expertise as an educator in OR? • How mature are evaluation processes for OR teaching faculty? What can be done to improve the evaluation criteria for teaching focused faculty? • What is the role of professional organizations, like IFORS, with respect to this emerging academic track for OR professionals?

OR Education 1

Cluster: OR Education
Invited session
Chair: *Gerhard-Wilhelm Weber*
Chair: *Milagros Baldemor*

1 - On Efficiency and the Jain's Fairness Index in Integer Assignment Problems
Julio C. Góez, *Mario Guajardo*, *Nahid Rezaeinia*

Given two sets of objects A and B, the integer assignment problem consists of assigning objects in A to objects in B. Traditionally, the goal is to find an assignment that maximizes or minimizes a measure of efficiency, such as utility or cost. Lately, there is growing interest in incorporating a measure of fairness. This paper studies the trade-off between these two criteria, using Jain's index as a measure of fairness. The original formulation of the assignment problem with this index is a non-linear non-convex problem. We develop two reformulations, where one is based on a convex quadratic objective function and the other is based on Mixed Integer Second-Order Cone Programming. We use these reformulations in instances of real-world data from an assignment of students to projects and test the model using real data of 2017 and 2018, in joint collaboration with the administrative staff of the program.

2 - The Importance of Operations Research Education for Health Systems Management
Zaida Estefanía Alarcón-Bernal, *Ricardo Aceves-García*

A health system is established to satisfy a manifest social function of needs and demands for health services; they are an interrelationship of resources, finances, organization, and administration, culminating in providing health services to the population. Health systems and their subsystems (clinics, hospitals, medical units and health control) must be efficiently managed to meet the needs of society, considering patients expect high-quality care at an affordable cost.

From the management engineering perspective, creating specific and complementary competencies in Operations Research comprises a complex and challenging objective - also essential since healthcare systems are changing and new health services are emerging. Most hospitals accustomed to empirical management are unprepared. Human resources with innovative systems engineering approaches are needed to achieve optimal results in providing services through various strategies, policies, and procedures in line with the evolution of management concepts and techniques.

In this paper, we present a proposal for linking theoretical concepts with applications in real health systems through the integration of a training strategy considering OR techniques within health services management engineering to expand the knowledge base, as well as providing decision-making tools and train human capital with the appropriate skills for the management of these services.

3 - Teaching OM with Experiments
Haokun Du

Operations management involves numerous elegant theoretical models (e.g. news-vendor model and beer game), and they are normally taught at the undergraduate level. Instead of teaching the models with slides, however, the instructor could develop experiments to engage students prior to showing them the "optimal solutions" to the models. The collected data could be used immediately after the game concludes to showcase the relationship between decisions and performances. Monetary rewards to the best performing students can be used to increase attention. There are multiple software that could achieve this, including oTree and SoPHIE. The collected data could also work as pilot data for behavioral researchers to investigate potential behavioral regularities; it could also be taught to the students to further their understanding on how those models work.

OR Education 2

Cluster: OR Education
Invited session
Chair: *Zilla Sinuany-Stern*

1 - The use of case study videos and a comparative analysis between teaching quantitative practices in face-to-face and hybrid asynchronous environments.
Marina Segura, *Mónica de Castro Pardo*, *Yolanda Durán*, *Cristina del Campo*

Social science students find it difficult to handle quantitative courses because they do not connect the course studied in class with practical situations where the subject could be applied. The objective of this work, associated with a teaching innovation project, is to improve the motivation and attitude of social science students toward quantitative subjects, as well as their active participation in the teaching-learning process. For this purpose, case study videos have been designed for students to see practical applications of what they have studied in the theoretical classes. In addition, the results are presented in terms of academic performance, perception and commitment of students from three Higher Education degrees for the subject Statistics in the first year and Decision Methods in the third year of face-to-face and asynchronous hybrid face-to-face teaching. Although the knowledge acquired was very similar in both methods, satisfaction is different between first and third year students.

2 - Social constraints and women's empowerment: How Does Religious Rule affect the strength of women empowerment? A micro level empirical analysis for Afghanistan
Muhammad Qahraman Kakar

This study evaluates the impact of Taliban religious rule on women's empowerment; we use a set of indicators from the Demographic and Health Survey for Afghanistan (the latest survey, first conducted in 2015), and, for empirical purposes, we use the diff-and-diff method. Depending on their year of birth and province of residence, individuals differed in the number of years they were exposed to the Taliban government while of school age. Our difference-in-differences estimates show an increase of 2.6 years in the number of years of exposure to Taliban rule, while the women were of school-age, decreased women's education by 0.27 years, compared to the control group. Similarly, 2.6 years of women's exposure to Taliban rule resulted in a lower likelihood of 1.5 percentage points of completion of 9th-grade schooling, compared to the women in the control group. In economic outcomes, women who were exposed to the Taliban rule are roughly 2 percentage points more likely to own land, compared to women who were in the control group. Moreover, they are 3 percentage points less likely to have a say in how to spend their husband's income. For decision-making autonomy, women who were exposed to Taliban rule are 4 percentage points less likely to decide about their healthcare, 6 percentage points less likely to visit their relatives and 5 percentage points less likely to decide on household purchases compared to the control group. In general, religious rule negatively affects women's empowerment. We compute a set of placebo regressions to support the assumption of parallel trends for the treatment and control groups, essential while using the difference and difference method. Our results for the placebo regression are statistically not significant, giving us validation for the methodology difference-and-difference model we have adopted. Our findings are not because of any policy shift and government change before the Taliban.

3 - Applications of OR in higher education Institutions: Review
Zilla Sinuany-Stern

Operations research (OR) has extensively been applied in many areas, such as business, industry, and healthcare. Although the vast majority of OR experts who publish in scientific journals are in academia, not much has been published about OR applications in higher education (HE). This article presents an overview of the use of OR methodologies in HE, and the functional areas in which these are used. Forty major OR journals are reviewed, such as the Journal of Operational Research Society, Management Science, Operations Research, and Omega. In these 40 journals, HE and OR methodologies appear in the title of only 0.3% of the articles during 1950-2019. Moreover, in 17 journals, HE did not appear in any article title. Looking at the web of science (WoS) during 2000-2019, we identified 58 main OR methods grouped into ten categories: OR/MS and their synonyms, decision analysis, mathematical programming, discrete optimization, stochastic, forecasting, simulation, multivariate statistics, heuristics, and expert systems. Leading these methods in HE (in terms of the number of articles) was simulation. Similarly, we identified 30 functional areas grouped into four categories: transportation, industry, R&D, and business. Leading these functional areas was business. In a deeper look at 12 selected specific OR methods in HE (out of the above 58 methods) by eight selected specific functional areas in HE (out of the above 30 functional areas), the leading combination was the data envelopment analysis method by the efficiency functional area. We concentrate on examples taken from the Handbook of Operations Research and Management Science in Higher Education by Z. Sinuany-Stern (2021, in International Series in OR & MS, Vol. 309, Springer), exemplifying the usefulness of OR methods for solving HE problems, such as student forecasting, exam scheduling, and budget allocation. In summary, there is a great potential for academics to utilize OR models to improve their own HE systems.

Gurobi Mini-workshop - How to Use It at Your Institution

Cluster: OR Education
Invited session
Chair: *Rodrigo Fuentes*

1 - Integrating Gurobi into Academic Institutions: Licenses, Portability, and Educational Resources
Rodrigo Fuentes

We will describe in detail how Gurobi can be used within academic institutions. This will include the following: • Licenses available to academic users • Take Gurobi with You - a license program for graduates who would like to continue using Gurobi • Educational resources available

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EWG-ORD Workshop 1 (OR for Development and Developing Countries)

Cluster: OR for Development and Developing Countries
Invited session
Chair: *Gordon Dash*
Chair: *Nina Kajiji*
Chair: *Gerhard-Wilhelm Weber*
Chair: *Olabode Adewoye*

1 - Carbon Pricing under Competition and Regulation
Bruno Kamdem

Even though worldwide greenhouse gas emissions have significantly declined because of COVID- 19 pandemic-related restrictions, emissions are likely to return to pre-pandemic levels, if governments do not prioritize policies addressing climate change. An illustration is the new U.S. administration's pledge to cut greenhouse gas emissions 50% to 52% below 2005 levels by 2030. To be effective, however, policies intended to reduce CO2 emissions must integrate competition within commodity extracting and commodity utility companies. In this paper, we successfully formulate and price a new carbon auction derivative, handling the competition-regulation dichotomy in carbon markets; it is simultaneously a put and a call option on carbon permits. Furthermore, it complies with the dynamics of both the commodity price and the carbon auction quote. The commodity price follows a mean reverting regime-switching jump-diffusion Levy process. We expound on the quantity of commodity produced in a non-cooperative differential game, where the Nash equilibrium is defined. To hedge against the auction liquidity risk, commodity extracting and commodity utility companies must wield the carbon auction derivative as a tool for extracting more, while polluting less. To policymakers, we pinpoint the dependency of the tax imposed by the government on the combined capacities of commodity companies to successfully decrease CO2 emissions.

2 - An optimization model for a real life single-track train timetabling problem
Renata Mendes, *Anand Subramanian*, *Teobaldo Bulhões*, *Bruno Bruck*

This work addresses a train timetabling problem arising at the Companhia Brasileira de Trens Urbanos (CBTU), a Brazilian state-owned railway company. A train timetable is responsible for setting arrival and departure times, at a series of stopping points belonging to the railroad. Determining these times is very relevant in the social context, given approximately 8000 passengers a day make use of public transport - an accessible and safe means of travel fitting into their routine.

Furthermore, the systematic functioning of a railway relies heavily on a train timetable being in place. Also, it is necessary to respect a series of security protocols referring to vehicle operations on tracks. Therefore, the main goal of this work is to assign routes and timings for the trains, so as to better satisfy the customers of the railway, taking into account a series of operational constraints, such as distance between stopping points, station demands, and security rules.

In practice, the CBTU's railroad studied in this work includes a 30 kilometer stretch of railway, starting at the city of Santa Rita, and heading to the city of Cabedelo, both located in the state of Paraíba. The trains need to travel in opposite directions using a single track; in case of a poorly planned timetable, this can potentially lead to collisions between vehicles during the journeys, resulting in big tragedies, as happened recently in the city of João Pessoa. Efficiently solving the timetabling problem can be seen as great social responsibility.

Hence, this work proposes a mathematical formulation capable of solving the train timetable problem, based on the CBTU's railroad. The developed formulation can efficiently solve small-size instances. The current model does not have the same performance, however, when it comes to solving instances of realistic size. The next step of the research is to look for ways to devise a stronger formulation for the problem, as well as (math)heuristic approaches capable of solving larger instances.

3 - Total Factor Energy efficiency in Developing countries with specific reference to India: An Empirical Analysis using the SBM-DEA Model
Jinal Parikh, *Gerhard-Wilhelm Weber*

Energy plays a pivotal role in the economic development of all countries. The energy sector not only makes possible investments and innovations, but also creates new industries generating jobs, inclusive growth, and shared prosperity for economies. It is even more important for developing countries in view of their ever-increasing energy demand, augmented by demographic pressure and an increased urbanization rate, also leading to increased CO2 emissions. Nevertheless, developing countries are the hardest hit by the recent energy price shocks, exacerbating energy shortages and energy security concerns arising as a result of the COVID 19 pandemic and the Ukraine war. While SDG7 calls for universal access to affordable, reliable, sustainable, and modern energy by 2030, improving energy efficiency in these countries could be one of the key paths to address the issues of energy security, climate change and economic stability. According to the International Energy Agency (IEA) report 2022, "India becomes the world's most populous country by 2025 and, combined with the twin forces of urbanisation and industrialisation, this underpins rapid growth in energy demand, which rises by more than 3% per year in the STEPS from 2021 to 2030. It sees the largest increase in energy demand of any country. Even though India continues to make great strides with renewables deployment and efficiency policies, the sheer scale of its development means that the combined import bill for fossil fuels doubles over the next two decades in the Stated Policies Scenario (STEPS), with oil by far the largest component. This points to continued risks to energy security." Further, India is characterized by considerable differences in energy efficiency in different regions (i.e., 29 states and 7 union territories) resulting from differences in their economic and demographic trends, resource availability and industrial profiles. Given this background, this paper 1)explores the factors influencing Total Factor Energy Efficiency (TFEE) of the developing countries using the SBM-DEA model; 2)investigates the TFEE of different regions of India; 3)applies Moran index to TFEE values to examine whether there is spatial correlation between different regions; and 4)extends the first author's research presented at IFORS 2021, Seoul.

EWG-ORD Workshop 2 (OR for Development and Developing Countries)

Cluster: OR for Development and Developing Countries
Invited session
Chair: *Elise del Rosario*

Chair: *Leonidas Sakalauskas*
Chair: *Jinal Parikh*
Chair: *Gerhard-Wilhelm Weber*

1 - Kerkenes Eco-Center Project in Anatolia and future chances by OR
Gerhard-Wilhelm Weber, *Francoise Summers*

In this paper, co-authored with Geoffrey Summers, Francois Summers, and Soofia Tahira Elias-Ozkan from the Middle East Technical University, Ankara, Turkey, I will introduce, through an example, how Operational Research for Development applications are highly interdisciplinary in character, and how OR, together with state-of-the-art tools and devices from engineering, natural and social sciences, could serve projects of architecture, history, water management, agriculture and education, with the goal of improving living conditions. The Kerkenes Eco-Center Project was initiated in 2002 with the following objectives: - To advocate the use of renewable sources of energy; - To act as a stimulus and a catalyst for environment-friendly building with appropriate materials and energy efficient designs; - To act as a dynamic experimental base for testing designs, materials and activities suitable for viable and sustainable village life; and - To encourage village development and income generating activities that might halt and even reverse migration from rural areas to the cities. We will discuss a very successful program for the promotion of solar energy, a drip irrigation scheme for organic gardens, solid waste separation for composting and recycling, reuse of grey-water and promotion of appropriate materials and design for energy efficient buildings. Şahmuratlı Village possesses a world class cultural heritage site, ancient Pteria, an Iron Age mountain-top city founded on the Kerkenes Dağ. The Kerkenes Eco-Centre piloted schemes for renewable energy and appropriate technologies against a background of climate change, socio-economic inequality and rapid depopulation of rural areas in favor of urban growth. The Kerkenes Eco-Centre experiments with appropriate building materials and energy efficient designs, drip irrigation for organic gardens, solar energy, solar drying and cooking, recycling, stimulating and creating income-generating activities. International agencies assist in raising political commitment to a low-carbon, high-growth economy in Turkey. This small project makes use of an existing Eco-center in Turkey to promote energy efficient, renewable energy designs. It brings together local officials, businessmen, MPs and villagers to stimulate more formal work at the Municipal level, greater replication of ideas in other regions, and an increased media awareness of how local projects fit into bigger strategic goals.

2 - Comparing the predictive performance of Shallow and Deep Learning techniques in predicting South African SMEs' growth during COVID-19
Helper Zhou, *Gordon Dash*

This study compared the predictive performance of two popular machine learning algorithms, CatBoost and the enhanced Radia Basis Artificial Neural Networks (K4-RANN), in forecasting the growth of small- and medium-sized enterprises (SMEs) in South Africa during the COVID-19 pandemic. Using a dataset consisting of 603 SMEs' financial and non-financial indicators for the years 2019 and 2021, the two models were trained and tested on a subset of the data, and their performance was evaluated using standard evaluation metrics. CatBoost outperformed K4-RANN, an ANN typology, in predicting the growth of SMEs during the pandemic; specifically, it showed an Akaike Information Criterion (AIC) of -8956.45 and Mean Squared Error (MSE) of 0.00038, while K4-RANN achieved an AIC of -6436.22, and MSE of 0.00062. CatBoost, a deep learning technique, is more effective at capturing the complex relationships and interactions among the predictors than K4-RANN, a shallow technique, and is a promising machine learning algorithm for predicting the growth of SMEs during times of economic uncertainty, such as the COVID-19 pandemic. Also, the results highlight the importance of selecting an appropriate machine learning algorithm to achieve accurate and reliable predictions in the context of SMEs.

3 - IFORS Focus on Developing Countries Through the Years
Elise del Rosario

This presentation goes through the various activities IFORS has put into place since its first involvement with development issues dating back to the 70's. IFORS took the major step in 1990 with the formation of the Developing Countries Committee to take charge of activities related to OR in and for development.

Regular activities were pursued from one administrative committee to the next. A considerable contribution by regional groupings, specifically, EURO has helped the IFORS DC agenda. This revisit is meant to help stimulate discussion on where IFORS is now, with respect to its OR for Development focus, and decide a future direction.

Renewable Energy Integration

Cluster: OR in Energy
Invited session
Chair: *Rodrigo Moreno*

1 - Financial and Environmental optimization: Hybrid generation (wind-PV) with battery energy storage systems
Paulo Rotella Junior, *Arthur Leandro Guerra Pires*, *Luiz Celio Souza Rocha*, *Rogerio Peruchi*, *Karel Janda*

Generating energy from renewable sources is essential to combating global climate problems. The combination of wind and photovoltaic (PV) energy sources with the use of a battery storage system can mitigate one of the main characteristics of renewable energy - intermittency. The present study proposes a multi-objective optimization method for wind and photovoltaic (PV) hybrid generation with battery energy storage, considering a tariff policy issue for the grid-connected residential scenario. The proposed method used the Response Surface Methodology (RSM) to model two objective functions - one environmental (Carbon footprint) and the other financial (Net Present Value - NPV) in relation to four controllable variables. To perform the multi-objective optimization, the Normal-Boundary Intersection (NBI) was used to construct the Pareto frontier. Finally, the Levelized Cost of Energy (LCOE) criterion was used to select the best Pareto optimal point. The proposed model was applied in Brazilian cities from different geographic regions. Only regions with favorable environmental conditions and higher energy tariffs became financially viable for the proposed model, with NPV values ranging from R$ -76,080.94 to R$ 69,675.23. As for the Carbon footprint (emission of CO2eq), the values ranged from 8,951.47 to 27,939.78 kgCO2/kWh, being strongly influenced by the adopted power generation technology. The use of LCOE to select the best solution provided a metric for the cost of implementing a technology, whose values ranged from 1.093 to 1.981 R$/kWh. It is still not advantageous to opt for the use of batteries for later use at peak hours, even when the tariff modality selected was the white tariff; and energy storage systems enabling the implementation of this policy proved to be economically unfeasible. In current Brazilian legislation, the services and benefits generated by energy storage are not remunerated, penalizing investment in this technology. As proved, solar PV technology, despite being cheaper, was penalized by a greater need for storage capacity, leading to optimal configurations with greater participation of wind generation and indicating the need for incentives mainly related to wind energy and batteries, still expensive elements in the national scenario for residential generation, reducing the probability of achieving economic viability.

2 - Game theory-based charging strategy for aggregators of plug-in electric vehicles
Nicolas Valenzuela, *Javiera Barrera*, *Roberto Cominetti*

The increase in the number of electric vehicles worldwide is a phenomenon embraced by Chile; we will see a decisive transition towards electromobility in congruence with international agreements. This increase and the electrification of other sectors may jeopardize the electric system, so it is relevant to look for charging control structures for private electric vehicles to avoid consumption peaks at certain times. We study the behavior of the electric vehicle demand organized by aggregators confronted with energy prices driven by total demand. To

model the aggregator interaction, we use game theory models, but also analyze the historic electric demand and discuss if machine learning tools (to determine characteristic demand profiles) contribute to improving the aggregators' decisions. Numerical experiments were developed to consider various settings.

3 - Smart charging scheduling for photovoltaic battery swapping stations with energy storage system: A case study
Alejandro Uribe, *Mariana Yepes*, *Alejandro Arenas*, *Alejandro Montoya*

Electric vehicles have emerged as a solution to environmental concerns in the transportation sector; with sales increasing globally, challenges arise concerning charging infrastructure. The impact of electric vehicle demand on the grid and the speed of charging remain factors hindering the adoption of this technology. Battery swapping stations stem as an alternative to these problems by allowing charging strategies extending the useful life of vehicle batteries, satisfying user demand, and reducing operating costs. This research proposes an approach to the charging scheduling of battery swapping stations with photovoltaic generation and energy storage through strategic decisions seeking to minimize the sum of the cost associated with the degradation due to battery charging and the cost of purchasing energy from the grid. First, a mathematical approximation is developed to describe the problem, and we offer other charging policies based on a greedy and a heuristic approach aiming to achieve the same goal. As a case study, information from the Energética 2030 program is used where a photovoltaic charging station and a hybrid motorcycle were developed. For demand estimation, we use a discrete event simulation considering the operation of fleets of hybrid motorcycles interacting with a battery swapping station (such as the one developed in the framework of the project) and include radiation forecasts and solar panel models to know the energy generation every instant. We include a lithium battery degradation model considering different charging rates to quantify the cost associated with charging. Finally, this work compares results between methods to find an operation mode meeting the operator's and user's needs and encouraging the adoption of electric vehicles.

Hydrogen Planning and Operation

Cluster: OR in Energy
Invited session
Chair: *Enzo Sauma*

1 - Levelized cost of hydrogen production in Northern Africa and Europe for 2050 using a Monte Carlo simulation
Nicolas Wolf, *Michael Höck*

The production of green hydrogen by electrolysis using renewable energies is considered one of the central building blocks on the way towards decarbonizing the economy. Predictions about when, how much, and in which industries hydrogen will be needed are difficult even at this point and are strongly driven by assumptions due to political, legal, and economic influences. Hydrogen is seen as one of the most attractive options for future energy supply, however, as reflected in the increasing number of published national hydrogen strategies to promote and implement this energy carrier; the motivation behind this is manifold. Energy-hungry nations need a flexible and renewable energy source, especially for the immense energy requirements of their industries. Other countries have advantageous location conditions for the production of the necessary renewable electricity - specifically from PV or wind. Besides logistical and infrastructural challenges for hydrogen transport and political-economic criteria for international cooperation, the regional production costs and potentials of green hydrogen are above all the decisive criterion for the choice of a supply option. For the purpose of evaluating possible import options for the Central European region, a stochastic scenario analysis using a Monte Carlo simulation was performed to calculate the levelized cost of hydrogen (LCOH) for the European countries Germany, Norway, and Spain, as well as the North African countries Algeria, Morocco, and Egypt in 2050. As future cost developments are subject to significant variation due to the assumptions made, this study aimed to identify areas where future costs may lie at certain probabilities. Assumptions were based on a meta-analysis of literature data, as well as calculations using real data. In addition to its common form, an extension of the LCOH formula for a combined electrolysis operation was created for the German case. Hydrogen production from PV energy from the Southern European and North African regions is the most cost effective. Spain has the lowest cost range, closely followed by Algeria and Morocco. For Norway, onshore wind energy provides the greatest benefits. Germany reaches competitive prices for onshore and offshore based hydrogen.

2 - Hydrogen production and the power system network
Enzo Sauma

A model minimizing the operation costs of an electrolysis hydrogen (H2) production plant, from the perspective of the H2 producer, is presented. Hydrogen production is characterized when using electrolyzers in some locations of Chile. We use the proposed model to assess both the economic and the environmental impacts of complementing green H2 production with electricity from the power grid, when using ALK electrolyzers and when using PEM electrolyzers, in selected locations of Chile. Finally, we study the existing tradeoff between reducing the LCOH with more hydrogen production using grid electricity and increasing CO2 emissions by producing more H2 with grid electricity in Chile, defining a new cost index.

3 - Nash Bargaining game for cooperative and operational decisions for microgrids with hydrogen flexibility option
Yolanda Matamala, *Hadi Charkhgard*, *Felipe Feijoo*

Trading of electricity among connected microgrids has the potential to reduce the dependency on the independent system operator, in turn reducing the use of fossil fuels. In this paper, we study bargaining among micro-grids as a feasible solution for reducing the dependency on fossil fuels in periods with peak electricity demand. The bargaining game is modeled in the upper level of a stochastic Stackelberg model. We modeled a direct current optimal power flow with endogenous prices in the lower level and reformulated the Stackelberg model as a Mathematical program with equilibrium constraints. The computational study done on a 14-bus network shows trading of electricity between micro-grids increases operational stability while minimizing operational costs. Finally, this market achieves a fair distribution of the generated profit for all participating micro-grids, while reducing network prices.

Energy and Environment

Cluster: OR in Energy
Invited session
Chair: *Enzo Sauma*

1 - Simulation for the energy transition: evaluating the load curve effects from active demand-side management
Maritza Jimenez, *Carlos Jaime Franco*, *Isaac Dyner*

Current geopolitical conditions, coupled with the environmental effects of climate change and increased environmental awareness, have created an environment conducive to driving energy transition. This transition has allowed different market actors, including both the supply and demand sides, to change their strategies to favour their own profitability or sustainability objectives. In particular, the demand side has perceived the deployment of new opportunities for more active and rational management of its electricity consumption. Some of the available alternatives include the acquisition of low-cost energy-saving technologies enabling the realisation of energy efficiency and alternatives for energy conservation, including flexibility in changing consumption habits supported by the use of smart technologies or by conviction-based choices and increased environmental awareness. Other alternatives favoring changes in demand-side behaviour include the possibility of having their generation and backup system through

distributed generation. Further, technological development has also facilitated demand response pricing through the use of smart meters and devices helping to know the price of electricity in real time. Given these changing conditions, uncertainty arises as to how the load curve, as an indicator of technical market performance, would be affected by changes in consumption dynamics on the demand side. This paper builds a mathematical simulation model, based on system dynamics, allowing an understanding of the resultant load curve dynamics based on the realisation of demand-side management activities, such as energy efficiency, energy conservation, distributed generation or demand response alternatives in electricity markets, with an application case in emerging economies. Distributed generation is the alternative having the greatest implications on load curve dynamics, compared to the effects of other alternatives, enabling regulators to recognise the risks in the technical behaviour of the electricity markets and benefiting the design of policies to support a more sustainable energy transition.

2 - Toward Climate Neutrality: A Multi-Objective Policy Optimization Approach for Renewable Fuels in the Transport Sector

Ali Ebadi Torkayesh, *Sandra Venghaus*

To move toward a sustainable future, the European Union (EU) has set two important targets: reducing greenhouse gas (GHG) emissions by 55% by 2030 and achieving climate neutrality by 2050. In a recent decision, the German government intensified its ambitions, seeking to decrease GHG emissions by 65% by 2030 and achieve climate neutrality by 2045. The German transport sector has become a main concern, given previous policies in this sector have been insufficient and GHG emissions have remained at the same level as in 1990. Although the rail sector has successfully adopted renewable fuels (electricity), fossil fuels remain the main source of GHG emissions in the sector. In this regard, renewable fuels, such as power-to-X (PtX) fuels, advanced biofuels, and green hydrogen, are potential fuel alternatives to reduce GHG emissions. Considering the short time left for achieving the targets, implementing effective and efficient policy frameworks will be of high significance for the market development of renewable fuels. A previously conducted policy analysis has shown the market development of renewable fuels in Germany is mainly driven by a set of national policies, such as the Climate Action Plan, the National Hydrogen Strategy, the German Sustainability Plan, and the Renewable Energy Act. On the other hand, EU policies also play a crucial role, mainly through the Fit for 55 Package and the EU Green Deal. Among renewable fuels, PtX fuels currently have a high potential for being used in maritime and aviation modes to mitigate GHG emissions, due to their low modification costs. Considering the complexity of the policy system for deployment of PtX fuels, proper policy allocation for reducing GHG emissions and corresponding economic and environmental costs is significant. Therefore, this study presents a multi-objective optimization model to support the costing and GHG reduction of PtX fuels, considering resource and policy constraints. Various scenarios on incentives, subsidies, and taxes are investigated to measure the impact of policies on the development of PtX fuels. The proposed optimization model presents optimal solutions to improve the utilization of PtX fuels to cut GHG emissions in the transport sector, through the implementation of a national and European optimal policy framework to achieve the German 2030 target and climate neutrality by 2045.

3 - Unit Commitment problem for Local Energy Communities

Cristian Aguayo, *Bernard Fortz*

With the rise of renewable energy, collective organizations, such as Local Energy Communities (LECs), play a key role in the transition to more sustainable energy generation. From the point of view of the Distribution System Operators (DSOs), however, the production of energy at minimum cost is still a topic of interest. For the last five decades, the Unit Commitment (UC) problem is one of the tools used to optimize energy generation, either with or without the incorporation of Renewable Energy Sources. In this work, the UC problem is extended to a LEC schema. For modeling purposes, LECs are considered as sets of consumers and prosumers with uncertain RES availability and uncertain power loads. The objective is to minimize the total operation costs over a time horizon. Additional features, such as power storage and energy sharing among members of a LEC, are also considered and evaluated using benchmark instances. This work is developed under the framework of the SEC-OREA project.

4 - Bifurcation Analysis of Capacity Charge Policy in a National Electricity Market: A Mathematical and Business Approach

Johnny Valencia-Calvo, *Gerard Olivar-Tost*

This paper proposes a novel bifurcation analysis approach to understand and to define the complex behavior of a national electricity market. We develop a set of ordinary differential equations capturing the demand and supply-side strategies of the market, with a particular focus on the impact of renewable energy sources and the growing interest in personal self-generation. No previous work has applied bifurcation criteria to study this topic.

The national grid may face a standstill and low investment, if the trend towards personal self-generation using renewables continues. It is crucial to maintain the grid as a reliable power supply, however, for domestic and commercial demand. Therefore, we investigate a zero-rate demand growth scenario and find the system dynamics are highly sensitive to variations in the capacity charge policy. We identify a bifurcation point where the system equilibrium switches from feasible to virtual, and a set of pseudoequilibria emerge.

Our results highlight the importance of the capacity charge policy as a strategic tool to manage the system generation price scheme and preserve investments in the market. From a business perspective, our findings emphasize the need to understand the effects of the capacity charge policy on the behavior of the national electricity market. From a mathematical standpoint, our analysis demonstrates the usefulness of bifurcation analysis for studying complex systems, like electricity markets.

Optimization for Electric Power Systems Connected to Water or Hydrogen Networks

Cluster: OR in Energy
Invited session
Chair: *Alvaro Lorca*

1 - Optimization-based expansion planning for flexible power and hydrogen systems with feedback from a detailed unit commitment model

Lucas Maulen

This research presents a novel long-term model for the joint expansion planning of power and hydrogen systems with short-term operational considerations. We propose linear reserve constraints with adjustable parameters within the planning model to address the reliability requirements from significant levels of variable renewable generation. These adjustable parameters are calibrated using an iterative training methodology that connects the long-term planning model with a short-term unit commitment model. A crucial aspect of our methodology is the iterative improvement of investment decisions through the feedback obtained by evaluating the operational performance of the investment decisions in different scenarios computed under the unit commitment model. Computational experiments in a case study of a large-scale Chilean power-hydrogen system show the effects of the proposed methodology on capacity expansion recommendations, where a correct balance between variable and flexible technologies is obtained. Moreover, when simulating the operation of the system for a full year, we observe that the proposed methodology generates an investment plan that achieves a lower total cost compared to other methodologies commonly used in the literature. Additional experiments in 100% renewable scenarios show how conventional methodologies reaches levels of not-supplied-energy between 2-7%, while the proposed methodology achieves less than 1% in the same metric.

2 - Medium-term stochastic hydrothermal scheduling with short-term operational effects for large-scale power and water networks
Marcel Favereau

The high integration of variable renewable sources in electric power systems entails a series of challenges inherent to their intrinsic variability. A critical challenge is to correctly value the water available in reservoirs in hydrothermal systems, considering the flexibility it provides. This paper proposes a medium-term multistage stochastic optimization model for the hydrothermal scheduling problem solved with the stochastic dual dynamic programming algorithm. The proposed model includes operational constraints and simplified mathematical expressions of relevant operational effects, allowing a more informed assessment of the water value by considering the flexibility necessary for the system's operation. In addition, the hydrological uncertainty in the model is represented by a vector autoregressive process, capturing spatio-temporal correlations between the different hydro inflows. A calibration method for the simplified mathematical expressions of operational effects is also proposed, allowing correct linking of a detailed short-term operational model to the proposed medium-term linear model. Through extensive experiments for the Chilean power system, the results show the difference between the expected operating costs of the proposed medium-term model and the costs obtained through a detailed short-term operational model to be only 0.1%, in contrast to the 9.3% difference when a simpler base model is employed; this shows the effectiveness of the proposed approach. Further, this difference is also reflected in the estimation of the water value - critical in water shortage situations.

3 - Simplifying Capacity Planning for Power Systems with Hydroelectric and Renewable Resources
Ramteen Sioshansi, *Kenjiro Yagi*

Capacity-planning models for electricity systems are inherently large-scale and complex. Hydroelectric and renewable generation can increase the complexity of such models further. In this talk, we present some approaches to reduce and to decompose these problems, making them more computationally tractable. Results are demonstrated for a case study based on the Columbia River system in the Pacific Northwest region of North America.

4 - Optimization-Based Analysis of Decarbonization Pathways and Flexibility Requirements in Highly Renewable Power Systems
Alvaro Lorca

We present a novel planning model for electric power systems, including an effective representation of the operational aspects of the system to understand the key role of flexible resources under strong decarbonization processes in highly renewable power systems. A case study is developed for the Chilean power system, which is currently undergoing an ambitious coal phase-out process, including the analysis of a scenario that leads to a completely renewable generation mix. The results show highly renewable generation mixes are feasible, but rely on an effective balance of the key flexibility attributes of the system, including ramping, storage, and transmission capacities.

Energy System Modeling

Cluster: OR in Energy
Invited session
Chair: *Vicente Munoz*

1 - Capex temporal allocation and cost recovery in long-term generation capacity expansion planning
Efraim Centeno, *Fco. Alberto Campos*, *Luis Jesús Fernández Palomino*, *Javier Maguregui*, *Sonja Wogrin*

This work revisits some interesting properties of long-term generation models and sheds light on cost-recovery properties associated with this representation in the framework of marginalist remuneration electricity markets. We propose a sound way of handling the allocation of investment cost (CapEx), when analyzing minimum-cost generation capacity expansion planning by using overall investment cost; we compare it with the most common approach, based on cost annualization, usually disregarding, or using a simplistic representation of, future years. The overall cost-based representation shows some advantages with respect to the annualized alternative. First, it does not require fixing a criterion for investment cost annualization; second, it provides a coherent definition of long-run cost (or prices) when assuming infinite life companies by modelling residual values; third, it allows for an adequate representation of the life span of generation assets; and, finally, it allows for a yearly tracking of company cost - very useful if including taxes or financial constraints in the model. On the other hand, the cost recovery property in marginal pricing, holding for annualized cost representation under some reasonable hypothesis, is not satisfied for overall cost representations in some situations. We analyze in detail some conditions required to get full cost recovery, showing a connection between cost recovery and the presence of investments in the last year of the studied horizon. Besides, some case studies check the effect of overall cost representation in scenarios with demand shape modifications, the inclusion of new technologies, or the closure of old plants. Additionally, we analyze the relationship between long- and short-run costs (or prices) in this context, showing, due to a duality gap in the model, some differences appear, reduceable by decreasing the times of the study.

2 - Inattention cost of energy
Vicente Munoz, *Sebastián Cea*, *Felipe Feijoo*

In a capacity investment framework, we study regulator preferences, with respect to environmental awareness, represented through a structure with rational inattention, according to the seminal contribution by Sims (2003); the planner has a noisy estimation of the emission's CAP and makes investment decisions to reduce potential gaps between the environmental-sustainable CAP and the actual CAP. We define a cap-and-trade model constituted by a planner and energy generators, differing on technology, following Amigo et alii (2021). The planner has to optimally decide: i) the level of accuracy with respect to the carbon budget and ii) initial price of allowances. Energy generators choose: i) capacity expansion, ii) production plans and iii) allowances trading strategy. Lack of accuracy may involve higher prices, in comparison to situations where the regulator is less attentive or accurate in the assessment of environmental policy.

3 - Long-Term Energy System Decarbonization Under Economy-wide Constraints Considering Power-To-X Technologies
Francisco Flores, *Felipe Feijoo*

We present a novel methodology using a soft-linking approach between an Integrated Assessment Model and an Energy System model. The first one is The Global Change Assessment Model (GCAM) with a detailed Chilean representation; this model allows the simulation of different mitigation strategies with a five-year steps resolution scale. The second one is Highway to Renewable Energy Systems (H2RES), a model for capacity expansion and optimization of energy with an hourly resolution scale. This approach allows us to assess decarbonization pathways' feasibility and Power-To-X technologies' function with an hourly resolution scale. Soft-linking is through the capacity additions of the power generation technologies resulting from the mitigation strategies evaluated in GCAM, and these capacity additions are an input in the H2RES model. It is possible to use the capacity obtained from GCAM-Chile and implement it on an hourly scale. The feasibility of implementation, however, depends on high levels of flexibility. H2RES generates a different structure than GCAM, resulting in differences of approximately 5% in wind technology and 3% in solar technology, driven by the higher capacity factors of wind and solar in Chile.

Optimal Operation of Energy Systems

Cluster: OR in Energy
Invited session
Chair: *Rodrigo A. Carrasco*

1 - Optimal Operation of a Green Hydrogen Plant using Wind Energy and BESS
Andrés Lagos

The objective of this study is to optimize the operation of the Green Hydrogen Plant 'Haru Oni' in Magallanes, Chile. At first, a perfect information model was created and a simulator was programmed that would help to evaluate the different proposed policies using wind data on site. Then the problem was solved using a Markov Decision Process (MDP) that performed 5.18% less than the global optimum, that is the perfect information model. Other policies were studied in comparison with the MDP solution using the simulator.

2 - Tightening bigMs for Optimal Transmission Switching
Salvador Pineda Morente, *Juan Miguel Morales*, *Álvaro Porras Cabrera*, *Concepción Domínguez*

The optimal transmission switching (OTS) problem determines the lines to switch off in an electricity network to reduce the operation cost. Using the linearized version of the power flow equations, the OTS problem can be formulated as a mixed-integer linear programming model, including large enough constants. When these constants are too high, however, the branch-and-bound algorithms used to solve the problem become computationally intensive due to poor relaxations. In this work, we present an efficient methodology to find tight values for these large enough constants. By doing so, we can find the global optimum of the OTS problem in significantly less time.

3 - Prescriptive scenario generation for solar energy management with storage
Rodrigo A. Carrasco

Governments have pushed for a higher penetration of variable and intermittent energy sources to alleviate the effects of climate change. Furthermore, storage systems have seen their prices drop significantly and are considered the key to dealing with the variability of some renewable energy sources.

This talk presents a novel approach to scheduling storage units in a photovoltaic generation system based on stochastic optimization. A common approach to take advantage of historical data for stochastic optimization has been to use machine learning techniques to compute relevant scenarios. Instead of this "predict THEN optimize" strategy, we show that using a combined "predict AND optimize" approach results in better recommendations. The resulting scenarios capture the relevant effects on the decision process - not just data features. We show experimental results applied to a real-life control system with limited computation capacity and further validate our results by testing the resulting schedules in an actual prototype.

Non-electricity Energy Models

Cluster: OR in Energy
Invited session
Chair: *Rodrigo Moreno*

1 - An Investigation of the Interaction Evidence between Carbon Credits and Crude Oil Prices of the International Markets
Renato Barros Lima, *Andre Assis de Salles*

An essential production factor for economic activity, energy has a prominent place in the global economy. Since the end of the last century, concern about global warming has been the object of global policies and has encouraged the production of energy from renewable sources and the growth of the carbon credits market. Studies have been carried out on related topics, particularly on the oil and gas markets and their interaction with renewable energy and carbon credits markets, mainly concerning the interaction of prices practised in these markets. This work aims to verify the relationship between crude oil and carbon credits in international markets, specifically studying the interaction between the price returns practised in the markets for Brent crude oil and carbon credits traded in the first contract month of the futures market for these credits. The primary data comprised the weekly closing prices spanning from February 2009 to August 2022. Thus, this work refers to the transmission of shocks from crude oil prices to carbon credits prices. To achieve the objectives of this work, initially, a study of the basic assumptions of the time series used in the models estimated for this study was carried out. Next, the cointegration hypothesis tests between the time series of changes in oil prices and carbon credits traded in international markets were carried out concomitantly with implementing a bivariate vector model with error correction – VECM. This model estimation enabled inferences of the causality relationship between the oil price and carbon credit returns. Therefore, it analysed how the variation in prices practised in the crude oil market is absorbed in the variations in prices practised in the carbon credit market and conversely. The impulse-response functions obtained for these variables showed what magnitude shocks in one of the variables are absorbed by the other variable and their persistence in time. In addition, heteroscedastic econometric models constructed to observe the occurrence of volatility peaks and clusters were estimated, verifying how short-term shocks in the prices of these variables interact with risk in these markets and how these shocks persist over time. Finally, the behaviour of the dynamic correlation of these returns time series was studied based on the estimation of a multivariate GARCH model. Thus, inferences were made regarding the dynamics of volatility contagion between the two markets studied.

2 - Waste-heat recovery potential for district heating systems under diverse pricing schemes: a bi-level modelling approach
Juan Jerez, *Claire Bergaentzlé*, *Dogan Keles*

Data centres produce significant amounts of waste-heat, a valuable resource in cold climates where data centres tend to develop. District heating systems provide heat to multiple users, through a network of underground pipes, and may leverage waste-heat to substitute for other heating fuels, lowering heat supply cost and emissions, while providing additional revenue and reduced cooling needs for data centre operators. Waste-heat recovery projects involve expenses related to lifting the heat's temperature to the district heating network's standards and its transport; their economic viability depends on the long-term certainty of the waste-heat price paid by the utility and how frequently the utility requires it. Various factors influence these aspects, however, such as the utility's own production cost, level of heat demand, and applicable district heating regulations, giving the utility an informational edge. This work examines how different pricing schemes influence the effective utilization of waste-heat potential, based on the dispatch decisions of the utility's heating and data centre's cooling portfolios. We propose a bi-level optimisation problem to adequately model their interaction, testing pricing schemes based on fixed values, time-of-use, and carbon intensity. The upper-level problem captures the district heating utility's objective of minimizing heat supply costs, based on its generation portfolio and waste-heat pricing. The lower-level problem represents the data centre operator's objective of minimizing its cooling costs, while considering alternative cooling equipment, such as free-cooling and electric chillers, including revenues from heat sales. We also develop a single-level model for comparison purposes, where the utility directly controls the data centre's cooling portfolio. The results illustrate the allocation of economic benefits between the parties and the impacts on their operations. Specifically, we evaluate the heating plans displaced and changes to carbon emissions; from the data centre's perspective, we analyze the economic indicators of the waste-heat project and how it increases its electricity use. This study and its methodology provide valuable insights for stakeholders in identifying the specific benefits

associated with waste-heat recovery projects and for policymakers in designing effective pricing schemes to maximize these benefits.

3 - A binary expansion approach for the water pump scheduling problem in large, high altitude water distribution networks
Denise Cariaga

The water pump scheduling problem is an optimisation model determining the water pumps to be turned on or off at each period. In this work, we tackle the optimal operation of a desalinated water system, with reservoirs and pumps sending water to mining companies at high altitudes. The optimisation of this process faces several difficulties derived from the following: i) the non-linearities of the friction loss equations along pipes and pumps and ii) many possible combinations of head pressure and flow leading to high computational costs, making it an NP-Hard problem. These limitations prevent solving the problem in a reasonable computational time in water distribution networks with more than two pumps and tanks, as occurs in different networks worldwide. Therefore, in this work, we develop new optimization models of the pump scheduling problem, using a binary expansion approach to tackle the non-linearities to minimize the systemic costs and the computational cost of the original MINLP. We tested these models in different network topologies and solved them with Julia and Gurobi.

Challenges in Energy Systems Planning

Cluster: OR in Energy
Invited session
Chair: *Angela Flores*

1 - Hybrid decomposition for power system planning under uncertainty
Angela Flores

An accurate representation of short-term flexibility issues in long-term planning models is required to accurately assess the value of investing in flexibility options. Uncertainty must also be captured in long-term planning models to anticipate future scenarios and avoid the risk of locking into inefficient investment decisions. Including both short-term flexibility requirements and long-term uncertainty in a unique planning framework, however, leads to large-scale multi-stage stochastic mixed-integer programming problems. Therefore, efficient solution methodologies are required. This work investigates possible ways of combining column generation, lagrangian relaxation, and Benders decomposition in a hybrid decomposition kmethod for efficiently solving power system planning problems under uncertainty, to improve convergence by exploiting the strengths of the different decomposition methods. The proposed hybrid decomposition is implemented using distributed computing. In this way, each decomposition approach is started in parallel, with the possibility of exchanging bounds and solutions between the methods. The solutions obtained at each iteration of the Benders decomposition and bundle method may be used to generate new columns for the column generation approach. Likewise, the columns obtained by column generation can be used to derive new cuts for Benders decomposition and the bundle method.

2 - A long-term generation and transmission expansion planning model considering desalination flexibility and coordination: A Chilean case study
Manuel Portilla Paveri, *Denise Cariaga*, *Alvaro Lorca*, *Miguel F. Anjos*

The electrical grids have undergone a great transformation, bringing new challenges to energy systems, such as new requirements to ensure the reliability of the network and the adequacy of supply and its balance with the energy demand. The need for new schemes allowing generation and/or demand to be adapted to energy variability become essential, and demand response is usually presented as one of these flexibility sources. In parallel, water scarcity worldwide and in Chile has increased in recent years, presenting itself as one of the great challenges arising soon. As an approach, Reverse Osmosis is presented as a mature technology, capable of supplying water on larger scales to various sectors from a practically inexhaustible source, the sea; it is a highly energy-demanding process, however, due to the use of high-pressure pumps used to desalinate the water through the membranes of the internal modules, where this consumption could mean more than 35% of the operating costs. In this context, this study develops a long-term planning model of the Chilean electricity system under various scenarios, considering the presence and implementation of desalination plants to respond to water scarcity from a centralized and coordinated point of view, taking advantage of the opportunities provided by flexible operation strategies of desalination plants, given by the nature of high-pressure pumps. These strategies enable a demand response source to minimize the impacts of the high-variable renewable energy sources power capacity expected in Chile. The study explores the value added to the system given by the coordination of desalination plants through defined signals, such as energy price, centralized dispatch in a water distribution system and demand response schemes. With this water-energy nexus model, the main objective is to identify the impact of high desalination participation scenarios on the power system dynamics and in transmission and generation capacity expansion planning. These main results aim to shed light on the need for investment, impact and alignment in decarbonization policies, new policies regarding desalination and links with the electrical system.

3 - Modern Preference Learning Model Evaluation for Individual Discrete Energy Policy Choices
Sheng Lun Cao, *Destenie Nock*

Decision aids for energy policy option recommendations can be customized for stakeholders by estimating individual stakeholder preferences using statistics and machine learning (ML). Learning individual preferences (behavioral choice rules) is difficult, however, due to the malleability of those choice rules, heterogeneity across decision-makers, and the limited availability of choice sets. It is currently unknown what estimation method can best estimate individual preferences, without prior knowledge of the choice rules decision-makers will use. This study evaluates four preference learning models (Multinomial Logistic Regression, Generalized Additive Model, Twinned Neural Network, and Gaussian Process), with respect to their capacity to learn and predict five choice rules exhibited by energy policy stakeholders (Linear Strong Utility, Monotonic Strong Utility, Ideal Point, Lexicographic Semiorder, and Multiattribute Linear Ballistic Accumulator). Three Monte Carlo experiments were performed to assess model performance when increasing a) number of attributes in the choice alternatives, b) number of training choice sets, and c) choice rule determinism. Preference learning models were further evaluated on a real energy policy discrete choice dataset. Some models can outperform others for individual choice rules; for example, GAM outperforms other models using limited choice sets in recovering Linear Strong Utility by 0.004 (TNN), 0.016 (MNL), and 0.027 (GP), as measured by Brier Score. No model dominates, however, in performance across all choice rules and contexts. Model performance improved by 8% to 68% in Brier Score with an increase in training choice sets and improved by 1% to 63% with an increase in choice rule determinism, but the impact of number of attributes differs by choice rule and model. All four models can learn and predict real energy policy discrete choices, with TNN outperforming other models by 0.006 (MNL), 0.025 (GP), and 0.199 (GAM) in Brier Score. This research explored the performance of modern preference learning models at the theoretical boundary and demonstrated a customizable individual energy policy decision aid is possible using preference learning.

Demand-Side Energy Optimization and Smart Grids

Cluster: OR in Energy
Invited session
Chair: *Young Lee*

1 - Optimization of Energy Load Curtailment Planning to Achieve Net-Zero Energy Use in Buildings
Young Lee, *Michael Risbeck*, *Chenlu Zhang*, *Saman Cyrus*

To combat climate change, buildings can be operated with net-zero energy use - meaning all energy consumed by the building is balanced with corresponding renewable energy generation on site. If this goal is achieved over the course of a year, the building has no net effect on climate change. Unfortunately, due to the inherent randomness of weather, building occupants and other disturbances, a building nominally designed for net-zero use might not actually achieve the goal in practice; it might be necessary to curtail discretionary use, if energy consumption out-paces generation. To determine when curtailment actions are necessary, we propose an iterative planning strategy minimizing the total cost of curtailment actions needed to achieve net-zero use by the end of the year. By solving the underlying optimization problem repeatedly throughout the year, the plan can be updated to account for the actual realized generation and consumption likely to deviate from original forecasts. Although the decision variables are discrete, this problem can be solved efficiently using dynamic programming, facilitating successful deployment. We present the problem formulation and illustrate performance via simulation, showing that the iterative closed-loop strategy adequately accounts for uncertainty, obviating the need for more computationally demanding stochastic formulations.

2 - Smart line identification for smart grids
Larraitz Aranburu, *Aitziber Unzueta*, *María Araceli Garín*, *Juan Ignacio Modroño-Herran*

One of the problems faced by electricity distribution system operators is to know with certainty the real location of all their assets, to properly manage the network and offer the best service to their customers. In this paper, we present a procedure for the identification of low-voltage feeders or distribution lines in smart grids, based on the mathematical formulation of the problem as an optimisation model. In particular, we define the model with 0-1 variables (as many as the number of meters to be identified in the different feeders) and with as many constraints as points in time are considered. Given the large size of the problem in practice, the use of conventional optimisation software becomes unfeasible. Based on this approach, and making use of the linear relaxation of the problem, some analytics on the coefficients (i.e. the meter loads) and the special structure of the problem itself, we have developed an iterative procedure allowing us to recover the complete solution of the initial model in an efficient way. We have carried out a computational experiment on a set of anonymised real data, obtaining results supporting the efficiency of the proposed procedure.

3 - Facility location problem for Hydro-Quebec supply chain network design
Abderrahman Bani, *Amira Dems*, *Rachid Hassani*, *Issmail El Hallaoui*

Hydro-Quebec (HQ) is Canada's largest electricity producer and one of the largest hydropower companies in the world; to ensure reliable operation of its distribution system, HQ employs workers responsible for the installation, extension, and maintenance of sub-transmission power lines. Service Centers (SC) are buildings accommodating these workers by offering office spaces, storage area for material they use and parking area for their special vehicles.

In this study, we will introduce a new mathematical formulation describing the novelty of the Service Centers Location Problem (SCLP); it is a new attempt, using the workload in various cities as the demand points. In addition, it uses real transportation time, to generate SC's coverage area boundaries, and a new definition of SC capacity constraints.

SCLP considers simultaneously both design and redesign features, constraints on sharing capacity between resource units intra-service center as well inter-service centers. It is used as a support decision tool for Hydro-Québec planners to evaluate their service accessibility, adjust allocations of cities to SC for more efficient utilization of service capacity and set utilization levels in a centralized manner.

Contributions to Military OR

Cluster: OR in Military, Defense, and International Security
Invited session
Chair: *Greg Parlier*

1 - Robust capability allocation problem for modular block-based organizations
Luis San Martin, *Jorge Vera*

An organization can accomplish an operational task by a capability, directly related to minimal organizational modules called building blocks (BBs) - each BB delivers a particular capability; an organization must design the allocation and combination of different BBs to achieve the desired capability. This problem exhibits a combinatorial nature and several sources of uncertainties, for example, in the capabilities and the required tasks. In this research, we propose a novel and tractable binary optimization model to allocate the BBs, following either an additive or a nonlinear rule, i.e., all modules proportionally contribute with a capability to reach the global capability balance or the contribution of capabilities depending on the number of BBs allocated, respectively. We use robust optimization to address uncertainties and reformulate some nonlinear constraints to make them tractable; the robust solution at optimality can effectively control the effects of uncertainty. Complementarily, we present a heuristic for solving the capability allocation problem - in most instances, providing an optimal solution in a fraction of the time of the optimization model. This heuristic delivers an advantage to decision-makers; it provides a feasible and near-optimal solution in less than a couple of seconds, even if we only run the construction stage. Both the optimization model and the heuristic can combine with time-dependent models, addressing the capability life-cycle behavior once implemented, exhibiting its flexibility. Finally, we present two applications of this formulation, in contexts different from the defense sector, to test its flexibility and significance. We obtained an effective formulation, letting decision-makers plan the organizational design, not only from a qualitative perspective, but also by estimating quantitative behaviors - especially important for emergency and first-response organizations, service providers prohibited from exhibiting a lack of capabilities because of their relevance to society.

2 - Mini-Tutorial : Strategic Analytics for National Defense and International Security
Greg Parlier

This hour long tutorial focuses on the future of the Military Operations Research profession. Where do we need to be going? What should we be doing? How can we address, in imaginative and creative ways, persisting and seemingly intractable regional and global security challenges confronting us? Strategic Analytics, the alignment of analytical methods and OR models with the "ends-ways-means" strategy paradigm, is introduced. To fully capitalize on advances in information technologies and rapidly growing analytics opportunities, the complementary power of Operations Research, data sciences, and management innovation will be essential. Foundational building blocks for Strategic Analytics are presented: decision support capabilities, engineering systems, dynamic strategic planning, "engines for innovation", and analytical architectures to encourage and guide transformational endeavors. As illustrative examples, three recent applications of Strategic Analytics to US Army enterprise system challenges are described: defense resource planning, global logistics supply chains for materiel readiness, and recruiting an All-Volunteer Force. Strategic Analytics integrates our intellectual capacity, considerable strategic planning acumen, diverse analytical skills, and brings them all to bear on contemporary security challenges.

OR in Sports I

Cluster: OR in Sports
Invited session
Chair: *Celso Ribeiro*

1 - Organizing Fair Rogaining Competitions
Joonas Pääkkönen, *David Van Bulck*, *Benjamin Jacquet*, *Dries Goossens*

Orienteering is a cross-country running sport where competitors use a map, a compass and navigational skills to visit control points as quickly as possible. In classic orienteering, the number and visiting order of control points (CPs) are given and dictated by the course setter. We discuss a variant of orienteering called rogaining. The main differences of rogaining compared to classic orienteering are that in rogaining each CP is assigned with a score, competitors are allowed to visit the given CPs in the order of their own preference, and there is a time limit that prevents competitors from visiting all control points. Hence, it is important for the competitors to carefully plan which control points they are going to visit and in which order.

In rogaining, competitive performance is measured in the cumulative amount of scores the competitor gathers in a limited amount of time. Therefore, winning a rogaining competition not only requires physical (running) skills but also strategic skills. Indeed, in order to collect the highest cumulative score within the given time limit, the participants not only need to carefully determine the subset of CPs to visit within the given time limit (like in knapsack) but they also need to determine a visiting order (like in TSP).

The set-up described above gives rise to the following problem from the organizers' point of view: how can scores be assigned to a given set of CPs in a fair manner, such that neither physical skills nor strategic skills are overly emphasized? In practice, this typically translates to designing rogaining competitions such that brute physical skills are not overly favored.

To tell whether or not the fairness of score assignments in real-life rogaining events can be improved, we follow a bi-level optimization approach where the outer-layer assigns scores to CPs and the inner-layer simulates a portfolio of pre-defined competitors. The result is a Pareto front of possible CP score assignments with distinct trade-offs between physical and strategic skills.

2 - Revenue Management in a Best-of-n Series in Sports
Shubhabrata Das

In many sporting contests, the winner between the two competing teams or players is decided on the basis of best-of-n games (with n typically being 3 or 5 or 7), rather than the outcome from a single game. Play-off matches in the NBA and NHL, the world series in baseball, and bilateral series in cricket are some examples, where there are gaps of a few days between the successive games. This is not the routine framework of contests in tennis, badminton, table tennis, and volleyball, where the games are held consecutively, without any substantive breaks in between.

In either scenario, whenever such a format is adopted, different games have possibly differential importance in the context of deciding the series. To objectively determine this, we obtain analytical expressions for the three probabilities - the game being the decider, the game taking place and the winner of the game eventually winning the series. The corresponding conditional probabilities, given the outcomes of the previous games, are also calculated, to facilitate dynamic adaptation.

We subsequently incorporate them in our modeling framework, used in the context of revenue management from the series. The framework can be different in various situations. In a simple set up, we consider revenue maximization under suitable constraints. In alternative situations, where demand is largely inelastic, we bring in alternative optimization frameworks.

In the first set of examples, with longer gaps between successive games, we consider dynamic pricing of tickets, with a different possible objective and framework. In contrast, for the second set of examples, where games are held consecutively, this is proposed for dynamic and adaptable advertisement rates.

3 - Alternative approaches to game scheduling of multiple round-robin tournament: Korea professional soccer league (K league 1) in focus
Ko Daegon, *Taeho Kim*, *Beom-Jin Kim*

This study evaluates the following: (1) the quality of the current schedule of a professional soccer league, K League 1 (Korea Professional Soccer League), regarded as the top league of Asian professional soccer leagues and (2) some different characteristics from European leagues regarding aspects of the possibility of an odd number of games between some pairs of teams and the final 5 round games in two separate groups dependent on the performance in previous rounds, based on the total travel distance of teams to play all games scheduled, match fairness, and attendance fairness. Match fairness implies each team should have the opportunity to play against other teams under similar performance conditions; teams can be under different performance conditions during a long season because of several reasons, such as injuries and the level of team spirit. Attendance fairness includes the number of minimum and maximum home series in a round, the number of consecutive home or away series, and the minimum and maximum number of weekend home series of each team. Alternatives prioritizing the minimization of the total travel distance and satisfying other factors are presented. The requirements of soccer league game scheduling differ in certain aspects from those of other sports leagues like baseball league. Moreover, minimization results are compared with the 2023 real schedule of the K League 1 and the schedules generated by a couple of tournament scheduling approaches, such as the English Tournament Scheduling approach, where teams play with other teams in the reverse order in the previous round, and Monte-Carlo based scheduling. Although numerous studies have examined the sports scheduling problem, this study develops a new integer programming model for soccer leagues, applies an existing problem-specific heuristic, and applies this to the K League 1 - the focus of this study. Using quantitative methodologies to analyze the source of match generation and adjustment problems demonstrates there is ample room for improvement in soccer game scheduling, in terms of enhancing the aforementioned factors.

4 - Dynamic scheduling of e-sports tournaments
Celso Ribeiro, *Zhilong Dong*, *Fengmin Xu*, *Ailec Zamora*, *Yujie Ma*, *Kui Jing*

Electronic sports tournaments are well adapted to dynamic scheduling. A dynamic approach for scheduling e-sports tournaments based on a modification of the Swiss-system design is proposed, using Colley's method to update all competitors' ratings at every round. The ratings are used for maximizing game fairness and viewers' utility in the integer programming formulation of the team pairing and game scheduling problem solved at each round. The approach was validated using real-life data from the 2020 Honor of Kings World Champion Cup group stage and further evaluated using randomly generated test problems with up to 80 competitors, illustrating the approach's applicability.

OR in Sports II

Cluster: OR in Sports
Invited session
Chair: *Frits Spieksma*

1 - Recommending player signings to football teams: A data-driven optimization approach
Pedro Hamacher, *Silvio Hamacher*

Football teams spend billions of dollars yearly signing new players to improve their squad and to fill identified areas of need. Despite having available complete statistics from players all around the globe, teams often do not use this data at its total capacity to identify potential signings. Looking to fill this void, this work develops and makes

available online, using real-world data from top leagues, an optimization tool helping teams (looking to sign new players) by suggesting the ideal signings fulfilling their specific needs - giving them a competitive edge.

To find answers to these questions, a data-driven optimization approach was implemented. Data was collected from fbref.com, including 147 different per-game statistics from 2665 players from the top 5 European leagues during the 2021-2022 season, totaling 98 clubs potentially signing each other's players. Each player's market value at the end of the referred season was collected from Transfermarkt. Aggregating this data, we can get a broad picture of the performance of the top players in soccer and the capital needed to sign them.

Multiple Mixed-Integer Linear Programming models were devised using this data to indicate to teams the players they should hire, given their needs; they include finding the minimum cost necessary to build a team in the top percentile in presented statistics; finding the adequate players a team needs to sign to improve in some determined criterion; minimizing the team's distance to the top clubs in some statistics, given budget constraints; and minimizing the cost while staying in a top percentile, in as many of the selected statistics as possible.

Alongside the mathematical models, a web application was developed and made available as a decision support tool for teams looking to sign new players cost-effectively. This allows anyone to access the framework online and find the model's player recommendations for an arbitrary criterion, maximizing some statistics they feel are needed on a team under budget constraints or minimizing the team's investment, while guaranteeing top performance in selected areas of the game.

2 - Formula One Constructor Team Performance
Elmer Sterken

Formula One race performance is determined by the skills of the driver, the nature of the circuits, weather conditions and the knowledge and abilities of the Constructor Teams. Focusing on the contribution of the mix of 'the driver and the car' to success, there is an informal 20-80-rule. Phillips (2014 and Van Kesteren and Bergkamp (2022), using sophisticated statistical (Bayesian) models, estimate 'only' 14% of ultimate performance is attributed to the driver. In this paper, we analyse the (86% explanation) performance of Constructor Teams in Formula One racing events in detail in the years 2017-2022. A Formula One Team consists of two drivers, using the cars provided by, and trained and coached by, the Constructor Teams. The FIA awards not only the individual World Drivers' Championship, but also the World Constructors' Championship standing.

Given the latent and slowly changing nature of Constructor Team performance, we develop a rating method based on the Elo rating in Chess. The Elo rating system assumes an unknown quality/performance of the player, while match results update the measurement of quality. We use the results of 123 races of six rather homogeneous seasons (2017-2022) with ten Constructor Teams. For each Constructor Team, we measure team performance, including an indicator based on success of both drivers and one based on the success of the best driver of the team comparative. We use variables to indicate race performance: either via two-team competitive outcomes or via final ranking results and/or FIA-points obtained, and we discuss the impact of Constructor Team performance in qualification on ultimate race success. We analyse whether the Elo ratings reflect relative performance in the World Constructors' Championship. As an example of the use of the Elo-based performance ratings, we model the performance of the two star-drivers in the 2017-2022 sample: Lewis Hamilton and Max Verstappen.

3 - How to Design a Stable Serial Knockout Competition
Frits Spieksma, *Roel Lambers*, *Rudi Pendavingh*

We investigate a new tournament format consisting of a series of individual knockout tournaments; we call this new format a Serial Knockout Competition (SKC), recently adopted by the Professional Darts Corporation. Depending on the seedings of the players used for each of the knockout tournaments, players can meet in the various rounds (e.g. first round, second round, up to semi-final, final) of the knockout tournaments. Following a fairness principle of treating all players equally, we identify an attractive property of an SKC: each pair of players should potentially meet equally often in each of the rounds of the SKC. If the seedings allow this property to indeed be present, we call the resulting SKC stable. We show how to formalize this notion, and we address the question: do there exist seedings for each of the knockout tournaments so the resulting SKC is stable? We show, using a connection to the Fano plane, the answer is yes for 8 players. We show how to generalize this to any number of players with a power of 2, and we provide stable schedules for competitions of 16 and 32 players.

Bayesian Models for Football Analytics

Cluster: OR in Sports
Invited session
Chair: *Denis Saure*
Chair: *Mario Guajardo*

1 - Bayesian Models for Scouting and Multi-Season Squad Planning
Pablo Galaz

Professional football clubs seek to obtain the best possible performance in all competitions in which they participate; the Sport Manager must assemble, maintain and update a competitive squad at all times by negotiating contracts with incumbent and new players in the transfer market. A common strategy, adopted by the best clubs in the world, is to hire the best players within their reach, to improve the overall quality of their squad. Regrettably, this strategy is not feasible for every club, because of various constraints, e.g. budget and economic fairness rules. The problem of maintaining the best possible squad is complex, due to the many decisions regarding arrivals and departures of players required at the beginning of each season.

In this work, we formulate a framework for multi-season squad planning supporting the Sport Manager and the club in making decisions regarding the contracts of incumbent and new players, to improve the quality of the squad at all times while considering budget and other constraints. We estimate the performance of various squad configurations, and we use an analytical approach with event data from professional football to model match dynamics considering player-level interactions, to predict the development of a match.

The underlying model visualizes the development of a match as a discrete-time Markov Chain, whose transition probabilities depend on parameters, regarding the cognitive-perceptual and technical characteristics of the players. The approach enables measuring the influence of individual players on the collective performance of a team and can also be applied, for example, to guiding a team's scouting process. We use a Bayesian inference approach to estimate the Markov Chain parameters, using data from 5 European leagues. Using the above, we formulate the problem of defining a squad management policy using mixed-integer programming.

2 - Detection of playing styles in professional football through Bayesian Inference
Constanza Encina

Football analysis covers a wide range of techniques and applications, including player tracking, performance analysis, optimization of game strategies and scouting. In regards to scouting, professional clubs seek to bring in new players who can contribute to their game strategy for the new season. Currently, they bring in players who were successful at other clubs, without necessarily taking into account the difference between playing styles of the respective teams. This raises the difficult task of integrating them into the team dynamics and adapting them to the game plan.

These new signings must adapt as quickly as possible, so they perform at the same level as in their previous clubs or, even better, they attain superior performances. The objective of this research is to detect team playing styles, to identify similar ones and to improve adaptation of the new player.

To achieve this, an unsupervised classification method is proposed - in particular, a bayesian inference model, to provide a probabilistic

framework for relationships between metrics of performance of each team and the playing styles. It incorporates prior knowledge about the data and adjusts the model accordingly, leading to more accurate and robust results.

The project uses InStat data from the 2021 championship of the Chilean first division. The variables considered describe in aggregate form what happened on the field at the match and team level, such as defensive disputes, offensive disputes, passes and shots on goal.

The proposed Bayesian model estimates the probability distribution of the parameters "playing style" and "types of team", given data. This allows us, through an analysis of the results, to declare certain "playing styles" and the teams belonging to each one, with a certain probability. Subsequently, a sensitivity analysis will be carried out to better adjust the model and define parameters, such as how many clusters are to be obtained, how many performance variables should be considered in the data, and, more importantly, the specific variables.

This model could potentially be extrapolated to many leagues, from many countries and in different team sports, to obtain more accurate results, to facilitate adaptation efficiency of a player into a new team or to analyze a rival team's playing style.

3 - Optimizing Soccer Tournament Attractiveness Through Benders Decomposition and Dynamic Scheduling
Alejandro Cataldo, *Antoine Sauré*, *Pablo A. Rey*, *Gustavo Angulo*

This paper presents an approach based on mathematical models to determine the attractiveness of a soccer tournament, taking into account all possible positions teams can achieve in future dates. Additionally, a method is proposed to build a dynamic schedule maximizing the tournament's attractiveness. The approach is based on Benders decomposition and is used to optimize the scheduling of matches date by date. Experimental results are presented demonstrating the effectiveness of the proposed method in terms of attractiveness and balance of the tournament. The proposed method can be a valuable tool for soccer tournament organizers and other sports events to maximize the attractiveness of the audience and improve the competitiveness of the tournament.

4 - A mathematical model for football results prediction in the World Cup Qatar '22
Guillermo Durán, *Alejandro AIvarez*, *Alejandro Cataldo*, *Manuel Duran*, *Ivan Monardo*, *Pablo A. Rey*, *Denis Saure*

Sports results prediction using mathematical models is of great interest not only to sports team managers, coaches and players, but also fans and bettors. Various methodologies have been applied in recent years to design these models. This presentation reports on work done through a football prediction website at the University of Buenos Aires, whose address is 301060.exactas.uba.ar, in homage to Diego Maradona (the number in the URL being the late Argentine footballer's date of birth). The model underlying the site is a variation on a predictive model devised by Dixon and Coles in 1997, assuming goal-scoring follows a Poisson distribution. Our version includes home-away factors specific to each team, rather than general ones, as in the Dixon and Coles approach. In our view, this is more realistic than specifying them without distinctions by team. This reformulation, previously employed to predict the outcomes of the 2018 World Cup, the South American qualifiers for the last two World Cups, the 2019 and 2021 editions of the Copa America, and the most recent Argentine football seasons, was used again for the Qatar World Cup in 2022. Evaluations using various metrics for real games and tournaments have demonstrated our model is a good predictor of real game outcomes.This presentation will include some of the results on the teams the model favoured to win the 2022 World Cup and the predicted ordering—Brazil, followed by Argentina (the actual winner) and France (the actual runner up). We will also present the model's predictions for the tournament's individual matches and some comparisons between its predictions and those of various betting websites. In addition, some extensions of the approach implemented in our model to basketball and rugby will be discussed. Finally, the coverage garnered by our model in the media has proved to be an effective way of promoting interest among the general public in the use of mathematical and computational models for solving real-world problems.

On Sustainability

Cluster: Packing and Routing
Invited session
Chair: *Trevor Hale*

1 - A simple heuristic for the design of economically sustainable biogas plant networks
Jaime Bustos Gómez, *Renato Casas*

The establishment of economically sustainable biogas plant networks for the generation of electrical energy was investigated. Dairy cows have a huge impact on the environment when their manure is not treated, so biogas technology appears as a possible answer. The magnitude of this contribution and the economic viability of its implementation have not been sufficiently addressed in the literature, however, since they depend on the particular characteristics of each country, the geographical location of this waste, energy markets, and associated policies and laws. Based on the information on the cost of plants and biogas energy found in the literature, together with data on the location and number of dairy cows from farms in southern Chile, economic analyses were carried out to establish their NPV. This function is nonlinear since the efficiency of the reactor increases with the amount of biomass available, implying the common assumption (it is optimal to assign each property to its closest plant) is not always true. Considering a set I of potential locations for biogas plants and the set J of farms potentially supplying the network, a configuration is defined as a set of indices of farms P (subset of J) supplying a selected biogas plant. Potentially I = J, i.e., any farms in J can house a plant. A Combination is defined as a set of configurations. If a combination does not present collisions (i.e., there are no farms associated with different plants), it is considered feasible. A simple search heuristic is developed starting with a population of combinations of one plant and generates new iterations by inserting additional biogas plants whenever the NPV increases. At each iteration, only a diverse subset of the combinations is selected. This approach is compared to the application of the ArcGIS Network Analyst (NA) function for the set covering problem, commonly used in the literature for biogas plant network location problems. Using the technical parameters for the operation of biogas plants found in the literature, the proposed methodology provides better results than the NA algorithm in terms of economic benefit. Therefore, it can be used as a suitable tool for the design of profitable biogas networks. In the future, ad-hoc metaheuristics could be developed for this problem.

2 - A model of the very long-term evolution of the city
Francisco Martínez-Concha, *Ricardo de la Paz Guala*, *Daniel Martinez*

This work reports the first attempt to simulate the evolution of cities in the very long term (about 300 years), designed as a research platform allowing analysis of different paths a city may take, according to the agents' perceptions of agglomeration economies and transportation accessibility, extracting lessons regarding the quality of life, productivity, and sustainability of the environment under different policy scenarios. We present the Very Long-Term Land Use and Transportation (VLT-LUT) model and report preliminary results of the evolution of a fictitious city, simulated in a symmetric, flat, and homogenous plain, initialized with population and firms distributed homogeneously. The city dynamic depends on an exogenous population growth pulse, while keeping memory of the past built infrastructure.

The model runs hands-off integrating the following processes: - Demographic and firmographic econometric models, where the modeler sets the pace of total population growth over time steps, describe the number of residential agents by socioeconomic group and non-residential agents by industry. - CUBE-LAND random equilibrium bid-rent model, calculates the allocation of all agents, the supply of real estates and its rents, in a grid of zones. - Generation and trip distribution entropy model, generates trips between the pair of zones. -

Markovian Traffic Equilibrium model, computes the expected minimum travel times of each arc and trip. - City border model, defines the evolution of the zones of the grid becoming urban over time.

We developed a solution algorithm and, from its computational implementation, we highlight the following results for an artificial city (a 20x20 grid of square zones of 25 km2 each): - Symmetrical initial distributions of agents and road network yield a symmetric city. - Segregation between different activities follows the perception of agglomeration economies. - The structure of transportation network strongly affects the long term urban structure. - Rents scale with population non-linearly, but are affected by agents' perceptions on economies of agglomeration and by the transport network. Additionally, a set of indicators are defined and computed to analyze the city's evolution. This software allows the study of the long-term impact of policy scenarios in real and fictitious-lab cities.

3 - Qualitative modeling approach for addressing uncertainty in Sustainable Development
Tatiana Merino, *Luis Antonio Bojórquez-Tapia*

This study addresses the challenges of conflict and uncertainty in environmental planning, hindering the achievement of sustainable development. Decision-makers often neglect the thresholds where socio-ecological systems become vulnerable, leading to undesirable long-term effects. In addition, multi-sectoral decision-making, involving conflicting interpretations, further complicates the planning process. We propose a methodological framework incorporating qualitative modeling of system dynamics and decision-making under deep uncertainty (DMDU) in transdisciplinary processes of co-production of knowledge. We applied this framework in the forecasting stage of the Ecological Ordinance of Yucatán, Mexico, one of the legal instruments used in environmental planning in Mexico. Results involve the detection of ecological risk thresholds for the development of early warning indicators and the technical-scientific motivation of ecological regulation guidelines, strategies, and criteria. The framework allows decision-makers to make more informed and sustainable decisions, minimizing environmental conflicts and contributing to the overall well-being of the Yucatan territory. We emphasize the importance of incorporating uncertainty into sustainability analytics and modeling, providing effective tools to navigate complex and uncertain environments.

4 - Sustainable closed-loop supply chain network design and fleet planning under various carbon policies
Grigory Pishchulov, *Sushant Kumar*

A recent development in sustainable supply chain management research involves convergence of two streams of work traditionally addressing supply chain network design from two perspectives: product re-use and reduction of carbon emissions. Several modeling approaches in the literature establish an optimal design of a closed-loop supply chain network, while considering various carbon regulations. We develop a unified framework integrating practical features often disregarded in the related work, such as co-location of facilities, fleet composition, and accurate carbon emission accounting based on the load factor of the vehicle. The framework comprises five decision models, incorporating five carbon regulation policies: carbon tax, carbon cap, carbon cap-and-trade, carbon tax-and-penalty, and a novel incremental carbon tax policy. Using a data set combining real and simulated data, we employ the proposed framework to conduct a numerical study of network design for a hypothetical garment supply chain in India and investigate the impact of regulatory policies on strategic and tactical decisions, resulting costs and emissions across the supply chain. The novel incremental carbon tax policy has the potential to reduce the emissions significantly, at various tax levels, in comparison to the carbon tax policy. Further, our findings indicate ineffectiveness of the carbon tax and tax-and-penalty policies at prevailing rates and effectiveness of the carbon cap policy, albeit impractical for implementation. Therefore, we recommend the novel incremental carbon tax policy as a substitute for existing policies.

5 - A set cover location approach to the burning number of a graph: The contagion number
Trevor Hale

We define a variant of the well-known graph-theoretic burning number (BN) metric we coin the "contagion number" (CN). This effort proffers a novel set cover location methodology to solve for the CN of any tree in polynomial time; we then delineate the optimality conditions for the associated BN problem. We test our method on some randomly generated scale-free graphs, and our findings indicate the CN to be a robust, tractable (the BN is known to be NP-hard even for tree graphs) and effective metric for decision-makers. Our contributions advance disease/information/alarm spread understanding, list solvable cases of the BN, and reveal the importance of the underlying network structure.

Packing and Routing

Cluster: Packing and Routing
Invited session
Chair: *Aldo Vecchietti*

1 - Modeling and solving an electric vehicle routing problem integrated with V2G operation planning
Luis Fernando Rodriguez, *Caio dos Santos*, *Washington Oliveira*, *Christiano Lyra*

The reintroduction of electric vehicles (EVs), a sustainable solution for the mobility of passengers and freight, offers an efficient alternative to address fuel shortages and climate change. With the increase in the EV fleet, challenges are emerging in the planning stage - for example, identifying the impacts of installing charging stations (CS) on power systems and electrifying the entire fleet in the logistics and freight transport sectors. From a power system perspective, EVs introduce new expansion planning challenges (for instance, reinforcement of circuits), business opportunities (car-sharing and EV charging services), and flexible alternatives for the operation and maintenance of the network - the vehicle-to-grid, V2G.

Faced with the correlation between the challenges of both systems, a widespread investigation was dedicated to the definition of the EV charging operation associated with the EV routing problem, verifying the literature about it is incipient, making it an open research area in operation research. This paper aims to integrate the EV routing problem with V2G, with a mathematical model and solution methods explored. The model extends the usual vehicle routing problem for EVs, where a set of customers must be visited to meet the customer demand, and an additional set of CS can be visited to perform an optional recharge operation. The customer visits occur in mandatory time windows, while the recharge operations occur according to the battery level to complete the EV routes.

The V2G technology provides flexible alternatives for network operation, with the stored energy in the EV battery exported to reduce losses and control voltage magnitudes. The model minimizes the overall costs based on traveling time, while considering the operational constraints of the network. The main aspect of this contribution is determining EV routes with time windows balancing the energy bidirectionally between the grid and EV, contributing to maintaining a safe operation and reducing operation costs. The studies certify the benefits of the proposed approaches in the EV routing problem by providing ancillary services to the network; preliminary experiments demonstrate the quality of the solution methods in achieving feasible solutions.

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2 - Holistic approach for aircraft trajectory optimization using optimal control
Hasnae Kasmi, *Serge Laporte*, *Marcel Mongeau*, *Andrija Vidosavljevic*

At Airbus, we are committed to leading the decarbonisation of the aerospace sector, including reducing the CO2 emissions of our aircraft, as well as our industrial environmental footprint. Our commitment includes actively contributing to meeting key industry-wide environmental performance targets. In this context, this study proposes an optimal control approach for commercial aircraft trajectory planning by minimization of the fuel burned and focusing on the vertical profile. The main contribution is an optimization model related to the whole trajectory (mission) without prior separation into different flight phases (climb, cruise, and descent), contrary to traditional approaches considering the flight phases sequentially. The proposed optimal control problem (OCP) is formulated and solved using a direct collocation method. Initial results yield optimal trajectories featuring a gradual ascent during the cruise phase. This result corresponds to the theoretical fuel consumption minimum of the vertical profile. Then, a penalization is introduced to ensure vertical profiles featuring horizontal cruise levels on so-called flight levels, compliant with current Air Traffic Management (ATM) regulations. To become even closer to real flight operations, we further generalize the application of our approach to situations involving a horizontal wind field. The use of direct methods to address these OCPs induce large-scale non-linear optimization problems we solve using interior point methods. This methodology leads to local optima, likely to have poor objective-function values, but embedding it into a simple multi-start heuristic shows this is not the case. Our approach is suitable for commercial aircraft flight planning purposes; it leads not only to economical savings, but also to important improvements with respect to environmental impact by reducing CO2 emission.

3 - An optimization model for solving a simultaneous problem of production planning and delivery logistic with limited stock storage

Aldo Vecchietti, *Yanina Fumero*, *Gabriela Corsano*, *Jorge Marcelo Montagna*

Operations Research (OR) is an analytical method based on mathematics, applied to a wide range of real-life problems, to support decision-making. One active research area is the application of OR models to solve production operations, such as planning, scheduling and logistics, in complex production environments (highly combinatorial), where reaching an optimal solution is very difficult. Given the complexity of these problems, it is common to find solutions dealing with just one operation, even when better solutions could be obtained solving a model covering different problems, simultaneously. In this work, two operational problems, production planning and logistics, are solved at the same time, since the products produced in a day must be delivered; there is limited space to store them given the large volume of the products. The production environment consists of four lines - each one for a particular product family, produced in two work shifts; each line has a different set of products with diverse characteristics and models. Each production section has a limited amount of space to keep products (around 10% of the production can be stored for the next day); therefore, most of the production (90 %) must be delivered to customers on the same production day. Product transportation is made by trucks, and its cost is expensive; for this reason, trucks must be loaded above a certain percentage, more than 80% of truck capacity. There are two customer categories - those where all the products requested in an order must be delivered and those who will receive an incomplete order. The problem belongs to a medium-size company, with several hundreds of customers located in various cities, some of them far away from the production facilities; the delivery of the orders is not trivial. To solve the problem, a mixed-integer linear program (MILP) is formulated. Due to the problem size and its combinatorial nature, several assumptions have been made to reach a solution in reasonable CPU times, among them, delivery routes connecting several customers are proposed considering the ones most often used. According to the customer's order, its characteristics and the routes connecting them, the model decides the orders to be produced in each shift, the product to keep for the next day and the routes to use for delivery. The objective function is production maximization.

Plenary Address - Juan Carlos Muñoz

Cluster: Plenary Talks
Plenary session
Chair: *Jorge Vera*

1 - From Academia to Politics: A Vision for Addressing Urban Transport Sustainability Based on Lessons from Santiago's Transport System

Juan Carlos Muñoz

The author was appointed as Minister of Transport and Telecommunications after 25 years of professorship in Transport Engineering. The talk will address his approach towards urban transport sustainability. The talk will mainly focus on Santiago's transport system evolution, identifying some of its strengths and weaknesses, and linking to contributions that have come from academia.

EURO Plenary Address - Paolo Toth

Cluster: Plenary Talks
Plenary session
Chair: *Anita Schöbel*

1 - EURO Plenary: Metaheuristic Algorithms for Location-Routing Problems

Paolo Toth

We will consider the family of optimization problems including both "location" and "routing" aspects. After a description of the main characteristics of the "routing problems" and of the "location problems", three problems will be addressed in more detail: the Generalized Traveling Salesman Problem (GTSP), the Capacitated Location-Routing Problem (CLRP), and the Latency Location Routing Problem (LLRP). The Generalized Traveling Salesman Problem (GTSP) is a generalization of the well-known Traveling Salesman Problem (TSP) in which the set of nodes is partitioned into clusters. In the GTSP the aim is to find a minimum-cost simple cycle visiting exactly one node for each cluster. The GTSP is NP-hard, since it generalizes the TSP. In the Capacitated Location-Routing Problem (CLRP), we are given a set of available depots (each depot is located at a node of a network, and has an associated cost, a capacity and a set of identical vehicles stationed at the depot) and a set of customers (each customer is located at a node of the network and has a positive demand). All the demands of the customers must be satisfied through a set of routes (each route starts from a depot, visits a subset of customers whose global demand must not exceed the capacity of the associated vehicle, and returns to the starting depot). In addition, each customer must be visited by exactly one route, and the global demand of the customers visited by the vehicles associated with a depot must not exceed the capacity of the depot. The aim of the CLRP is to determine the subset of depots to be opened, the customers to be assigned to each open depot, and the routes to be performed to satisfy the demands of the customers. The objective is to minimize the sum of the global cost of the open depots, of the global cost of the used vehicles, and of the global traveling cost associated with the performed routes. The CLRP is NP-hard since it generalizes two well-known NP-hard problems: the Capacitated Facility Location Problem (CFLP) and the Multi Depot Vehicle Routing Problem (MDVRP). The Latency Location Routing Problem (LLRP) is a variant of the CLRP where the objective is the minimization of the sum of the arrival times at the customers (latency or cumulative cost), instead of the minimization of the sum of the traveling costs associated with the performed routes. In addition, no costs are considered for the opening of the depots and the utilization of the vehicles, and no constraints are imposed on the capacities of the depots. This problem is appropriate for modeling customer-centric systems, in which customer satisfaction is more important than economic issues. The LLRP is NP-hard since it generalizes two well-known NP-hard problems: the Facility Location Problem (FLP) and the Cumulative Capacitated Vehicle Routing Problem (CCVRP). The most effective metaheuristic algorithms proposed

for the solution of the GTSP, of the CLRP and of the LLRP will be described and experimentally compared on the benchmark instances from the literature, by taking into account both the quality of the solutions found and the CPU times required to obtain the solutions.

Plenary Address - Margaret Brandeau

Cluster: Plenary Talks
Plenary session
Chair: *Alice Smith*

1 - Advancing Analytics for Better Health and a Better World
Margaret L. Brandeau

All countries, whether resource-limited or high income, face pressing public health problems in many areas. For example, how can outbreaks of COVID-19 and other diseases be better predicted? How should scarce vaccines for communicable diseases be allocated? What is the best way to detect cases of drug-resistant tuberculosis? Should investment be made in diversion programs for low-level drug offenders? What policies would be most effective for controlling the US opioid epidemic? What would be the health impact of reducing homelessness in the US? What impact will climate change have on crop nutrition globally, and how can that impact be mitigated? This talk describes models to support decision-making regarding these and other public health and social problems and illustrates the role operations research and data analytics can play in informing good decisions. We conclude with a discussion of key areas for further research.

Plenary Address - Andres Weintraub

Cluster: Plenary Talks
Plenary session
Chair: *Rafael Epstein*

1 - How OR has Impacted Decisions in Natural Resources
Andrés Weintraub

OR has been very successful in supporting managerial decisions in several areas of natural resources. This talk will mostly present work we have carried out applying OR and Analytics in multiple problems in forest decision making. This considers problems on how to best harvest forests, including locating harvesting machinery and roads, spatial aspects related to environmental issues, uncertainties due to market conditions and how to integrate supply chains. These problems have led to difficult-to-solve models. Techniques used include LP, MIP, Heuristics and Meta-Heuristics ,Simulation, Stochastic Programming. In most cases, we can show the advantages of using these techniques, and discuss where they have been successfully implemented and why not in other cases. Our latest work is in fuel management related to forest fires, that is, how to manage a forest (developing fire breaks and areas treated so fire can be stopped) so that when fires break out, damage can be minimized. The damage is measured in risks to human lives, property losses, carbon emissions and damage to wildlife. We are developing techniques based on developing large data sets, machine learning and stochastic simulation to interact with optimization techniques to support these decisions. We will also show successful models to support decisions in mining extraction and salmon farming.

Supply Chain Management II

Cluster: Production Management, Supply Chain Management, and Location
Invited session
Chair: *Martin Grunow*
Chair: *Fidel Torres*

1 - Comparison between wholesale price selection schemes to improve the efficiency of a supply chain under exponential price elasticity and supplier cost asymmetry
Fidel Torres

Two wholesale price selection schemes in a supply chain have been previously studied in the literature: Uniform Price Model (UPM) and Specific Price Model (SPM); we analyze these models in the context of a supply chain made up of a dominant supplier and two retailers. Both models are studied under assumptions not treated previously in the literature: (a) a non-linear exponential model of elasticity of demand and (b) asymmetric costs of the supplier toward its retailers. Consistent with previous studies, we found the following: 1) the supplier prefers SPM; and (2) the retailer, requiring fewer variable costs from the supplier, also prefers SPM. Comparing supply chain gains, we present a new result - SPM is also the best scheme; it allows the retailer, requiring fewer variable costs from the supplier, to also benefit from a lower wholesale price. Consequently, the retailer can offer a lower selling price to its customers and, therefore, gain more market share. As the retailer requiring more costs from the supplier prefers UPM, a new win-win negotiation contract is proposed in line with previous works, where each retailer obtains its profits according to its preferred model. At the same time, the new contract allows the dominant supplier to earn higher profits than it would under SPM. For this contract, the supply chain also obtains the best possible efficiency, according to the ideal model of an integrated supply chain.

2 - A gentle path towards stochastic optimization for strategic capacity management in the medical devices industry
Braulio Brunaud, *Haokun Yang*, *Elbio Avanzini*, *Nelson Torres*, *Burcu Kose*, *Andrew Keyes*

Stochastic Optimization has been identified as one the most relevant techniques to achieve resilient strategic decisions. However, its implementation in practice is too complex, with challenges in describing uncertainty and explaining the optimization outcomes. In this work we describe the path towards the adoption of optimization under uncertainty for the medical devices supply chain from uncertainty description and scenario analysis to stochastic optimization, to ensure adoption by decision-makers. The supply chain studied comprises distributors and health-care providers, whilst considering more than 100 suppliers and around 3200 components. The suppliers have shared capacity, so anticipating capital investment is fundamental for fulfilling material flow for the links of the chain. The objective of this strategic planning is to make timely recommendations on manufacturing capacity expansions for both finished goods, and components, to attend demand and meet inventory targets while keeping costs under control and efficiently utilize capacity. Uncertainty in finished goods demand is considered with a Monte Carlo simulation using parameters that are simple to understand such as market potential changes and adoption rate of new products launched. The forecast simulation based on the Bass diffusion model for new product growth allows the business to explore the uncertainty space in familiar terms. A mixed-integer programming model is proposed to identify the optimal investment strategy for sampled cuts of the forecast simulations, that helps trading off investments in capital with strategic inventory prebuilds. The optimization model is also used to evaluate each potential plan to assess the robustness of each proposal under the full range of uncertainty. For each potential plan, a set of risk metrics is computed to give more insights to decision-makers. The risk metrics considered include key supply chain descriptors like idle capacity, missed sales, effective capacity utilization, among others. Finally, non-anticipativity constraints

are added in the same schema to implement a 2-stage stochastic solution. The layering nature of the developments performed allows business decision-makers to achieve a successful implementation of a decision support system under uncertainty, resulting in more than 20% cost savings and very high acceptance with supply chain leaders.

3 - Application of a Grey Markov GM (1, 1) model for demand forecasting in the supply chain
Francisco Trejo, *Rafael Torres Escobar*

As obtainable information is usually limited and falls under the category of uncertainty circumstances, a variety of uncertainty system theories, such as fuzzy sets (FS), rough sets (RS) and grey system theory (GST), has emerged, conforming to the requirements of the new era. The GST is a multi-disciplinary theory for systems lacking information. GST is a novel system theory mainly focusing on analyzing and modelling problems with limited data or poor information (Xie, 2017) - one of the characteristics prevailing in the supply chain. Neither all the information nor its reliability is always possible. All these models have solved practical application problems, such as economic forecasting, management decision-making, scientific evaluation, energy management, industrial process control, water resource analysis, risk management and agricultural breeding research (Lin, et al., 2004); none have been applied in the supply chain area. A grey model based on limited data is a new forecasting model for solving prediction problems based on limited valuable sequence data, not always possible when forecasting demand in supply chain. As a result of this investigation, this model can obtain better prediction results, especially for data of small sample sizes (at least 30 records). The paper presents a methodology for incorporating limited or incomplete data into a modified GM (1,1) model applied in the supply chain area. The results obtained exceed other models and methodologies, such as linear regression, moving averages, exponential smoothing, and are applied where ARIMA is impossible. The model also identifies the algorithm to identify when the GM (1,1) is applicable - limited amount of data, stationary is not present, no seasonal or cyclical demand is found, and forecast projections are required for periods >n+1. The evaluation methodology included forecast error, mean absolute error, mean square of error and mean absolute percentage error. The results by using the GM (1,1) are better than the results of the linear regression and moving averages, 2.28% vs 3.97%, respectively, when forecasting warehouse space for a 3PL company.

Cutting and Packing

Cluster: Production Management, Supply Chain Management, and Location
Invited session
Chair: *Jonas Tollenaere*

1 - Multi-objective optimisation of the generalised bin packing problem
Rosephine Georgina Rakotonirainy

In this talk, a multi-objective model of the generalised bin packing problem is presented. Originally, the generalized bin packing problem consists of loading a set of profitable non-compulsory and compulsory items into bins so the total cost, given by the difference between the total cost of the selected bins and the total profit of the loaded items, is a minimum. In this work, the problem is modeled as a multi-objective problem with respect to two conflicting design objectives involving minimization of the number of bins used (or the costs associated to the selected bins) and maximization of the profits of packed items. An evolutionary algorithm is proposed to address the problem, providing a set of solutions offering a range of trade-offs between the two objectives. Extensive numerical investigations are performed on various test instances and the performance of the solution approach is compared with other methods to illustrate its efficiency.

2 - A mathematical programming model for 2D rectangular cutting problems arising in the ornamental stone industry
José Fernando Oliveira, *Maria Antónia Carravilla*, *Rui Guerreiro*, *Fernando Sousa*

In the ornamental stone industry, the cutting of natural stone involves solving a two-dimensional cutting problem. In addition to the usual constraints of cutting and packing problems, the nature of the raw material and the cutting technology impose constraints not found in other industries.

The component of the production process we will address in this presentation is the cutting of stone panels. From a geometrical point of view, these panels are treated as two-dimensional objects, they have an irregular shape, they have defects and, most importantly, they are thick and very heavy, compared to the most commonly treated raw materials in the literature. On the other hand, the cutting is done with a saw and, therefore, the patterns must be guillotineable.

The thickness of the board, together with the cutting technology, produces an effect called overcut, consisting of a cut extending beyond the boundary of the piece being cut. This effect can damage pieces placed on top of the cut, unless there is sufficient separation between the pieces or alignment with another cut in the same direction. Some cutting machines have built-in suction cup technology allowing the half-cut parts to be mechanically removed from the cutting area, so they are not damaged by subsequent orthogonal cuts. This operation consumes two important resources, time and energy, however, and its cost must be balanced against the cost of the waste created by the piece separation in the cutting plane. This constraint has never been explicitly treated in the literature, and it is not trivial to address.

This presentation will focus on the presentation and formal definition of these particular constraints and objectives, illustrated by videos, photographs and real cutting plans from the stone industry. Then, starting from the floating cuts model for two-dimensional guillotine and non-guillotine cutting problems, a mathematical programming model, including constraints and goals related to overcuts, is presented, and the computational results of its application are discussed.

3 - A new fast-fail collision-detection system and guided local search heuristic for 2D irregular cutting and packing problems
Jeroen Gardeyn, *Tony Wauters*

Cutting and packing problems featuring irregular shapes are widespread and occur in a range of contexts, such as laser cutting, 3D printing and garment cutting. Determining whether it is possible to place an item at a certain location is an essential component of the nesting algorithms used to solve these problems; this typically involves ensuring there is no overlap between polygons. Cutting and packing problems with irregular shapes, thus, not only require us to deal with their combinatorial aspect, but also with the complex geometry of the shapes involved. The efficiency and accuracy of collision-detection methods are, therefore, crucial in terms of producing quality solutions within reasonable computation time. In this research, we have developed a new collision-detection approach for irregular cutting and packing problems. Our technique is inspired by concepts used in computer graphics and combines speed, accuracy and robustness; it consists of a two-phase approach, where a broad phase efficiently eliminates as much of the required computational work as possible using inexpensive checks. This initial phase involves performing checks on a quadtree-based datastructure. Afterwards, a narrow phase performs edge-intersection and polygon-inclusion tests; these checks are very precise, but also expensive. On top of this collision-detection technique, we also designed a heuristic to solve the actual optimization problem. While many heuristics in the literature focus heavily on their constructive strategies, our approach instead focuses on incremental improvement. This is achieved by employing a ruin-and-recreate strategy, partially destroying and rebuilding the solution each iteration. We combined this strategy with a guided local search dynamically assigning values to every item. New solutions are accepted if the total value of excluded items is smaller than the previous best solution. These two components together result in a general 2D nesting algorithm, capable

of handling a range of problem features, such as free rotation, irregular-shaped bins, holes and quality zones. Although research remains ongoing, the results produced by our approach are promising. Our results are competitive with the state of the art on traditional nesting benchmarks (simple shapes and very limited rotation) and make significant improvements with respect to Baldacci's leather nesting dataset.

4 - Solving 3D irregular open dimension problems using a triangle mesh collision detection approach
Jonas Tollenaere, *Tony Wauters*

The problem of packing irregular, three-dimensional items efficiently into containers is a common problem in several sectors, such as logistics and additive manufacturing. Despite their relevance, these problems have not been studied as extensively as either their regular counterparts or their two-dimensional equivalents. Nevertheless, several approaches to solve them have been proposed in the literature. Many of these approaches limit the free rotation of the items, however - maybe not a requirement of the desired application; therefore, they needlessly limit the achievable solution quality. For example, techniques like no-fit polyhedra (NFPs) and voxelization methods both provide data structures usable to evaluate the non-overlapping constraint between the items efficiently, but they would have to be recalculated for every new orientation. In this research, we use the triangle mesh representation of the items. Evaluation of the non-overlapping constraints is achieved through collision detection between the meshes. While this can be computationally expensive, techniques like bounding volume hierarchies (BVH) can accelerate this process, greatly. Furthermore, if faster computation is needed, the meshes can also be approximated with lower quality ones having a smaller number of triangles. Items with any arbitrary shape can be robustly handled; it also allows for continuous free rotation of the items through the use of transformation matrices. This makes the approach generally applicable and flexible when designing optimization heuristics. In this work, we focus on open dimension problems specifically, where the objective is to minimize the height of a container, where a given set of irregular items has to be placed. We will investigate if heuristics based on this representation can improve the results of other research in computation time or quality.

Lot Sizing, Lot Scheduling and Production Planning I

Cluster: Production Management, Supply Chain Management, and Location
Invited session
Chair: *Marius Drechsler*

1 - Energy-efficient lot-sizing with intermittent renewable sources
Ruiwen Liao, *Céline Gicquel*

With increasing concern on climate change and global warming, industrial companies, among the largest carbon emitters, are urged to reduce the carbon footprint of their manufacturing processes. Moreover, the sharp increase of energy prices globally put strong pressure on industrial companies, especially those using energy-intensive processes. A potential solution to cope with these two challenges is to build, directly on the manufacturing site, a decentralized energy system involving power generation units using renewable energy sources (solar or wind). The quantity of on-site generated electricity will be highly variable, however, so it will still be necessary to buy electricity at a time-varying price from an external energy source to power the industrial process. As a consequence, the energy cost of a manufacturing site depends not only on the total amount of consumed energy, but also on the timing of this consumption, itself depending on production planning decisions. An integrated production planning and energy supply planning problem should thus be studied. This work focuses on simultaneously planning the industrial operations and energy supply for an industrial plant equipped with a local energy system, including a renewable energy power generation system and an energy storage system. The production planning problem is modeled as a single-machine multi-item lot-sizing problem with time-dependent changeover times and costs. A new modeling approach based on a two-level discretization of the finite planning horizon is proposed. Thus, a first coarse time discretization is used to track the demand satisfaction. A second finer time discretization is introduced to track the energy consumption, generation and trading and to build the industrial production plan. To model the problem as a mixed-integer linear program, we introduce a new extension of a small-bucket lot-sizing model called the Proportional Lot-sizing and Scheduling Problem. This extension involves, among others, sequence-dependent changeover times, overlapping multiple periods and energy-related constraints. The resulting mathematical model enables us to obtain good-quality production and energy supply plans with a computational effort much smaller than the one required by a previously published model based on a large-bucket lot-sizing model.

2 - Aggregate Production Planning with uncertainty in demands considering space allocation
José Emmanuel Gómez-Rocha, *Eva Selene Hernández Gress*, *Cipriano Santos*, *Jaime Mora Vargas*

Aggregate Production Planning (APP) is essential for supply chain design, sales and operations planning; when uncertain parameters exist, stochastic programming can model with deterministic equivalents to solve problems that are hard to solve because of their size. In this study, some procedures are presented for solving aggregate production planning problems without a hiring-firing policy and considering space inventory constraint via a knapsack formulation. The solving method is a Mixed Integer Linear Programming (MILP) solved with Branch-and-Bound and some heuristics in the preprocessing; some bounds are calculated for first stage decision variables - solving the problem with fewer iterations and CPU time. The strategy is compared with the original problem, and a sensitivity analysis was carried out to know the impact of the available area in the model. Results of this study allow us to deal with problems where the size of the deterministic equivalent was more than one million integer decision variables and more than three million constraints in a reasonable number of iterations and CPU time. APP determines at the least cost the number of workers and the production plan to meet demand (Liu and Yang, 2022); this in a finite planning horizon ranging between 3 and 18 months (Yu et al, 2022). The main objective is to meet customer demands efficiently using all the resources available to the organization (Jamalnia et al., 2019). Additionally, it must guarantee the correct and efficient flow, ensuring the product has the desired quality (Khaled et al., 2022). One of the trends for APP in the future is to make it feasible to apply to decision support systems (Cheraghalikani et al., 2019), and the way to achieve it is by combining it with other critical problems in the organization. In this study, we want to contribute to solving real problems in the industry, so a multi-product and multi-period stochastic APP is solved where, in addition to the production plan, the accommodation of inventory in a certain area is proposed. The innovation of this study is to combine the APP with the inventory accommodation problem, which has not been treated in the literature as part of the formulation of the mathematical model; in addition to proposing some bounds in variables, that the problem can be solved through mathematical programming exact methods.

3 - Preventing Accidents on the Shop Floor 'On the Edge' - An Exploration of IIoT Solutions for Improved Safety in Production Environments using Scenario-based Designs
Marlen Rimbeck, *Michael Leyer*, *Alistair Barros*

Due to rapidly evolving and increasingly complex market requirements, manufacturers are implementing more Industrial Internet of Things (IIoT) solutions to enhance the efficiency of their operational processes. Despite the related increase in automation, shop floor workers are still exposed to various safety risks, including handling liquids and toxic chemicals or lifting and carrying heavy materials. IIoT solutions self-perform working activities, provide employees with immediate feedback on their activities/output and transmit real-time data

to central user systems. Accordingly, IIoT solutions are not merely useful for enhanced efficiency with regard to various process parameters, but also for proactively monitoring safety aspects on the shop floor. In contrast to widely used IIoT solutions transmitting data to a central system, decentralized processing and communication between devices offers the potential to increase speed in emergent situations and to adapt to local differences. This not only creates decentralized sub-processes, but also a new way of information distribution, self-organization and control structures, neglected in previous research. Considering the employee perspective through the lens of agency theory, we examine the relationship between employees and IIoT solutions providing 'on the edge' real-time recommendations with regard to security aspects at the local level. Using a scenario-based design, we elaborate on the evolution of the relationship between the different actors and whether, for example, wearables are perceived as a threat or a facilitator. This behavioral perspective is important to understand how to design process and information system architectures running successfully together with employees 'on the edge'. In doing so, we contribute to the literature on business process management in relation to IIoT and, thus, extend existing technical approaches toward the operations management perspective.

4 - Procurement and production planning for horticulture with consideration of short-term re-order options
Marius Drechsler, *Andreas Holzapfel*

The procurement and production planning of ornamental plants, perennials and cut flowers constitutes a significant challenge for small- and medium-sized enterprises in the horticultural business. Lead and production times of several months, as well as distinctive seasonality and high perishability of the products, have to be considered. Demand is typically volatile and influenced by seasonality, trends, events and the weather. To address these challenges, companies usually distinguish between Own Production or pre- and re-orders. Own Production, as well as pre-orders with several months of lead time prior to the start of the sales season, ensures a basic level of availability and sufficient quality. When making production or pre-order decisions, only rough demand forecasts are available, however, and trends can only be estimated vaguely. Re-orders made during the sales season, in turn, have a lead time of at most a few weeks, providing short-term flexibility to respond to deviations from the estimated demand. In-season re-ordering decisions can be made quite accurately, as up-to-date demand data and weather forecasts are available, but they are subject to fluctuations in price and quality. We present a stochastic procurement and production planning model reflecting these conditions. A MILP approximation is used to determine production/pre-order quantities and estimates for potentially necessary re-orders.

Lot Sizing, Lot Scheduling and Production Planning II

Cluster: Production Management, Supply Chain Management, and Location
Invited session
Chair: *Benjamin Anthouard*

1 - A mathematical programming model for solving the batching, production scheduling and vehicle routing problems in batch industries
Aldana Tibaldo, *Jorge Marcelo Montagna*, *Yanina Fumero*

Since production and distribution are two essential activities in supply chain management, interest in simultaneously solving short-term production and distribution scheduling has increased in recent years. The integration of both problems is very valuable in real-word applications, especially in industries where final products must be delivered to customers shortly after production, such as in the case of perishable or customized products. Despite the above, since production and distribution decisions belong to different departments within a company and both problems are of combinatorial complexity, they are often decoupled. Although this sequential methodology simplifies the problem, it can lead to suboptimal solutions for the integrated problem. Therefore, the development of efficient optimization approaches is a great challenge to the research community. This work presents a novel mixed-integer linear optimization model solving the integrated short-term batching, production and distribution problem in multiproduct batch facilities, with multiple parallel units of different sizes to satisfy customer demand at minimum operating cost. General precedence relationships are used to represent the sequencing of batches in the units; unlike traditional approaches where the sequence of customers visited by each vehicle is a decision of the model, the routing of each vehicle in our approach is represented by a novel strategy only considering the possible routes vehicles can travel. A preprocessing algorithm, based on domain information, is developed to generate the feasible routes. This approach is very valuable for two reasons: infeasible routes are not considered in the problem formulation (reduction of the search space) and several important decisions are made simultaneously when a route is selected, such as the allocation and sequencing of the customers visited in each route, allowing us to achieve a computationally efficient model. The problem consists of determining the number and size of batches processed for each product (batching), their allocation and sequencing in the units, and timing of these batches, as well as selection of routes, allocation of batches to routes, departure time of the vehicle traveling along each route and delivery times to customers. The new model was tested with different cases of study. Medium-large scale problems were solved optimally with good CPU times.

2 - The production-remanufacturing-transportation lot-sizing problem with recovery targets: formulation and solution procedures
Luciana Vidal, *Pedro Piñeyro*, *Omar Viera*

We address the problem of simultaneously determining the production, remanufacturing, and transportation periods and quantities to meet the demand of a single product from a set of customers (retailers), over a finite planning horizon, considering collection and remanufacturing targets and minimizing the sum of the costs involved. Set-up and unit costs are assumed for the activities, as well as unit costs for holding inventory of used and final products at retailers and the producer-remanufacturer. First, we provide a mixed-integer linear programming model for the problem, extending existing formulations in the literature for the economic lot-sizing problem with remanufacturing (ELSR), an NP-hard problem under different cost settings, similar to the one used here. Second, we suggest and evaluate a heuristic procedure to solve the problem, with five steps different variants, based on the Tabu Search metaheuristic, consisting of an initialization phase, followed by an exploration phase. The initialization phase is to determine an initial feasible solution ensuring demand compliance for all retailers, as well as collection and remanufacturing targets. The objective of the exploration phase is to evaluate different feasible solutions (as many as possible) with the hope of achieving a final solution of good quality, i.e., close to optimal. For the first and simplest variant, the exploration phase is based on first swapping the transportation periods, one at a time. For each new transportation plan, the same procedure is used to determine a new remanufacturing plan. The production plan is determined through the Wagner-Whitin algorithm. The second variant was designed to reduce the computational time required by first one in the exploration phase, fixing the transportation plan in the initialization phase. The three remaining variants were defined based on the composition of the previous variants and the exchange of more than one period at a time in the exploration phase, also including other characteristics of the problem. To evaluate the suggested solution procedures, we compare their results with those of a commercial solver, over two sets of instances, with 12 and 24 periods, respectively, defined from instances of the ELSR and similar problems from the literature. According to the results obtained, at least one of the proposed heuristic procedures is effective in cost and/or execution time, even achieving the optimal solution for some of the instances.

3 - An iterative LP-Simulation algorithm for order release based on Lagrangian decomposition
Hubert Missbauer, *Reha Uzsoy*, *Gregor Blossey*

Optimization models for order release planning, determining order releases for a multi-period planning horizon, perform production smoothing over time and cycle time control (by controlling the level of work in process in the manufacturing system) simultaneously. Anticipating the effects of a specified order release schedule on the time-dependent cycle time distribution is the crucial modeling task here. The most advanced modeling technique is the use of allocated clearing functions relating the planned capacity load of a work center in a planning period to the expected or maximum output in the period. Past research has shown these models work reasonably well, but also reveals the extreme difficulty in improving the models beyond today's state. This limitation can be overcome by decomposing the order release problem into a production smoothing subproblem, usually a linear program, determining the order releases for given (possibly time-dependent) lead times, and a cycle time estimation subproblem for given releases, usually solved by discrete-event simulation. The subproblems are solved iteratively until convergence. This procedure can fail to converge, however, and the procedure is a flawed application of mathematical decomposition, most likely explaining its shortcomings. In this presentation, we work out a mathematical decomposition approach based on Lagrangian relaxation starting with an MILP model performing order release and production scheduling simultaneously. We then decompose the model into an order release subproblem and a production scheduling subproblem. Coordination is performed by Lagrangian multipliers acting as prices for capacities and for short cycle/lead times. Preliminary computational results are presented and open questions are discussed. The paper aims to contribute both to the literature on order release planning models and to the integration of mathematical programming and discrete-event simulation.

4 - Timed Route Approaches for Complex Production Planning with Time Constraints
Benjamin Anthouard, *Quentin Christ*, *Stéphane Dauzere-Peres*, *Renaud Roussel*

Semiconductor manufacturing processes are probably the most complex manufacturing processes - characterized by long cycle times and a very large number of operations, requiring hundreds of different machines to process a large volume of wafers in manufacturing facilities, called fabs. Time constraints (TCs) increase the complexity of the management of semiconductor fabs; they are defined between two processing steps (consecutive or not), where a lot must respect a maximum time to ensure the quality of wafers in the lot. Our problem is a multi-product, multi-step, multi-machine production planning problem; each product has a route, i.e., needs to perform a certain sequence of processing steps, and each step has a processing duration, performed by multiple machines. Moreover, TCs must be respected. The goal is to minimize the work in process (WIP), inventory and backlog costs. To solve this problem, mathematical programming methods with fixed lead times can be used. To better model and to use production capacity, however, in particular when dealing with long routes with long cycle times and many processing steps, workload dependent lead times or flexible lead times are much more appropriate. This work focuses on the integration of TCs and practical considerations in tactical production planning, using the notion of Timed Routes and a column generation approach from the literature; a Timed Route (TR) is where every processing step is assigned to a period. We extend this concept to a Machine Timed Route (MTR), where the machine to process each step is also specified. Three models are proposed to integrate time constraints: a fixed lead time model, a TR model and a MTR model. Models have been compared using industrial instances; the MTR model outperforms the fixed lead time model and the TR model, in terms of computational times and solution quality. As expected, TCs have a negative impact on the quality of the optimized production plans as they reduce the capacity to fulfill the demand, and operational problems are observed in tactical plans. This work has multiple perspectives; the initializations of the TR and MTR models can be improved with a better set of initial patterns. Moreover, considering periods of different lengths should be relevant to optimize production plans on long horizons.

Supply Chain Management I

Cluster: Production Management, Supply Chain Management, and Location
Invited session
Chair: *Ana Paula Barbosa-Póvoa*

1 - Control and Enforcement in a Public Sector Direct Delivery Supply Chain, Considering Horizontal Interaction and Supply Disruption
Matan Shnaiderman, *Liron Ben-Baruch*

Our research deals with Direct Vendor Delivery Supply Chains - common in public and government sector organizations and agencies, such as hospitals, universities and public offices. We consider multiple retailers/facilities and the possibility of limited supply available to a supplier, and we consider behavioral operations factors affecting a supply chain member's performance and decisions. Retailers independently order products, receive shipments from a single supplier, and provide products to their internal consumers, without charge. The retailers cannot directly enact sanctions on the supplier and need to persuade the purchasing department's representative to penalize the supplier, due to contract breaches, by investing time in enforcement efforts. We formulate a three-echelon supply chain model consisting of a supplier, multiple heterogeneous (public / government sector) retailers, and their internal consumers. We review different scenarios, featuring supply disruptions (limited supply below a retailer's requirements), different inventory allocation methods, and different attentiveness levels of the organization's purchasing department representative to the retailers' enforcement efforts against the supplier. We show the purchasing department's response to the retailer's enforcement efforts has a direct effect on the service level provided by the supplier to the retailers and on the organization's ability to fulfill its internal consumers' needs. When the supplier has a limited amount of inventory available for retailers, informing the retailers about the expected shortage and the chosen inventory allocation method enables them to prepare for the shortage and set the optimal values in their decision parameters. If the supplier chooses to share the required information with the retailers, they may choose one of the inventory allocation methods covered in the existing literature ("proportional to order quantity" or "uniform" allocation method) to minimize the retailers' enforcement efforts, their potential penalty costs and the retailers' enforcement costs. On the other hand, if the supplier chooses to withhold the information from the retailers, they have to deal with a large amount of enforcement hours, and, therefore, should choose an inventory allocation method taking into account the enforcement policy of each retailer to reduce penalty costs.

2 - Availability and affordability in the design and planning of socially responsible pharmaceutical supply chains
Ana Paula Barbosa-Póvoa

The incorporation of sustainability principles in pharmaceutical supply chain management is a major concern; this poses challenges to the management of supply chains in this sector. Moreover, the social pillar of sustainability is still a critical area requiring further exploration , in particular concerning equitable access to pharmaceutical products. In this set, the Access to Medicine Index (AtMI) emphasizes the importance of ensuring availability and affordability of pharmaceutical products in all countries, especially in those with a higher disease burden and lower capacity to acquire these products. This study aims to address this challenge and presents a multi-objective mixed integer linear programming model to support decision-making at strategic and tactical levels while considering economic, environmental, and social principles. In the economic pillar, an objective function where the Net Present Value (NPV) is maximized is considered. The environmental impact assessment is addressed through the Life Cycle Analysis methodology, where the environmental impact of supply chain activities is minimized. The social assessment focuses on availability and affordability concerns and uses two different approaches: the Disability-Adjusted Life Year (DALY) and the concern of affordability exploring the concept of demand-to-price elasticity. The decision support tool is applied to a case study on the distribution of a vaccine, where different

optimization scenarios are considered and trade-offs among the three pillars of sustainability are discussed. Besides comprehending the impact of strategic and tactical decisions on each sustainability objective and to better understand the performance of the combined indicators, the application of the model also allows to identify improvement opportunities regarding the achievement of more socially responsible pharmaceutical supply chains.

3 - Optimal Process Planning in Co-production Systems
Anand Paul, *Vashkar Ghosh*, *Zhechao Yang*, *Lingjiong Zhu*

We study the production planning challenges involved in co-production systems, motivated by LED manufacturing. The production output in this industry is characterized by a stochastic distribution over the targeted production metric; thus, the whole range of production is unsuitable for a specific application. We formulate a stochastic profit optimization model and determine the optimal production parameter setting and the batch size, analytically. Our analytical model is based on a real-world problem gleaned from interactions with a large semiconductor manufacturer. The optimal policy depends on the characteristics of the underlying production distribution and tolerance level; even when the output production distribution is symmetric, the corresponding symmetric production setting is not necessarily optimal. The optimal process setting depends on the sharpness of the density function of the production output. We complement our analytical results with Monte Carlo simulation and computationally verify the robustness of our analytical results on optimal process settings in an approximate model, derived from the intractable exact model; the optimality gap between the exact model and the approximate model is at most 1 percent. To gain further insights into the interplay between different process settings and performance measures, we make a computational study of an augmented model with service level constraints, to determine batch sizes meeting a target service level. Our simulation results highlight how the percentage yield and batch size are impacted by service level contracts.

4 - Combinatorial Auction Design for Networked Returns: Mitigating Demand Uncertainty and Externalities in Online Retail Marketplaces
Christina Liepold, *Pedro Amorim*, *Maximilian Schiffer*

Online retail marketplaces, such as Zalando or Farfetch, provide advantages for both suppliers and consumers; while suppliers gain an additional retail channel, consumers benefit from large product ranges in a one-stop-shop setting, the convenience of comparing multiple retail goods, and buyer-friendly shipping and return policies. With the success of online retail marketplaces, the amount and impact of retail return shipments, however, have also increased. For example, in the U.S., the percentage of returns among online retail sales increased from 10.6% to 20% in 2020, resulting in high financial and environmental costs. To mitigate these costs, we propose exploiting the distinct characteristics of retail marketplaces, namely the retail platform's knowledge of global customer demand and the interconnections within the network of suppliers selling through the platform. Using a unique dataset of retail marketplace transactions, we examine whether an auction mechanism can mitigate demand uncertainty and environmental externalities by establishing connections between suppliers through networked returns. We design an auction-based setting where suppliers bid on customer-issued returns within the marketplace to increase their welfare, while reducing environmental externalities. Compared to an individual supplier, the platform can globally track where items have been sold and, thus, permanently update estimations about demand distributions. The platform may use this knowledge about geographical demand distributions to redirect returns to suppliers with a higher reselling likelihood. Based on the implementation of networked returns, the suppliers may gain additional welfare by reselling the respective returns. The platform may reduce its environmental impact by decreasing the shipping distance compared to the original return shipments. An auction-based system, where suppliers bid on customer-issued returns, reduces returns' shipping distance by up to 88% and can consequently increase the resell value of returns on average by 5%. Overall, the auction-based setting for networked returns can mitigate the drawbacks of benevolent return policies of retail marketplaces.

Lot Sizing, Lot Scheduling and Production Planning III

Cluster: Production Management, Supply Chain Management, and Location
Invited session
Chair: *Dominik Zehetner*

1 - MIP model for integrated production and distribution problem with order consideration and cargo arrangement for the textile industry
Giovanna Abreu Alves, *Roberto Tavares*, *Victor Claudio Bento Camargo*

In a process industry with sequential production, storage, and distribution activities, operations planning is usually performed individually, from predetermined decisions of previous activities. Production and distribution are two functions needing to be viewed as integrated, however, to obtain better operational performance. At an operational level, integrated production and distribution planning must simultaneously define the number of items to be produced and the production sequence in the machines and vehicle decisions, such as routing and cargo arrangement. Furthermore, produced items must be grouped into orders to meet customer demands. This work presents a mixed-integer programming model to support integrated production and distribution decisions at an operational level in the textile industry, trying to fill a literature gap. Therefore, a significant contribution of this paper is to incorporate order fulfillment in lot-sizing and distribution decisions with carryover setup sequence-dependent constraints and distribution decisions based on unitization cargo pallets. A comparative analysis of the integrated model is performed with three scenarios of hierarchical models. Moreover, a computational study is presented to evaluate model behavior.

2 - Machine Learning-Based Decentralized Collaborative Production Planning in Additive Manufacturing
Dominik Zehetner, *Margaretha Gansterer*

The remarkable success of sharing economy (SE) platforms in the B2C sector has led to increased attention from both practitioners and researchers seeking to apply these models to the B2B sector. Studies have already demonstrated, combined with cloud manufacturing (CMfg) and Additive Manufacturing (AM), SE frameworks can considerably reduce costs, while increasing the responsiveness of a supply chain. CMfg usually connects many participants who want to collaboratively share resources or exchange jobs effectively, however, and, as a result, there is a need to design an efficient resource allocation mechanism. Promising approaches for this environment are decentralized auction frameworks, used to exchange jobs to decrease production costs of operations efficiently and effectively. In these approaches, agents need to determine the bids of forwarded jobs offered by an auctioneer, then finding the optimum job allocation via a combinatorial auction. In conventional approaches, bids are determined by solving numerous production planning problems with commercial solvers or heuristics. Both approaches lack suitability for a large-scale CMfg platform, however, as they may find inefficient solutions or are too time-consuming. This study closes this research gap by applying supervised machine learning (ML) models to estimate production costs and report bids, effectively. We investigate the effectiveness of over 40 ML models and compare the estimated objective value to the exact solution and a well established heuristic for a single machine AM production planning problem. We then demonstrate the effectiveness of the most accurate ML model on a decentralized framework, based on a truthful combinatorial reverse auction. This framework allows machines to autonomously exchange jobs over a CMfg platform to reduce overall and individual production planning costs. Our enhanced approach significantly decreases computational time, while delivering efficient results.

3 - A supervised machine learning approach for replenishment policy decisions under transportation disruption uncertainty
Daniel Müllerklein, *Pirmin Fontaine*, *Janosch Ortmann*

The problem of determining optimal inventory replenishment policies seeks to balance the costs of excess inventory with the risk of shortages through manageable decision rules. While demand uncertainty has been the focus of stochastic inventory modeling, the effects of transportation uncertainty, despite its importance on total costs, is not well understood. Additionally, most approaches assume knowledge of the stochastic distributions at hand. In practice, however, transportation modes are prone to disruptions, such as low water levels in inland shipping, resulting in transportation stops and cost increases. While historical data on disruptions are available, it is difficult for practitioners to understand how replenishment policies need to be adjusted to account for this uncertainty. To overcome this gap, we combine mathematical optimization with supervised machine learning to obtain decision rules for a replenishment policy with multiple vendors and cost uncertainty. The problem is modeled as stochastic Inventory Routing Problem with Direct Deliveries (IRPDD) that minimizes total expected costs. We particularly extend the standard problem setting by incorporating transportation cost uncertainty. The optimal replenishment decisions are used as labels for the supervised training of a Classification And Regression Tree (CART) algorithm to obtain a decision tree using features from inventory control and disruption related information. We present a case study for the IRPDD with recurring transportation disruptions that result in cost increases from vendor to customer. This case, motivated by a real-life example at the river Rhine in Germany, considers two suppliers, lead time differences, and direct deliveries. The relevant features include the inventory position, historical water levels and trends, rainfall, and temperatures; using these features, the decision tree can predict the right timing and choice of supplier with an accuracy above 90%. Compared to an (s,Q)-reorder policy, applying the decision tree can reduce costs by more than 30%, thus achieving significant savings.

4 - The multi-stage two-dimensional cutting stock problem with usable leftovers and demand uncertainty
Douglas Nogueira do Nascimento, *Adriana Cherri*, *José Fernando Oliveira*, *Beatriz Brito Oliveira*

The two-dimensional cutting stock problem with usable leftovers (2D-CSPUL) consists of cutting large rectangular plates to produce a demanded quantity of smaller rectangular items, considering the possibility of generating leftovers to return to stock for use in the future - not accounted as waste. They must be planned to increase their probability of future use, minimizing the loss in a multiperiod perspective and offering several advantages to companies. In real situations, information about demand may be unknown when cutting plans need to be established, causing many decisions to be based on average values or approximating demand values through forecasting methods determined by historical series. Despite being simple and easily implemented, these methods disregard a wide range of possible values of uncertain parameters, obtaining poor solutions when these parameters occur. In this context, a new problem arises, consisting of determining the number of various items produced in each period of a planning horizon, aiming to minimize the loss of material and storage costs and allowing both the anticipation of the production of items and the generation of usable leftovers - the multi-stage two-dimensional cutting stock problem with usable leftovers and demand uncertainty. A multi-stage stochastic model represents this problem, where uncertain demands are approximated by a finite set of possible scenarios indicating the item demand in each period. The problem is modeled using a scenario tree approach, where the nodes represent different moments of the planning horizon. From the root node, associated with the first stage of the problem, with known demand, each node has multiple successors representing the possible demand occurrences in the following stages. From a predefined set of cutting patterns, the stochastic multi-stage model will determine their frequencies in each node, considering the decisions made in a given node are common to all successor nodes. Besides solving the multi-stage stochastic model directly through an exact solver, a matheuristic is being developed to obtain high-quality solutions for medium- and large-size instances in a reduced resolution time. The quality of the matheuristic will be validated by computational experiments with data from the literature.

Lot Sizing, Lot Scheduling and Production Planning IV

Cluster: Production Management, Supply Chain Management, and Location
Invited session
Chair: *Mahsa Alirezaei*

1 - Application of a discrete-event simulation model as a management tool: production planning in a large foundry
Breno Zeraik Lima Turner, *Fernando Marins*, *Aneirson Silva*

Production Planning and Control are a critical element for the success of any organization, but, especially in a foundry, the task of scheduling is quite complex, given the specific characteristics of its processes. While melting is a batch process, moldmaking is a one-piece flow system. Hence, Production Planning and Control in a foundry has the challenge of guaranteeing the synchronism between these two processes- distinct, but operating simultaneously. Discrete Event Simulation has been used to develop a management tool whose objective is to propose viable solutions to reduce the Work in Progress in the pouring floor to prevent the occurrence of blockage in the molding lines. The IDEF-SIM technique has been adopted to develop conceptual modeling and commercial software has been used to build the computational model. The model has been statistically validated, and the developed tool has been demonstrated to be useful to answer production planning questions at operational, tactical, and strategic levels. Different scenarios have been experimented, and the outputs have supported company management in decision-making processes.

2 - Creating Daily Shifts for Call Centers using a Two-Stage Model
Yu Song, *Hanlin Liu*, *Xiaodong Liu*, *Cheng Li*

This research discusses the scheduling problem of daily shifts in multitasking call centers and proposes a two-stage optimization model ensuring staff members do not change tasks, unnecessarily. The problem is formulated using an implicit modeling approach considering the varying skills and availability of staff members, as well as the changing demand for different tasks at different timeslots. In the first stage of the optimization model, the goal is to minimize understaffing in the call center. The model takes into account the skill level of each staff member for each task, the predicted demand for each task during each time slot, and the penalties for understaffing. The output of this stage is a set of variables indicating the staff members assigned tasks during certain time slots, as well as a measure of the total penalty for understaffing. In the second stage of the optimization model, the output of the first stage is used as a constraint, and the goal is to minimize the total number of task changes made by staff members. This stage takes into account staff members may change tasks during different time slots, but excessive changes are undesirable. The proposed optimization model is evaluated using a set of numerical experiments; it effectively reduces the number of task changes made by staff members, while maintaining the processing capacity of the call center. The model is a practical and effective solution to the scheduling problem in multitasking call centers.

3 - The impact of safety and productivity reminders on warehouse driver behavior: A VR experiment
Mahsa Alirezaei, *Jelle de Vries*, *René de Koster*

Balancing often-competing goals of productivity and safety is an ongoing challenge in warehouses; despite the organizations' emphasis on safe and productive work, the combined impact of emphasis on speed, quality, and safety remains unclear. This study does the following: (1) employs a laboratory experiment involving a VR simulator to examine the impact of audio reminders, with different levels of specificity in

terms of content and exposure time, on the performance of warehouse vehicle drivers; (2) measures individual differences between drivers, in terms of Regulatory Focus; and (3) tracks head movements as a potential mechanism in the relationship between audio, head orientation, and drivers' performance.

4 - Conceptual Map Design for the Visualization of Strategies
Camila Retamal, *Luis Quezada*

The advancement of technology does not depend on the experience of technologists and managers; companies generate more and more data every day, thanks to the dramatic growth of computers, the internet and advances in globalization technology. Currently, there is no tool visually displaying information, whether corporate, market and product, however, for strategic managers to make decisions. The need arises to make accurate decisions and in the shortest possible time; it can mean overtaking the competition or addressing any inefficiency developing within the company. For this, as a manager within an organization, it is key to have the support of the staff and to know how to show necessary information in the most agile and understandable way to carry out a constructive and efficient discussion. A review of the literature shows there is little material available, however, to guide managers in applying visualization techniques to assist in a strategy formulation process. The objective of this research is to design a system for visualizing business strategy, to allow business managers to make strategic decisions through a visualization system using a large database. The method used is based on mixed research, determining the investigative study for calculation purposes and the method used in the formulation of the foundation of the strategy in analytical tools and qualitative research, validating its applicability as a support tool in the strategy formulation process for strategic decision-making. Based on this, the design of a conceptual map is built to expedite decision-making within a multinational company in the field of logistics with more than 40 thousand employees.

Removed abstracts

Cluster: Removed and rejected abstracts
Invited session

Rejected abstracts

Cluster: Removed and rejected abstracts
Invited session

Recent Applications and Advances in Machine Scheduling

Cluster: Scheduling in Logistics
Invited session
Chair: *Simon Emde*

1 - Labor flexibility and staffing levels in a re-entrant flexible flow shop scheduling problem with missing operations
Johanna Mlekusch, *Richard Hartl*

Manufacturing layouts can usually be modeled as job- or flow-shop models, where every job visits the same stage only once. In some industries, however, the production process requires jobs to re-visit certain stages repeatedly. Our research arises in the context of companies using screen printing techniques, where the re-entrant production process occurs due to workflow requirements and quality problems. In addition to the re-entrant characteristic, the real-world problem is characterized by additional resources of workers needing to be assigned to production steps. The considered setting can be characterized as a scheduling problem with dual-resource constraints (DRC). In addition to the mentioned characteristics, we focus on a flexible production setting where at least one stage contains two parallel identical machines, and some operations may skip production steps. The objective is to minimize the maximum completion time. As the classical flow shop problem (FSP) with n jobs and more than two machines has been proven to be NP-hard, the setting under consideration is also NP-hard, implying finding an optimal schedule for the instances provided is time-consuming. To solve large instances in a reasonable time, we propose a hybrid genetic algorithm (HGA) based on an indirect and single-level solution representation combined with an effective decoding method. We show the efficiency of the method by comparing the solution quality and computational time to feasible results obtained by a commercial solver, and we further analyze the performance of our method on benchmark instances in a setting without labor constraints. Furthermore, we provide managerial insights on how various staffing levels and different flexibility degrees effects the objective function and the costs associated with different worker settings in the described production setting.

2 - Branch-cut-and-price for open-shop scheduling problems occurring in just-in-time logistics
Simon Emde, *Jens Lysgaard*

We address a general open-shop scheduling problem, where jobs have release and due dates, transferring between machines incurs a machine-pair dependent delay, and any regular objective defined over job completion times is minimized. These problems are widely encountered in practice, e.g. in industrial testing and maintenance processes and just-in-time logistics. Despite its relevance, exact solution methods from the literature have so far exclusively focused on the makespan objective or very specific special cases. Hence, we present an exact method for the general open-shop scheduling problem with any regular minsum objective. Moreover, we demonstrate how branch-cut-and-price methods can be applied to the open-shop. Finally, we also adapt the famous subset-row inequalities, originally proposed for the vehicle routing problem, to the open-shop. Our computational study on both newly generated instances as well as those from the literature demonstrates good performance on a broad set of different objective functions, finding tight bounds even for the largest problems.

3 - Bucket-Indexed formulation: a new approach to solve the parallel machine scheduling problem
Luana Mesquita Carrilho, *Silvio Hamacher*

Machine scheduling is a decision-making process present in most manufacturing and services industries; it handles jobs, allocated on available resources, in a period to find feasible scheduling. In the last decades, there has been a growth in parallel machine research, providing significant advances in the development of techniques contributing to theoretical knowledge and practical problems. We propose a mixed-integer linear programming formulation to solve an identical parallel machine scheduling problem, considering time windows constraints, precedence relation between jobs, eligibility, and machine availability constraints. The bucket-indexed (BI) formulation consists of partitions of the planning horizon into periods of equal length (buckets). The bucket size parameter might vary between 1 and the shortest processing time of jobs; larger bucket sizes result in fewer buckets created, reducing the model size. We test the proposed formulation in large real-world instances of the rig scheduling problem for the Brazilian oil and gas industry and compare the obtained results with the classical time-indexed (TI) formulation. The results of the proposed formulation highlight a better performance in all the tested instances, reducing computational time in all cases and solving large instances unsolvable by the TI formulation.

Recent Advances in Location, Allocation, and Routing

Cluster: Scheduling in Logistics
Invited session
Chair: *Arthur Kramer*

1 - A model to optimize the tenant mix in a shopping centre.

Grace Maureira-Alegría, *F.-Javier Heredia*, *Sergi Esteban*

The "tenant mix" is a crucial factor in the success of a shopping centre. It represents the combination of different retail types (categories) within the centre as the proportion of occupied space and location. Thus, the tenant mix problem consists of determining the optimal mix of retail types and the location-allocation of tenants within a shopping centre in order to maximize rental income for that centre.

In this study, we have formulated an integer linear programming model to find an optimal tenant mix of existing shopping centres. The objective function of the model is to maximize the total rental income, i.e., the rent that tenants pay to landlords. The main factors in calculating the rent for those tenants are their retail type, size (area), vertical location, and sales level, as well as the type of shopping centre. Constraints are mainly related to the available gross leasable area and units for stores.

Additionally, the model considers the synergy among the retailers to have a well-balanced tenant mix. This synergy means the affinity that a tenant has with its closest neighbours. To represent these synergies, we have collected all the historical configurations that there have been in different shopping centres in Spain, where each one is represented by the category that a store has and the categories of its closest neighbouring stores. These configurations have been scored based on the neighbourhood sales level. Then these scores have been included in the objective function to penalize the selection of inadequate configurations.

The numerical results are based on real data from existing shopping centres in Spain. The cases from two different types of shopping centres will be used to illustrate the performance of the proposed approach.

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2 - A bilevel allocation-production problem

Dámaris Arizhay Dávila Soria, *José-Fernando Camacho-Vallejo*

This work addresses an allocation-production decision problem, where a company needs to determine the assembly plants required to serve a group of customers. The customers have a specific amount of product needing to be satisfied, and once the assembly plants know the number of products required to meet the demand of the customers, they need to order the parts necessary for the assembly of the final products from external agents. The external agents produce one or more of the pieces required to assemble the final product, depending on their production capacity. Not all external actors produce all the necessary parts, and each piece produced has different prices and production times; the assembly plants start working when they receive all the pieces required to produce the complete products; various machines with varying production times and costs are used for this purpose. The company's objective is to maximize the customers' satisfaction in terms of service times, while the assembly plants aim to minimize production costs. According to the structure of the problem, it is modeled as a bilevel programming model, where the upper level corresponds to the company responsible for assigning customers to assembly plants, while the lower level corresponds to each assembly plant. To solve the problem, an evolutionary algorithm considering subpopulations is proposed. The algorithm finds the optimal or near-optimal solution by iteratively improving the subpopulations of solutions and by exchanging information between them. The proposed evolutionary algorithm is tested on a set of benchmark instances. The algorithm is effective in solving the problem, as it can find good-quality solutions within a reasonable amount of time. A real-life case-study is pointed out as the current research direction.

3 - Vehicle routing and time window selection for service delivery to minimize emission cost

Jiyin Liu, *Yizi Zhou*, *Rupal Mandania*

We study the problem of scheduling technicians, each driving a vehicle to perform service tasks at customer sites, with customers requesting services one day in advance. Each customer specifies a time window for the service to start and may choose to participate in a green delivery program, by indicating alternative time windows they can also accept. Traveling at various time slots of the day causes various amounts of emission because of various congestion levels. The savings in emission cost due to time window flexibility will be shared by the customers served in their alternative time windows. This multiple time window VRP has not attracted much attention in the literature. We formulated the problem as a MILP model, scheduling the service routes to minimize the emission cost; a self-adaptive simulated annealing algorithm is developed to solve the problem. Small instances solvable by optimization software are used to test the performance of the self-adaptive SA heuristic. The objective value of the heuristic solution is close to optimal. Real-life sized instances are then randomly generated and solved by the SA heuristic; the operation is simulated for several working days. Time window flexibility can help save emissions and improve the number of customers served when there is overbooking. More flexible customers or more available time windows for each customer can further reduce emissions and increase the number of customers served.

4 - Transshipment station location problem in the context of solid waste management of the Brazilian state of Rio Grande do Norte

Arthur Kramer, *Fernanda Rêgo*, *Katyanne Farias*

The problem of solid waste management grows according to the constant changes in the consumption patterns of society and the development of the current economic model; these factors cause an increase in waste generation and, consequently, have a negative impact on the environment and public health, since the final disposal of these materials is often inadequate. In Brazil, Law No. 14.026/2020 imposed new deadlines for deactivating open-air dumps nationwide. Many cities still perform the disposal incorrectly, however, mainly due to financial constraints making it impossible to invest in the construction, operation and maintenance of alternatives, such as Sanitary Landfills (SL). In Rio Grande do Norte (RN), Brazil, the State Plan for Solid Waste (SPSW) implemented the inter-municipal consortiums intending to reduce costs through the union of several municipalities. Each consortium has a city designated to receive the SL and a set of cities able to receive Transshipment Stations (TSs) to temporarily store the solid waste, enabling and reducing waste transportation costs between the cities and the SL. A city can also deliver the waste directly to the SL, if it is advantageous in terms of cost. Each TS has a storage capacity depending on the number of buckets to be deployed at the station. In this context, the TS Location Problem (TSLP) arises. In this problem, we determine (i) the cities where the TSs will be installed, (ii) the number of buckets to allocate to each TS, (iii) and the assignment of cities to TSs or SL. The objective is to find a solution minimizing the total cost, composed of the fixed cost of installing a TS, the total cost of deploying buckets at the installed TS, and the delivery cost between the cities and the TSs or the SL and between the TSs and the SL. The problem considers the cities deliver solid waste on a daily basis, it can be stored for at most two days at the TSs, and all deliveries are made at the end of the day. Furthermore, the TSLP considers each city has a vehicle to make deliveries of the city's waste to the TS or SL, and an unlimited fleet of vehicles able to carry at most a single bucket is available to make one delivery per day from a TS to the SL. To solve the TSLP, we propose a Mixed Integer Linear Programming model. The model was solved using Gurobi solver for a set of real instances. The solutions obtained will be validated and implemented within the RN SPSW.

Novel Approaches and Applications in Inbound Logistics and Warehousing

Cluster: Scheduling in Logistics
Invited session
Chair: *Maximiliano Cubillos*

1 - Simultaneous routing, scheduling and resource synchronization in the supply of materials for electric power generation
Gabriela Corsano, *Luciana Melchiori*

Electric power generation from forest biomass refers to the process of converting forest residues and sawmill byproducts, such as wood chips, sawdust, bark, and tree branches, into electricity. This method of electricity generation has several benefits, including the fact biomass is a renewable resource; it also helps to reduce greenhouse gas emissions, since burning biomass only releases carbon dioxide the trees absorbed during their growth. Specifically, in Northeast Argentina, due to the large number of sawmills installed, the use of byproducts significantly reduces air pollution caused by burning. These power plants receive a large number of vehicles daily transporting logs and harvest residues from the forests, as well as chips and sawdust from various sawmills, making the entry of trucks into the plant a bottleneck; scheduling the arrival of these trucks becomes a challenging problem. Furthermore, there is a limited number of resources for unloading the material, also needing to be synchronized to avoid overlapping of unloading tasks. Inspired by a real-case scenario, this work addresses a pickup and delivery problem with full truckloads for an electric generation power plant. An integer linear programming model is presented for the optimal scheduling of truck arrivals at the plant and the synchronization of unloading resources. Knowing the sources of supply and the availability of each material, both in the forests and in the sawmills, the routing of the trucks is simultaneously solved, considering each vehicle leaves the plant, visits a single customer, and returns to the plant to be unloaded. Each truck has a limited working time per day, and a relationship between the required materials must be maintained. Different objective functions are used and analyzed, obtaining diverse logistics scenarios allowing assessment of the tradeoffs among the decisions to be made. The proposed model represents a useful tool for guiding the decision-making process in the supply of materials for electric power plants.

2 - Truck scheduling using estimated time of arrival for the yard management problem
Maximiliano Cubillos, *Ola Jabali*

In the transportation sector, technology advances and new information systems have made available accurate real-time predictions of the Estimated Time of Arrival (ETA) of vehicles. In this study, we focus on the synchronization of the use of ETA for trucks into the yard management problem, entailing the assignment of trucks to docks in large warehouses with uncertain truck arrival times. We quantify the added value of the use of ETA to generate schedules minimizing the waiting time of trucks; for this, we propose a Markov Decision Process (MDP) formulation of the problem. To overcome the explosion in the dimension of the state and action spaces, we propose a heuristic solution based on a roll-out algorithm and an Iterated Local Search (ILS) heuristic with a Variable Neighborhood Descent (VND) search, to efficiently select the underlying scheduling actions in the model. We perform extensive computational experiments to demonstrate the efficiency of our algorithm and compare the resulting policies with other benchmark scheduling rules used in parallel machine scheduling problems. Also, we assess the effect of different ETA modeling assumptions regarding distributional changes over time, the reliability of the ETA with respect to the distance in time with the actual arrival, the frequency of the ETA updates, and the use of partial ETA information - the use of ETA for a percentage of the total number of incoming trucks in a planning period.

3 - A MILP formulation for a Rich Technician and Vehicle Routing Problem of a Mixed Fleet with Time Windows, Multiple Depots, and Skills
Vidura Sooriyaarachchi, *Jiyin Liu*, *Anne Liret*, *Rupal Rana*

The prevalence of Electric Vehicles has led to research in the area of mixed fleet routing, combining EVs with Conventional Vehicles. This paper addresses this mixed fleet routing problem for service vehicles with considerations being made for the provision of convenient services to customers, the appropriate utilisation of the workforce and the handling of vehicle operating characteristics. The problem is examined in the context of utility services maintenance on a national scale. The objective is to reduce the total distance travelled and the number of vehicles deployed, as well as the energy costs of the electric vehicles. A Mixed-Integer Linear Programming model formulation is presented, with features including time windows for customer service provision and lunch breaks for technicians, multiple depots and matching technician skills to jobs. A mixed set of public and private charging stations is available and vehicles are allowed partial recharging, and a mixed workforce of full-time and part-time technicians is used as a resource alongside the vehicle fleet with considerations being made for shift times, lunch breaks and driving style. The problem is solved using an off-the-shelf solver. Experiments are also run to evaluate various scenarios such as a homogeneous vehicle fleet, and the performance of this deterministic method is discussed.

OR Approaches to Real-World Industrial Applications

Cluster: Scheduling in Logistics
Invited session
Chair: *Bernardo Zimberg*

1 - A stochastic programming approach for airline maintenance scheduling under uncertainty
Matias Villafranca, *Felipe Delgado*, *Mathias Klapp*

Aircraft maintenance tasks present variability in their processing time; if they take longer than expected, an airline operator could end up with delayed flights and/or infeasible maintenance schedules. Despite this potential cost increase, in the specialized literature the effect of task time variability in flight delays has not yet been anticipated and accounted for in aircraft maintenance planning operations. We acknowledge this gap and study an aircraft maintenance scheduling problem with stochastic task processing times to help plan an airline's daily operation. Decisions involve choosing the subset of tasks to execute in each aircraft and each task start time considering aircraft relocate among multiple airports, airports have a limited resource of technicians, and longer task time realizations can delay subsequent aircraft scheduled flights. The objective is to minimize the expected daily cost of flight delays and postponed maintenance tasks. We propose a solution to our two-stage stochastic model based on scenario sampling. Finally, we provide computational experiments to validate our approach, estimate the potential cost savings obtained by our solution when compared to a simpler airline maintenance policy, and estimate the cost of task time variability, by comparing our approach to the solution of a model with perfect information.

2 - Liquefied Petroleum Gas scheduling, blending and optimization model
Bernardo Zimberg, *Eduardo Camponogara*, *Pablo Monzon*

Liquefied petroleum gas (LPG), one of the main refining sets of products, is mainly a mixture of hydrocarbons with three and four carbons. Commercial grades comply to a set of specifications.

Given a time horizon, the objective of the scheduler is to find an optimal sequence of qualities delivered through the gas pipeline and final quality mixtures delivered to the market, while satisfying a set of constraints.

The proposed work develops a multioperation sequencing model finding an optimal solution for the scheduling problem in an affordable time.

3 - Critical path analysis for permutation flow shop scheduling problem
Daniel Rossit, *Jatinder N. D. Gupta*, *Martin Safe*, *Óscar C. Vásquez*, *Fernando Tohmé*, *Mariano Frutos*

Scheduling problems in flow shop processes have a great impact on a large number of applications, both at a production and industrial level, as well as process systems in general (information technologies and business). In all these applications, the most studied objective function is the makespan, seeking to minimize the total processing time for a given set of jobs - in its simplest structure (one machine per stage of the process, without release date, and no particular conditions for job processing), an NP-Hard problem for 3 machines or more. Within the way of approaching the problem according to the solution category, permutation solutions are the most widely used; in them, the same order of jobs is respected in all process stages. In the literature, there are a large number of approaches and methods proposed to address the optimization of the makespan for this problem. This paper proposes to study the structure of the solutions from the perspective of the structure of its critical path, considering as a critical path the set of operations supporting the makespan. In this approach, some results from the literature will be used to extend the solutions to other cases. In turn, the potential impacts of considering the solution structure for the design of solving methods will be presented and discussed.

Novel OR Applications in Healthcare and Beyond

Cluster: Scheduling in Logistics
Invited session
Chair: *Celia Glass*

1 - AI Rostering for NHS Doctors in Training: Enhancing Well-being with Mathematical Programming
Celia Glass

In this talk, I address an important aspect of hospital logistics - the rostering of staff, central to the efficient running of any hospital and to the lives of its staff. I explain how a sophisticated OR rostering tool allows us to address the well-being and progression of doctors in training in UK National Health Service (NHS) hospitals. Central to the approach is the use of HSE fatigue factors and prioritisation of staff training and leave preferences. Rostering is known to be an NP-complete Combinatorial Optimisation problem; all expected is a tolerably good solution. By capturing the mathematical structure of the underlying problem, however, we have solved it using Mathematical Programming Optimisation (MP); the application runs on an MPL-Gurobi commercial package, in the Cloud. In this talk, I report how the efficiency of our MP approach reduced doctors' reported fatigue, locum staff costs and rota manager's time. More consistent staff cover improved doctors' morale and caused less tiredness among doctors, leading to better patient care. The positive impact for the doctors, the hospital, and the patients provide win-win-win benefits. In particular, we demonstrate how training can be incorporated into hospital rosters. By planning training into the rosters, attendance at specialist training courses ceased to conflict with covering patient duties, and progression to consultant was improved. Personalised rosters doubled surgical training, while improving continuity of care for patients. We, thus, address the key issues of • doctors' well-being, • personalised training planned into department rosters, and • flexibility of working hours. I illustrate how training, progression and retention in the NHS can be significantly improved through the use of our MP rostering tool. The underlying model is transferable to other health systems across the world. The results present a positive paradigm shift for health professionals with mathematics, meaning caring for the carers!

2 - An Approximate Dynamic Programming Approach to Network-Based Scheduling of Chemotherapy Treatment Sessions
Pablo A. Rey, *Alejandro Cataldo*, *Antoine Sauré*, *Arturo Wenzel*

A solution approach is proposed for the interday problem of assigning chemotherapy sessions at a network of treatment centres, with a view to increasing the efficiency of system-wide capacity use. This network-based scheduling procedure is subject to the condition both the first and last sessions of a patients treatment protocol are administered at the same centre the patient is referred to by their oncologist; all intermediate sessions may be administered at other centres. The problem is modelled as a Markov decision process, then solved approximately using techniques of approximate dynamic programming. The benefits of the approach are evaluated and compared through simulation with the existing manual scheduling procedures at two treatment centres in Santiago, Chile. The approach would obtain a 20% reduction in operating costs for the whole system and cut existing first-session wait times by half. A network-based scheduling procedure brings no real benefits, however, if it is not implemented in conjunction with a proactive assignment policy like the one proposed.

3 - Study of waiting lists in health services based on medical planning
Kevin Roa, *Sebastián Dávila*, *Franco Quezada*

Medical staff planning can cause significant challenges for patients and healthcare systems and can substantially impact waiting lists; inadequate planning can lead to shortages of resources, delays in referrals, improper prioritization of patients and longer wait times for medical care. These issues can have severe consequences for patients' health and the effectiveness of the healthcare system as a whole. To address these challenges, we study the problem of planning medical staff for a discrete planning horizon, assuming the demand for medical care is unknown and dynamic. We use a two-stage stochastic programming approach, where medical staff is a first decision variable, i.e., they must be decided before the uncertainty realization and patient allocation (second-stage variables). We develop a mixed integer linear programming (MILP) model considering resource constraints and several specialties and allocating medical resources effectively to patients, to minimize waiting lists under various criteria. Three planning approaches are considered in the model: flexible, semi-flexible, and rigid; they address the uncertainties arising from demand for healthcare services and offer varying degrees of flexibility to respond to changes in demand.

Key performance indicators (KPIs) are used to evaluate the performance of medical formulations under each planning approach; they measure waiting times, utilization rates, and the number of patients waiting for treatment. The proposed models achieve superior performance indicators, compared to random and deterministic solutions, and provide medical assignments ensuring compliance with budgetary and material constraints, while improving waiting list management. They also show relevant managerial insight, such as the importance of considering flexibility in medical staff planning to respond to changes in demand and to optimize patient outcomes, offering an innovative optimization tool for healthcare managers.

Gurobi - New Highlights and Innovations

Cluster: Software for Optimization
Invited session
Chair: *Michael Winkler*

1 - Solving Optimization Problems with Gurobi - New Highlights and Innovations
Michael Winkler

We will give an overview on recent developments within Gurobi 10, including performance improvements on different general purpose optimization and decision problem classes, such as linear (LP), mixed-integer (MIP), convex- and nonconvex-quadratic (MIQCQP) problems.

Software for Optimization 1: Solvers

Cluster: Software for Optimization
Invited session
Chair: *Leona Gottwald*

1 - Recent advances in the FICO Xpress Solver
Leona Gottwald

This talk discusses the newest features of the FICO Xpress Solver, an optimization tool widely used in various industries to solve complex optimization problems. One of the newest features is Xpress Global, adding support for mixed-integer nonlinear programming problems. This allows users to leverage the advanced capabilities of the Xpress Optimizer to solve complex nonconvex nonlinear optimization problems involving discrete and continuous variables to proven global optimality.

2 - RAPOSa: A freely available global solver for polynomial MINLP problems
Julio González-Díaz, *Ignacio Gómez-Casares*, *Brais González Rodríguez*, *Beatriz Pateiro-López*

In this talk, we present the latest advances in RAPOSa, a global solver for mixed-integer polynomial optimization problems. RAPOSa is based on the Reformulation-Linearization Technique and incorporates numerous enhancements discussed in past literature, such as the use of J-sets, SDP-cuts, and bound tightening. This presentation is devoted to the latest functionalities incorporated into RAPOSa: i) its new capabilities to tackle problems with integer variables, ii) the use of machine learning techniques to tailor RAPOSa's configuration to the specific characteristics of the problem at hand, and iii) the explicit use of conic constraints in the branch-and-bound tree.

3 - A New Interior Point Approach for Linear Optimization
Daya Gaur, *Sajad Fathi Hafshejani*, *Robert Benkoczi*

Since the landmark paper of Karmarkar, interior point methods have been an active area of research; we propose an interior point method consisting of two steps for solving linear optimization problems. The proposed algorithm uses an auxiliary point with the same value as the principal point in the initial iteration. In the first step, we use a convex combination of the auxiliary and principal points in the previous iteration to find the search direction considering the barrier parameter. After computing the search direction, we update the auxiliary point to satisfy the feasibility condition. In the second step, we update the barrier parameter. Then, we use a convex combination of the auxiliary and principal points to compute the search direction. To update the principal point, we find the best value for step size, so the feasibility condition is held; we repeat this process until the stopping condition is reached. Since we use the information from the previous iteration to find the search direction in the first step, in each iteration of the algorithm, we compute the inverse of the system one time. Our approach is different from the algorithm proposed by Mehrotra; it uses second-order information in each iteration, while we use only first-order information. We compare our method with the classical algorithm of Roos, Terlaky and Vial.

We coded the two algorithms and tested their performance on the Netlib-lp dataset. The current implementations solved 35/138 instances optimally. The remaining instances were either not full rank or the initial solution was not feasible. The numbers of non-zero (nnz) elements are between 102 to 10708. We define the speed-up as the number of iterations for the classical approach divided by the number of iterations for the new method. We compute the average speed-up on all instances with nnz greater than some bound. The average speedup observed is 1.534. The speed-up of the new method increases significantly with the increase in the nnz. The proposed method is faster in terms of cpu-time. Motivated by the work of Czyzyk, Fourer and Mehrotra, we have implemented the algorithms to work on GPUs and are testing them on the Netlib-lp instances. We are also working on implementing methods for finding initial solutions; this will increase the pool of Netlib-lp instances that can be solved faster by the proposed method.

Software for Optimization 2: Modeling

Cluster: Software for Optimization
Invited session
Chair: *Robert Fourer*

1 - Advances in Model-Based Optimization with AMPL
Robert Fourer, *Marcos Dominguez Velad*, *FIlipe Brandão*

The ideal of model-based optimization is to describe your problem the way you think about it, while computers do the work of getting and reporting solutions. Recent enhancements aim to bring the AMPL modeling language and system closer to this ideal, on two fronts. — First, modeling language extensions are enabling more natural expressions to be used directly in AMPL model formulations. Conversions to the forms required by large-scale solvers are handled automatically, with support from a new C++ AMPL-solver interface library that adapts to handle diverse solver requirements. The new extensions include general quadratic expressions, numerous logical operators and constraints, and common near-linear and nonlinear functions, all combinable with familiar algebraic expressions. — Second, modeling system extensions are letting AMPL fit more naturally into the increasingly popular Python application programming environment: installing as an "amplpy" Python package, importing and exporting data naturally from/to Python data structures and Pandas dataframes, and supporting Jupyter notebooks that mix AMPL modeling and Python programming. In contrast to Python-only modeling solutions, AMPL's Python API offers straightforward, efficient model processing while leveraging Python's vast ecosystem for data pre-processing, solution analysis, and visualization. Examples include free prototyping in Google Colab and fast web app development using Streamlit.

2 - BilevelJuMP.jl: Modeling and Solving Bilevel Optimization in Julia
Joaquim Dias Garcia, *Guilherme Bodin*

In this talk, we present BilevelJuMP.jl, a JuMP extension allowing users to model and to solve bilevel optimization problems. BilevelJuMP relies on the JuMP ecosystem to automatically dualize any conic convex optimization problem and use it to model bilevel problems by building KKT conditions of the lower-level problem. The package has implementations of multiple formulations for complementarity constraints, such as SOS1, Fortuny-Amat, quadratic programming, and actual complementarity constraints. Since the package is built as a JuMP extension, it is automatically integrated with all solvers available to JuMP models. These implementations can help practitioners to save time and to think more about the modeling aspect of bilevel problems, than worry about the programming aspect of each reformulation strategy. We show how the packages were developed, relying on Julia the JuMP infra-structure, and we present some power system examples of bilevel problems.

3 - Remote solver execution with PIFOP, a toolbox for mathematical optimization
Davi Doro, *Ricardo Camargo*, *Fatima Lima*

Mathematical optimization problems, oftentimes, require a large amount of computing power to be solved in an acceptable time. In many cases, the amount of memory available in a modeler's laptop or desktop is simply insufficient to run the mathematical program to completion. For that reason, operations research academics and practitioners have always found ways to offload the solution computation

of optimization problems to remote high-end machines capable of doing the job, whether it is a machine located in their university, their company or somewhere in the cloud.

For a long time, the only way to run optimization solvers remotely was via SSH, still widely used today. In this approach, the modeler typically has a script to automate the process of copying their model over to the remote machine and running their optimization program in the background. To support this typical workflow, over the last two decades optimization software vendors started adding built-in remote execution features to their products, an important improvement over the SSH way. Those solutions only work for users committed to the specific software and their supported solvers, however, and even still, limitations will be encountered by users working with more complex mathematical programs, because they will be unable to offload the program execution in its entirety, but only the part of it running the commercial optimization software.

As an alternative to the existing ways of executing solvers remotely, PIFOP provides a new solution not only addressing the aforementioned shortcomings of others, but also offering an innovative way of sharing computer resources and licensed software among multiple people. In this work, we are going to present the design of PIFOP's remote solver execution solution, how it compares to other solutions, and how it enables PIFOP to meet the needs of mathematical optimization students, teachers, researchers and practitioners alike.

4 - GBOML: A modelling tool for structured MILPs

Bardhyl Miftari, *Guillaume Derval*, *Mathias Berger*, *Damien Ernst*

Many real-life problems can be tackled as Structured Mixed Integer Linear Programs (MILP), usually involving two tools : a modelling tool and a solver; this presentation focuses on modelling tools. Most modelling tools for mathematical programming typically fall into two broad categories: the Algebraic Modelling Languages (AMLs) and Object-Oriented Modelling Environments (OOMEs).

On the one hand, the Algebraic Modelling Languages (AMLs) are tools enabling the encoding of a broad class of mathematical problems, with syntax close to the mathematical notation; they enable models to be encoded by writing equations, i.e., providing the parameters, variables, constraints and objectives of a given problem. On the other hand, OOMEs choose a more object-oriented approach by providing the users with a library of generic pre-existing components - easy to manipulate and to assemble for building models. In other words, they are characterized by their ability to reuse predefined components and to assemble them to create instances of problems and build bigger models (features usually unavailable in AMLs).

Both AMLs and OOMEs suffer some drawbacks. Most AMLs fail to exploit the structure existing in structured MILPs or allow any reuse of subparts (or whole parts) of models; OOMEs lack expressiveness and hide the equations behind their components, making addition or modification complicated. Furthermore, OOMEs often rely on AMLs, making them inherit all their drawback.

In this presentation, we introduce the Graph-Based Optimization Modelling Language (GBOML), an open-source modeling tool combining the strengths of both worlds; it supports structure and offers an encoding close to the mathematical one and library-like functionalities, such as reuse and component assembling. GBOML is designed to deal with structured MILPs; it exploits the existing structure from model encoding to the solving. By illustrating on GBOML, we show structure exploitation can lead to a natural encoding of problems, faster time to build the intermediate representation and sometimes faster solving time. We benchmark GBOML, JuMP, Plasmo and Pyomo on a structured MILP.

This presentation is based on two papers:

https://joss.theoj.org/papers/10.21105/joss.04158 and

https://orbi.uliege.be/handle/2268/296930 (under review at Optimization Methods and Software journal).

Software for Optimization 3: New Directions

Cluster: Software for Optimization
Invited session
Chair: *Robert Fourer*

1 - JuMP to QUBO Automatic Reformulation

Pedro Xavier, *Pedro Ripper*, *Tiago Andrade*, *Joaquim Dias Garcia*, *David Bernal Neira*

Quantum Computing is currently one of the major drivers of scientific advancements in both academic and industrial settings, showcasing applications in Telecommunications, Cryptography, Chemistry, Fluid Dynamics, and Operations Research (OR). Quantum annealing, quantum gate-circuit optimization algorithms (Quantum Optimization Alternating Ansatz, Variational Quantum Eigensolver), hardware-accelerated platforms, such as Coherent Ising Machines and Simulated Bifurcation Machines, and many other Physics and Physics-inspired methods rely on the Quadratic Unconstrained Binary Optimization (QUBO) framework as a common language for representing combinatorial problems. This work presents ToQUBO.jl, a state-of-the-art compiler for translating general Mixed-Integer Nonlinear Programming (MINLP) models into QUBO; therefore, allowing for a much wider range of applications to be withdrawn from quantum technology. Deployed as a Julia package, our tool builds a bridge between the usual OR workflow and highly specialized methods, in terms of both software and modeling techniques. The whole process of encoding discrete and continuous variables, representing constraints, and estimating their penalties is carried out automatically by internally reinterpreting a regular JuMP (Julia Mathematical Programming) model and, then, remapping the gathered results back to the original setup. Our tool can manage more constraints, implement more binary reformulations, and perform more efficiently than any of the other tools available in the literature; this transparent behavior allows for an efficient switch from regular solvers to quantum and quantum-inspired platforms with a very modest coding and modeling overhead. To close the loop, we also present a simple, independent interface designed to effortlessly integrate heterogeneous QUBO solvers into the JuMP ecosystem. This second set of tools was proposed to be used by various audiences, for example, researchers developing new algorithms and quantum hardware manufacturers. Altogether, by providing the user with a smooth JuMP modeling experience, this work aims to bridge the gap between emergent computational methods and practical OR use cases.

2 - Logarithmic encoding of Hamiltonians of NP-Hard Problems on a Quantum Computer

Eric Bourreau, *Yagnik Chatterjee*, *Marko Rancic*

NP-hard problems do not have general polynomial time algorithms. Hybrid quantum-classical algorithms to solve them have been of great interest in the past few years; they are heuristic and aim to obtain an approximate solution. Significant improvements in computational time and/or the ability to treat large problems are some of the principal promises of quantum computing in this regard. The hardware is still in its infancy, however, and the current Noisy Intermediate Scale Quantum (NISQ) computers are relatively small. Moreover, the storage of qubits and the introduction of entanglement require extreme conditions. An issue with quantum optimization algorithms, such as QAOA, is they scale linearly with problem size; we propose a way of modeling scaling logarithmically with problem size - opening an avenue for treating optimization problems of unprecedented scale on gate-based quantum computers. For experimentation, we use problems, such as Maximum Cut and QUBO formulation of Minimum Partition. These algorithms are tested on a quantum simulator with graph sizes of over a hundred nodes and on real quantum computers up to a graph size of 256.

3 - The next era of OR Ops: A story of collaboration tooling in vehicle routing and beyond

Carolyn Mooney

When optimization technology works well, it feels magical — but it is not magic; good decision optimization is both an art and a science. The path to good, timely solutions for today's business operations is not always clear. The next era of optimization is not about building a better solver, but about leveraging collaborative tooling empowering entire teams — not just individuals — to move faster with less confusion and more access to the decision technology ecosystem. When decision optimization workflows make it possible to take a locally developed decision model and run it in a remote environment in minutes to power operations or experiment with new model iterations, OR teams spend less time on infrastructure and more time on model development - ultimately delivering more value out of their existing optimization stack with more buy-in across stakeholders. This session will demonstrate how a collaborative workflow looks, using a vehicle route optimization problem. There are several optimization hurdles to overcome: translating business rules into/out of mathematical representations, testing the model, validating and improving solver performance, and deploying to a production environment to have real business impact. For well-staffed teams, there is often coordination among operations researchers, data scientists, product managers, software developers, and devops engineers. For smaller teams, there is often a nontrivial learning curve to address any part of the optimization process. With an opinionated workflow, no team member ever becomes left behind or lost at a given step on the journey to a production environment. All team members need better visibility and understanding of how to work together and bring their skill sets — mathematical optimization, data analysis, software development, operational testing — to be successful.

This presentation will cover: - Elements of common optimization processes and opportunities/challenges - Demo an example of developing and deploying a VRP algorithm, using an opinionated workflow to start local code running against a custom endpoint in minutes - Overview of considerations for choosing how to model and solve - Demo a modeling example to illustrate the benefits of an iterative approach providing collaboration and conversation among teams

Panel: Opportunities at the Artificial Intelligence / Operations Research Interface

Cluster: Special Sessions
Panel session
Chair: *Laura Albert*
Chair: *Michael Fu*
Chair: *Lavanya Marla*
Chair: *David B. Shmoys*
Chair: *Ahmed Abbasi*

1 - Panel on Opportunities at the Artificial Intelligence / Operations Research Interface
Laura Albert

Artificial intelligence (AI) has historically focused on natural language processing, machine learning, and computer vision. AI has broadened its application domains to address many societal challenges due to the convergence of big data, high-performance computing, and machine learning algorithms. In addition, while AI has the potential to transform many industries, its deployment has often exposed and created inequities. There are many challenges for researchers to make fundamental advances at the intersection of AI and OR. This panel will discuss new opportunities and challenges in AI for the operations research community.

Panelists: • Michael Fu • Lavanya Marla • David Shmoys • Ahmed Abbasi

Mini Workshop: Communicating Your Research to the Public

Cluster: Special Sessions
Invited session
Chair: *Sheldon Jacobson*

1 - Workshop: Communicating Your Research to the Public: The Art of Data Science Communication
Sheldon Jacobson

Communicating scientific research to a broad audience has become a prerequisite for success in today's academic environment. This workshop discusses numerous facets of academic communication, with a focus on hands-on application of various techniques and principles to enhance your ability to reach a broad and diverse audience. Examples are provided to illustrate various techniques and principles of communication. By using communication as a branding tool, engineers, mathematicians, computer scientists, and operations researchers can create a media presence for themselves, but also promulgate the value of data science to the general population. Attendees are invited to bring examples of their research and use it to frame "30 second elevator speeches" to share with others.

2022 Franz Edelman Award: Analytics Saved Lives during the Covid-19 Crisis in Chile

Cluster: Special Sessions
Invited session
Chair: *Leonardo Basso*

1 - 2022 Franz Edelman Award: Analytics Saved Lives during the Covid-19 Crisis in Chile
Leonardo Basso

During the Covid-19 crisis, the Chilean Ministry of Health and the Ministry of Sciences, Technology, Knowledge and Innovation partnered with the Instituto Sistemas Complejos de Ingenier'ıa (ISCI) and the telecommunications company ENTEL, to develop innovative methodologies and tools that placed operations research and analytics at the forefront of the battle against the pandemic. These innovations have been used in key decision aspects that helped shape a comprehensive strategy against the virus, including tools that: (i) shed light on the actual effects of lockdowns in different municipalities and over time; (ii) helped allocate limited intensive care capacity; (iii) significantly increased the testing capacity and provided on-the ground strategies for active screening of asymptomatic cases; and (iv) implemented a nationwide serology surveillance program that significantly influenced Chile's decision regarding vaccine booster doses and that also provided information of global relevance. Important challenges during the execution of the project included the coordination of large teams of engineers, data scientists, and health care professionals in the field; how to effectively communicate information to the population; and the handling and use of sensitive data. The initiatives enjoyed ample press coverage and, by providing scientific evidence supporting the decision-making behind the Chilean strategy against the pandemic, they helped provide transparency and objectivity to decision-makers and the general population. According to conservative estimates, the number of lives saved by all of the initiatives together is close to 3,000, equivalent to more than 5% of the total death toll in Chile during the pandemic. The saved resources associated with testing, ICU beds, and working days amount to more than 300 million USD.

Meet the Editors of ITOR

Cluster: Special Sessions
Panel session
Chair: *Celso Ribeiro*
Chair: *Anna Nagurney*
Chair: *M. Grazia Speranza*
Chair: *Mario Guajardo*

1 - Meet the Editors of ITOR
Celso Ribeiro

The General Editor of the International Transactions In Operational Research (ITOR) will present some statistics, good publication practices, and information about the submission, refereeing, and publication workflow of the journal. The Associate Editors will discuss relevant results, recent trends and research opportunities in their areas. The Editors will be glad to welcome questions from the audience.

OR Practice at CMPC and the Pulp and Paper Industry: Past, Present and Future Challenges

Cluster: Special Sessions
Invited session
Chair: *Salvador Flores*

1 - Optimizing Continuous Processes in CMPC Pulp Mills
Abel Valdebenito

This talk will explore the application of Operational Research (OR) within CMPC, focusing on the unique challenges of improving efficiency in continuous process industries, such as pulp mills. Variability in raw materials, highly interconnected sub-processes, and varying levels of instrumentation and automation make this process a difficult one to optimize. We will present case studies that have been implemented in production and discuss the challenges that still remain.

2 - From Local to Mill-wide Optimization at CMPC
Raul Da Silva

In this talk, we will demonstrate how the utilization of advanced analytics and global optimization has revolutionized the solutions currently being applied in the continuous process industry. To further illustrate this, we will present a real-world case study of the global optimization of a large CMPC pulp mill in Brazil. This will showcase the difficulties associated with such a project, as well as the potential for OR research and software to make further contributions.

3 - Autonomous Mills at CMPC: Challenges Ahead
Salvador Flores

Autonomous mills are the ultimate goal of the so-called Industry 4.0. In this talk we discuss the gaps between present practice and capabilities and what it would take for such a dream to become a reality. Particular attention will be given to reinforcement learning as a cornerstone of this revolution, the base capabilities needed to support its development and how the industrial world poses unprecedented challenges as compared to autonomous driving or robotics.

Opening Ceremony

Cluster: Special Sessions
Invited session

Closing Ceremony

Cluster: Special Sessions
Invited session

IFORS Hall of Fame Ceremony

Cluster: Special Sessions
Invited session

IFORS Awards Ceremony

Cluster: Special Sessions
Invited session

Accounting for Equity and Diverity

Cluster: Sustainability Analytics and Modeling
Invited session
Chair: *Lauren Davis*

1 - Analysing child and overall poverty in Europe countries through quantitative techniques
Sandra González Gallardo, *Elena Bárcena-Martín*, *Salvador Pérez-Moreno*, *Mariano Luque*

Reducing the poverty rate is one of society's greatest challenges. In this sense, this work analyses the poverty in twenty-four European countries, through a combination of statistical and multiobjective techniques. Our focus is to analyze the potential impact on overall and child poverty of different features of social transfers. To this end, we first estimate two logistic regressions models with independent micro variables - sociodemographic characteristic - and macro variables - cash social benefits as percentage of GDP, cash child and family benefits as percentage of total cash benefits, percentage of mean-tested cash benefits over total cash benefits and percentage of cash benefits spent on poor children. Secondly, a multiobjective optimization problem with two objective functions is defined for each country using the previous models. The aim is to obtain the combination of the macroeconomic variables minimizing the rate of overall and child poverty. Indeed, the solutions obtained must keep the difference between the child poverty rate and the overall poverty rate lower than 1%, and increases in spending on child benefits must be accompanied by a reduction in mean-tested benefits, or vice versa. In most of the countries, given the value of cash benefits over the GDP, there is a tendency to increase child benefits rather than mean-tested benefits. At the same time, child benefits appear to be preferred as universal rather than conditional on income. Based on these results, we can suggest certain orientations in the design of benefits to fight global and child poverty in Europe, while reducing the differences between both rates.

2 - Socioeconomic markers of longer lockdown periods post COVID-19 emergence in the Santiago Metropolitan Region
Diana Prieto, *Diego Martinez*, *Felipe Feijoo*, *Felipe Pachano*, *Luis Lillo Otarola*, *Rodrigo Martinez*, *Sumona Datta*, *Carlton Evans*

To refrain from exponential growth of the coronavirus disease 2019 (COVID-19), stringent non-pharmaceutical interventions (NPIs) were implemented in South American metropolitan cities, exacerbating the existing landscape of socioeconomic deprivation. The Metropolitan Santiago Region in Chile has entrenched socioeconomic inequalities across its municipalities and presents a good setting to evaluate COVID-19 disparities. This paper uses survival analysis to assess the association between socioeconomic factors and the hazard of reopening or lifting NPIs. When tested in independent Cox proportional hazard models, educational attainment, domestic violence, income poverty, and human development index were significant predictors of longer lockdowns. This result enhances our understanding of disparities due to COVID-19 - Municipalities with structural disadvantages in social health determinants take longer to reopen. Therefore, in the absence of effective vaccines or financial support to stay at home amidst an emerging outbreak, interventions fostering individual resilience and social support should be considered for better management of future pandemic outbreaks.

3 - Improving food access through agency recruitment: Incorporating Diversity and Equity in Agency Location Problems
Lauren Davis, *Funda Samanlioglu*

Food Banks are non-profit hunger relief organizations that collect and distribute surplus food to individuals in need. Food distribution to individuals occurs through a network of partner agencies (like soup kitchens and food pantries). The number of partner agencies and where to recruit the agencies is an important network expansion decision as it increases food accessibility. In this work, we present a data-driven framework to identify how to grow a food bank's network through agency recruitment, while simultaneously considering their goals of increasing access to food to diverse populations. We specifically present a multi-objective location model to determine which potential agencies to partner with based on their capacity, programs offered, and population served.

4 - Smart Cities in Serbia: Measuring Success Beyond Economic Growth
Jelena J. Stanković, *Ivana Marjanović*, *Igor Novaković*

Smart city development has become increasingly important for enhancing the quality of life, sustainability, and economic competitiveness of cities. As cities in the Republic of Serbia strive to become smarter, there is a need for comprehensive and multidimensional measures of their performance. This paper develops a smart city index, incorporating economic, social, and environmental dimensions, using Entropy and Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) methods, and based on a set of indicators selected from existing literature and adapted to the local context of Serbia. The indicators are grouped into three dimensions: economic, social, and environmental; their weights are determined through the Entropy method, taking into account the degree of correlation between the indicators; and PROMETHEE is then used to determine the composite score and ranking of the cities in the sample. Additionally, the study examines the relationship between the smart city index and the at-risk-of-poverty indicator to explore whether smart development strategies are associated with greater social equity. The data is collected from various official sources, including the Statistical Office of the Republic of Serbia and the Ministry of Environmental Protection. The importance of smart city development lies in its potential to enhance the quality of life for citizens, promote sustainable development, and increase economic competitiveness. By leveraging technology and innovation, smart cities can improve the efficiency of public services, reduce traffic congestion and pollution, enhance public safety, and promote social inclusion. The smart city index proposed provides a valuable tool for policymakers and practitioners to assess and to benchmark the performance of cities and guide future smart development strategies in the Republic of Serbia; it can help identify areas for improvement and guide resource allocation toward priority areas. Furthermore, the study provides insights into the relationship between smart city development and social equity, informing policies aimed at reducing poverty and inequality. The findings can contribute to the broader global discourse on smart city development and provide insights for other countries and regions.

Climate Change and Resilience

Cluster: Sustainability Analytics and Modeling
Invited session
Chair: *Hulya Julie Yazici*
Chair: *Esnil Guevara*

1 - Changing Global Cargo Vessel Traffic in a Future with Declining Arctic Sea Ice
Elise Miller-Hooks, *Wenjie Li*

Global warming has led to declining sea-ice in the Arctic Ocean, making it easier for ice-class vessels to navigate Arctic waters for greater portions of the year. As sailing conditions in these waters improve over coming decades, these passageways are expected to open for larger portions of the year and to become increasingly viable options for unsupported transit and even open-water vessels. This presentation presents an optimization modeling methodology for global-scale solution and a data-driven Bayesian network risk prediction approach for estimating global maritime cargo flow patterns under future climate scenarios with declining Arctic Sea ice.

2 - Probabilistic Seismic Hazard Analysis for industrial-scale telescopes in Chile
Esnil Guevara, *Dora Jimenez*, *Anthony D. Cho*

Scientific progress in geography and celestial bodies has been made possible in large part thanks to industrial-scale telescopes; these instruments have allowed a better understanding of the structure and evolution of the universe. To obtain an ideal astronomical observation, telescopes are carefully placed in strategic locations to capture the best possible signals and images. Chile in particular has a series of geographical and climatic conditions suitable for the development of astronomy worldwide, one of these places is located in the Atacama Desert in the south of the American continent, since having a dry climate reduces atmospheric interference and provides clear skies. Chile has great potential to become - indisputably - the Astronomy Capital of the World in the next few years. Natural disasters are of special interest when evaluating the impact they can have on infrastructures of interest; in our case, we want to focus on the possible failures this extreme natural event can cause on the observatories where these industrial-scale telescopes are located. There is evidence natural disasters have the particularity of generating geographically correlated faults, this means the damage generated by a natural disaster has a radius of impact depending on the point of origin of the event; in the specific case of earthquakes, one of the influential factors is the proximity to the epicenter. For this reason, studying faults generated by earthquakes is not easy, since it is the most unpredictable natural disaster, with little occurrence in some cases, but with high impact.

In this work, we focus on the study of possible failures this extreme natural event may cause in the observatories where these industrial scale telescopes are located; we studied the seismic impact on industrial-scale telescopes located in Chile using probabilistic seismic hazard analysis (PSHA) to measure the reliability of the observatory structures. This strategy allows us to incorporate the geographical characteristics of the location of the telescopes. Within the experimental results, we observed how the failure probabilities increase as

more flexible damage levels are considered; we considered four damage classifications, from the HAZUS Manual for earthquakes. Likewise, we considered different infrastructure classifications from the same manual allowing us to consider the physic.

3 - Role of economic resilience on hurricane recovery
Hulya Julie Yazici

Hurricanes are devastating natural disasters, experienced with an increased frequency in US and abroad. Economic resilience refers to inherent and adaptive responses to disasters, leading individuals and communities to avoid potential losses. Several factors may help a local economy's capacity to withstand or to recover from market, competitive, and environmental shocks. Studies on the impact of disasters on regions reveal the influence of many factors on the preparedness and recovery capability. Previous research shows conflicted findings, with respect to economic resilience and recovery, based on unemployment rate, employment growth or income per capita. This study presents a framework on economic indicators explaining the role of economic resilience on regions dealing with repeat hurricanes.

4 - Data driven approach to exploring the applicable digital technologies toward energy transition in the oil and gas industry
Eunji Jeon, *Naeun Yoon*, *So Young Sohn*, *Su Jung Jee*

Both oil and gas (O&G) companies are confronted with significant changes toward a low-carbon economy. Implementation of digital technologies can play an important role for those firms in the energy transition era. Existing studies on the O&G industry's transitions have only examined one of the two main pillars, however, the shift to low-carbon energy and the adoption of digital technologies. Moreover, these studies have been conducted in a qualitative approach, such as based on the opinions of domain experts, prone to bias and subjectivity. In this study, we propose a data-driven approach to identify the digital technologies playing a major role when O&G companies with specific technological capabilities aim to achieve a certain directional energy transition. We perform association rule mining in terms of both energy transition and digital transformation, using patent classification codes from the patent applications filed with the United States Patent and Trademark Office. We extract the rules from green energy technologies in the O&G industry and from the digital technologies utilized in the process of energy transitions, respectively, expecting meaningful relations among traditional fossil fuel-related technologies, green energy technologies, and digital technologies. By linking the rules obtained from the perspectives of energy transition and digital transformation, we identify the digital technologies leveraged in undergoing specific energy transitions. This study employs a quantitative approach based on patent data to analyze the transition trends of specific low-carbon energy strategies and applicable digital technologies for each strategy, for the first time. Our results can assist O&G companies to design technology strategies for efficient energy transitions by leveraging digital technologies.

Humanitarian Operations

Cluster: Sustainability Analytics and Modeling
Invited session
Chair: *Gabriel Solari Carbajal*

1 - Crowdsourced Humanitarian Relief Vehicle Routing Problem - Definition and Formulations
Javaiz Parappathodi, *Claudia Archetti*, *Ivana Ljubic*

There has been a significant increase in the frequency and severity of natural disasters, causing a huge number of deaths and monetary loss across the world. Given the limitation on the part of the emergency services to plan for one-off unpredictable events, it is only logical to use crowdsourcing as an effective tool for humanitarian relief. In this problem, we consider a situation where people are in need of relief materials in the aftermath of a natural disaster. Some drivers have been crowdsourced to deliver relief materials to the people in need, after collecting them from a supply point in the geography. The need is to optimize the routing of these drivers to reach out to victims. We first look at the problem definition and the challenges of choosing the right objective function for humanitarian rescue efforts. We compare the effectiveness of different objective functions and their relative performance. We also develop three solution approaches - an iterated local search-based heuristic, a classic Branch-and-Cut and a decomposition-based method. The formulations are compared on the basis of quality and time performance. Additionally, the features of different formulations are compared to derive some interesting insights. We find that reducing the problem size does not result in any computational gains; instead, it hampers the performance. Computational experiments are conducted to investigate the variation of the performance of the problem with a change in problem parameters as well.

2 - Study of the Citizen Security in Peru under a Systemic Approach
Gabriel Solari Carbajal, *Esther Berger*

In Peru, according to figures from the Instituto Nacional de Estadística e Informática (INEI), as of 2022, 22.4% of people have been victims of some criminal act, and this number increases in large cities. The most frequent crimes are theft of money, cell phones and vehicles; threats and intimidation; physical and/or psychological abuse; and sexual offenses, kidnapping, extortion and fraud (INEI, 2023). El Consejo Nacional de Seguridad Ciudadana (CONASEC) published the National Citizen Security Plan 2019-2023 as the main management document of the Peruvian State to deal with a series of crimes in the country. The guidelines for government investment in citizen security are several years behind schedule.

The plans implemented by the central Government, Municipalities, Regional Governments and other instances are disjointed among themselves, reducing their effectiveness against insecurity; they do not contemplate all the components of the problem. The Population has expressed its perception of having suffered kidnappings, assaults and rapes, and they complain about inefficiency and corruption in precautionary security institutions. The population and municipalities have developed isolated security actions to reduce or end crime.

Among the causes of citizen insecurity are: unemployment, poverty, lack of education, lack of adequate laws and corruption of institutions, such as the Judiciary and the Police. Insecurity damages the process of many activities, especially economic ones, such as tourism, and those related to social welfare, such as health. This research reviews citizen security from a long-term systemic vision, including a greater number of components; under this aspect, decision-making will be strengthened.

3 - Should I stay or should I go? The challenge of dispatching the right ambulance in the real world
David Olave-Rojas, *Stefan Nickel*

Emergency Medical Services still face critical technical and logistical challenges, demanding decision support tools, specially designed for evaluating emergencies presented in modern society. Current tools do not always allow a correct evaluation when dispatching an ambulance to a specific emergency, however, partly because these tools do not evaluate only dispatch strategies, but dispatch-and-relocation approaches. In this work, we present a study based on a simulation-online optimization approach to face the ambulance dispatching problem. This study relies on the comparison of static, dynamic and mixed online dispatch strategies, by means of a realistic hybrid simulation model, composing a Simulation-Online Optimization Performance Evaluation Framework. Using two different case studies from German EMS, the proposed approach ensures a more realistic and accurate performance evaluation and comparison, as it takes into account the influence of the interrelation between resources, dynamic travel speeds, and the actual conditions in the system. Our study also presents the interplay between the number of ambulances versus demand and how this affects the dispatch strategy performance. Dynamic mixed dispatch approaches are more reliable, with better performance and

better response to emergencies versus classical approaches, for realistic scenarios.

Sustainable Transportation & Energy

Cluster: Sustainability Analytics and Modeling
Invited session
Chair: *Fatma Gzara*

1 - Blockchain for Sustainable Distribution: Counterfeit Detection in Pharmaceuticals
Samir Elhedhli, *Joe Naoum-Sawaya*, *Paulo Carvalho*

Counterfeiting is a worldwide problem, exacerbated by the ease of access through e-commerce and online shopping; this calls for innovative technologies, such as blockchain, to enhance the distribution of pharmaceutical products by preventing fake products from reaching consumers. We investigate the strategic use of blockchain technology to deter deceptive counterfeits from infiltrating legitimate distribution channels and consider a setting where blockchain increases the capability of detecting counterfeits. This capability comes at an increasing cost, possibly financially discouraging manufacturers from adopting the technology. Blockchain is not always financially beneficial, and manufacturers can strategically balance between product quality and blockchain investment. Furthermore, genuine manufacturers may be less interested to differentiate products based on quality, but rely on blockchain to block counterfeits.

2 - Network Design for Urban UAV Traffic Management
Fatma Gzara

Unmanned aerial vehicles (UAV), or drones, are seen as a sustainable alternative to trucking for last mile delivery in urban and suburban areas; their wide-spread adoption faces hurdles, such as when it comes to the necessary technology and infrastructure to manage UAV traffic. UAV traffic management systems (UTM) are being developed, and one strategic decision facing UTM providers is how to design the airspace available for UAV flight. We consider a UAV traffic network design problem in an urban setting where UAVs fly along the street network. The decision is to select a subset of the existing street network and to design their three dimensional projection into the skies. We develop models to address the various issues relevant to UAV traffic, such as the trade-offs between risk and cost of the traffic network, effects of deviation from minimum risk and minimum length paths, and hedging against uncertainty in flight origins, destinations and frequency.

3 - Performance-Based Contracts for Energy Efficiency Projects
Ali Shantia, *Sam Aflaki*, *Roman Kapuscinski*

Energy efficiency projects are often executed by specialized entities, namely energy service companies (ESCOs), whose typical core business uses performance-based contracts, where payment terms depend on the energy savings achieved. ESCOs, despite their success in some sectors, face several challenges in others. First, some clients are more risk averse and, thus, less willing to contract for projects whose outcomes are uncertain. Second, a lack of monitoring protocols leads to ESCO's moral hazard problems. Third, the resulting contracts for an energy efficiency project often lead to changed consumption behavior; hence, it is more difficult to evaluate the energy savings due to the project itself. This paper studies ESCO contract design issues emerging from these challenges and shows when coordinating contracts exist and when they may not exist. Various customers and different informational requirements (particularly, the capability to verify the achieved energy efficiency) lead to different designs of contracts. Even in the most challenging case of individual customers, however, simple piecewise linear contracts work reasonably well. To improve their profitability, ESCOs can reduce uncertainty about the EE technology level employed and/or develop ways of verifying post-project energy efficiency. Since policymakers are understandably keen to promote energy efficiency, we also show how regulations and monetary incentives can reduce inefficiencies in ESCOs' relationships and maximize environmental benefits.

Sustainable Systems

Cluster: Sustainability Analytics and Modeling
Invited session
Chair: *Carlos Ernani Fries*

1 - A Strategic Gaming Model for Equitable and Financially Sustainable Health Systems
Luis Lillo Otarola, *Diego Martinez*

Today, 30% of world population lacks access to basic healthcare services, and one in every four people confronts significant catastrophic expenditure. The UN and the WHO have made a worldwide call to action for universal healthcare to ensure all people enjoy healthy lives in equity.

Acute unplanned illnesses and injuries happen everywhere daily, regardless whether there is an accessible and affordable health system to address them. These emergency health conditions significantly contribute to out-of-pocket spending, bankruptcy, and poverty worldwide, making them a significant part of the global disease burden. Improving access to quality emergency treatment has the potential to prevent death and disability around the world, and this has been enshrined as a global health priority in multiple World Health Assembly declarations. While the emergency care system (safety net) is an essential component of universal healthcare, the link between progress on universal healthcare and emergency disease outcomes is still unknown. Our first science question is, on a global scale, does more universal healthcare result in better emergency care outcomes?

Chile has the third highest emergency care system utilization rate in the OECD. Despite pursuing universal healthcare since 2005, Chile's progress has been hampered by underinvestment and poor management in government-funded organizations and by rising costs in the private system. Social determinants of health, including place of residence, socioeconomic status, education, and ethnic characteristics, create further overlaying complexities. Major social and political Chilean stakeholders are currently debating the future of the Chilean health system with a long-term perspective on equity and financial sustainability. Specifically, the transformation of Chile's health system from a volume to a value-based payment system. For example, under a volume-based scheme, a provider can be compensated for an initial surgery and then compensated again if the patient needs to be readmitted. With a value-based approach, providers are given compensation a single time and would not be compensated for readmission. Our second research question is, on a national scale, can we design an optimal value-based system for Chile with equity and financial sustainability while considering the strategic behavior of typical stakeholders in two-tiered health systems?

2 - A bi-objective optimization framework for designing a carbon capture and storage supply chain network with pricing policy
Arman Derakhti, *Ernesto D.R. Santibanez Gonzalez*

Carbon capture and storage (CCS) technology and pricing policies are two fundamental mitigation strategies employed to address the issue of carbon emissions and climate change. The successful implementation of these strategies is contingent, however, upon addressing the uncertainty surrounding public reaction to the installation of CCS infrastructure. These uncertainties can result in project cancellations or delays and subsequently impact the overall cost of deploying CCS infrastructure. The entire CCS supply chain must operate in accordance

with sustainability policies. Previous studies have predominantly focused on investing in mitigation strategies or exploring the integration of social objectives with CCS technology; none have addressed the influence of social objectives on the openness of reservoirs. Thus, there exists a notable research gap in comprehending the impact of social objectives on reservoir openness and the total cost associated with the CCS supply chain while considering pricing policy. This article examines the influence of social objectives on reservoir openness and overall cost of the CCS supply chain; to achieve this, a two-stage mixed-integer linear programming approach is developed to optimize the design of the supply chain network. In the first stage, a single-objective model is employed to minimize the costs regarding capture, transportation, and sequestration, in addition to considering the cost of CO2 emissions to the atmosphere across the various carbon tax prices. Moving to the second stage, a bi-objective model is implemented to maximize social acceptance towards CO2 injection wells (reservoirs) and analyze the impact of cultural dimensions. Through this approach, the objective is to design a sustainable supply chain network for CCS technology, simultaneously optimizing economic and social objectives, while also accounting for CO2 pricing. To validate the proposed model, a case study is conducted within the European Union cement industry, a prominent contributor to carbon emissions across industries. When social objectives are maximized, there is an increase in costs compared to the economic optimum.

3 - Data envelopment analysis applied to indicators of sanitation service in Brazil
Carlos Ernani Fries, *Andréia May*, *Ana Camanho*

This study applies the Data Envelopment Analysis (DEA) technique to evaluate the efficiency of the provision of water supply and sewage services in Santa Catarina state, Brazil, serving approximately seven million people. The data were collected from the database from official sources for the year 2021. Intensive exploratory research in the laws, norms, and technical documents from the main sources related to Brazilian basic sanitation allowed the identification of the most relevant variables for the analysis. These key indicators were framed in specific categories related to quality in the provision of services and financial sustainability. Contextual variables were also considered to assess their effect on Decision Making Units' performance. Finally, the categories and factors having a major impact on the efficiency and universalization of water supply and sanitation services in Santa Catarina were determined by the specification of Composite Indicators. Several municipalities have not yet reached the desired efficiency levels; their performance can be improved by planning actions, focused on the categories with performance levels below expectations. In turn, the identification of efficient municipalities allows benchmarking of best practices. This allows for exploring the decisions made in pursuing enhanced service levels, alongside the reduction of water loss and optimization of resource usage. Applying the scientific method and unbiased research instruments sheds light on the recent discussions involving the update of the Brazilian legislation on basic sanitation, and it allows for the design of assertive public policies. Thus, this study can contribute to the definition of guidelines for a regulatory framework, foreseeing the universalization of sanitation services by 2033 for the entire Brazilian territory, with estimated investments of around $70 billion.

4 - A Dynamic Model Development of the Effect of Installed Fan Speed on Temperature, Humidity, and the Weight of Agricultural Products in a Greenhouse
Linda Orjaroen, *Chulin Likasiri*

Solar greenhouse drying is a widely used method for preserving and drying agricultural products. Maintaining optimal conditions within the greenhouse can be challenging, however, due to fluctuations in temperature and humidity in and outside the greenhouse. This research aims to develop a dynamical model incorporating the effect of installed fan speed on temperature, humidity, and the weight of agricultural products in a greenhouse.[U+202F]The model is tested using data collected from two case studies: banana drying and herb drying. Collected data include air temperature, air humidity, irradiance, product weight, and product temperature. A system of Ordinary Differential Equations (ODEs) is used to describe the dynamics of the system, and unconstrained optimization is used to estimate the parameters giving the best-fit model for the collected data. The model's performance is tested using statistical analysis. The model can effectively predict temperature and humidity changes in the greenhouse as well as product-weight loss over time. The outcome of this research is a mathematical model effectively predicting the weight of the finished products given the speed of the installed fan.

Stress-testing Algorithms via Instance Space Analysis

Cluster: Tutorials
Tutorial session
Chair: *Kate Smith-Miles*

1 - Stress-testing Algorithms via Instance Space Analysis
Kate Smith-Miles

Instance Space Analysis (ISA) is a recently developed methodology to support objective testing of algorithms. Rather than reporting algorithm performance on average across a chosen set of test problems, as is standard practice, ISA offers a more nuanced understanding via visualisation of the unique strengths and weaknesses of algorithms across different regions of the instance space that may otherwise be hidden on average. It also facilitates objective assessment of any bias in the chosen test instances, and it provides guidance about the adequacy of benchmark test suites and the generation of more diverse and comprehensive test instances to span the instance space. This tutorial provides an overview of the ISA methodology and the online software tools (see matilda.unimelb.edu.au) enabling its worldwide adoption in many disciplines. Several case studies from classical operations research problems will be presented to illustrate the methodology and tools, including timetabling, travelling salesman problem, and 0-1 knapsack; applications to machine learning will also be highlighted.

Seaside Planning: Overview and Implementation 1

Cluster: Tutorials
Tutorial session
Chair: *Rosa G. González-Ramírez*

1 - Seaside Planning: Overview and Implementation Part 1
Rosa G. González-Ramírez, *Eduardo Lalla-Ruiz*

Maritime transport and international shipping are the backbone of global supply chains and, therefore, have a significant role in international trade. In this context, container terminals are strategic logistics nodes aimed at providing cargo transfer services while enabling the connection of multiple modes of transportation. Resources at terminals, such as equipment, personnel, quay and yard space, as well as landside access and parking spaces, are scarce. For that reason, managers and relevant stakeholders must be supported by decision support systems to fully utilize them. This involves efficiently planning, executing, and controlling different terminal operations, such as berthing, quay deployment, yard allocation, etc., so their realization meets certain predefined goals, e.g., short waiting time, low costs and service level, among others. In this tutorial, we will provide participants with an overview of the main planning decisions at container terminals and depict their main features. We will focus on optimization problems arising at the seaside of the terminal, giving more attention to berth scheduling operations by means of the well-known berth allocation problem. We will review some variants and approaches for that problem, as well as specific features of real operations at port terminals. The second part of this tutorial is practical - we will hands-on implement a berth allocation model in a computational language and solve

some instances with free and commercial solvers. Results will be analyzed to discuss the main trade-offs, as well as the main challenges, in the literature and practice of this problem. The tutorial is divided into two sessions: -Session 1 (90 minutes): Seaside planning: overview -Session 2 (90 minutes): Seaside planning: model implementation (practical session) Requirements For the second session, participants should bring their laptops. We expect participants may have some basic programming skills and some basic knowledge of mathematical modelling (i.e., MILP, ILP, IP). The tutorial is also helpful for those participants interested in learning about implementing an optimization model. The participants will receive a brief tutorial to install the required software.

Seaside Planning: Overview and Implementation 2

Cluster: Tutorials
Tutorial session
Chair: *Rosa G. González-Ramírez*

1 - Seaside Planning: Overview and Implementation Part 2
Rosa G. González-Ramírez, Eduardo Lalla-Ruiz

Maritime transport and international shipping are the backbone of global supply chains and, therefore, have a significant role in international trade. In this context, container terminals are strategic logistics nodes aimed at providing cargo transfer services while enabling the connection of multiple modes of transportation. Resources at terminals, such as equipment, personnel, quay and yard space, as well as landside access and parking spaces, are scarce. For that reason, managers and relevant stakeholders must be supported by decision support systems to fully utilize them. This involves efficiently planning, executing, and controlling different terminal operations, such as berthing, quay deployment, yard allocation, etc., so their realization meets certain predefined goals, e.g., short waiting time, low costs and service level, among others. In this tutorial, we will provide participants with an overview of the main planning decisions at container terminals and depict their main features. We will focus on optimization problems arising at the seaside of the terminal, giving more attention to the berth scheduling operations by means of the well-known berth allocation problem. We will review some variants and approaches for the problem, as well as specific features of real operations at port terminals. The second part of this tutorial is practical - we will hands-on implement a berth allocation model in a computational language and solve some instances with free and commercial solvers. Results will be analyzed to discuss the main trade-offs, as well as the main challenges, in the literature and practice of this problem. The tutorial is divided into two sessions: -Session 1 (90 minutes): Seaside planning: overview -Session 2 (90 minutes): Seaside planning: model implementation (practical session) Requirements For the second session, participants should bring their laptops. We expect participants may have some basic programming skills and some basic knowledge of mathematical modelling (i.e., MILP, ILP, IP). The tutorial is also helpful for those participants interested in learning about implementing an optimization model. The participants will receive a brief tutorial to install the required software.

Machine Learning

Cluster: Tutorials
Tutorial session
Chair: *Andres Gomez*

1 - Inference via Discrete Optimization: State-of-the-Art and New Frontiers
Andres Gomez

Machine learning (ML) and artificial intelligence (AI) methods have advanced tremendously over the past three decades: accurate facial/voice recognition technologies are now commonplace, and AIs consistently exhibit super-human intelligence in games (such as Go and Poker). Most ML/AI methods require two settings to be effective, however - access to massive amounts of data and relatively low-stakes situations. Moreover, they are extremely sensitive to data quality and tend to be biased. As a consequence, AI/ML is neither effective nor reliable in the context of several important engineering and societal problems.

There is a recent stream of results showcasing how mixed-integer optimization (MIO) can be used to improve current ML/AI methods. In particular, MIO can incorporate prior beliefs on the structure of the process of interest (such as sparsity) in the form of logical priors, can be used to design interpretable models, can easily accommodate fairness considerations and can handle robust variants of common ML methods. In this tutorial, we review recent applications of MIO methods to improve AI/ML models. We explore the current capabilities and limitations of MIO solvers and discuss the theory and design of effective MIO techniques.

Inventory Problems with Heterogeneous Customers

Cluster: Tutorials
Tutorial session
Chair: *Nesim Erkip*

1 - Inventory Problems with Heterogeneous Customers
Nesim Erkip

Inventory Theory is considered one of the earliest topics in the operations management/operations research field. One of the standard assumptions in inventory-related research is the homogeneity of customers. In fact, customers in most practical applications may not be homogenous; they are affected differently by taste, prices, lead time, service quality, return conditions, and other factors. The decision problem we consider is similar to the decisions of the classical inventory theory, with some customer choices available in the environment. We name these problems as inventory problems with heterogeneous customers.

For a single-item environment, one way of differentiating customers is to assume they belong to different priority classes. Traditionally, demand for a customer class is assumed to be independent from the demand of others. For inventory systems with multiple items, the classical assumption considers mutually independent demands, whereas, in reality, substitution is possible. Customer choice models consider the interaction of an assortment of variety stocking decisions and customer choice decisions. Hence, these models consider the endogeneity of demands for multiple products.

This tutorial aims to review contributions of inventory problems with heterogeneous customers. As much as possible, we aim to exclude the vast literature regarding the revenue management topic and concentrate more on an abstract aspect resulting in heterogeneity. Of course, pricing strategy is one of the factors resulting in customer heterogeneity, where customers are price sensitive.

We review three groups of research: 1) Customers are grouped in different priority classes for a single item inventory problem. 2) Customers are grouped in different priority classes for a multi-item inventory problem under substitution. 3) Customers are differentiated by their perception of available choices, reacting to decisions made by the solver of the inventory problem.

The focal point of the tutorial is to emphasize the role of considering demand endogeneity for decision-making in inventory systems.

A Tutorial on Quantum Computing and Combinatorial Optimization

Cluster: Tutorials
Tutorial session
Chair: *Carleton Coffrin*

1 - A Tutorial on Quantum Computing and Combinatorial Optimization
Carleton Coffrin, *Fred Glover*, *Gary Kochenberger*

Recent years have witnessed a series of exciting developments in quantum computing and its potential for solving combinatorial optimization problems. In this two-part talk, we first give an overview of quantum computing technology, its present state, breaking developments, and most promising forms. This introduction to the technology is followed by an overview of how quantum-based solvers are being used to solve combinatorial optimization problems, including an introduction to the fundamental QUBO model - how it is formed and how it is used to solve important problems. Accompanying this, we describe important extensions and variations of the QUBO model, expanding its range of application, bolstered by several explicit examples and substantial computational experience.

Innovations in Urban Delivery

Cluster: Urban Transportation
Invited session
Chair: *Lei Zhao*

1 - Deep reinforcement learning models for solving practical time-dependent vehicle routing problems
Zhaoxia Guo, *Feng Guo*, *Miao Wang*, *Qu Wei*, *Stein W. Wallace*

Time dependencies of travel speeds in time-dependent vehicle routing problems (TDVRPs) are usually considered by discretizing the planning horizon into several time periods; practical TDVRPs need to face complex road networks and frequently time-varying travel speeds. Considering the frequently time-varying travel speeds and the heterogeneity of travel speeds on each road link, the computational complexity of TDVRPs will be greatly increased, since a large number of time periods are used to evaluate candidate solutions accurately in model and solution construction for practical TDVRPs. We develop novel deep reinforcement learning (DRL) models, with dimension-reduction and gate mechanisms, to solve practical TDVRPs in real urban road networks. In our models, a multi-head attention-based dimension-reduction mechanism is proposed to reduce the dimension of model inputs and obtain enhanced node representation, where a gate mechanism is introduced to obtain better information representation. Based on a travel speed dataset from a Chengdu road network, we conduct numerous experiments to evaluate the effectiveness of the proposed models on practical TDVRPs, regardless of consideration of time windows. Our models can solve TDVRPs with 240 time periods and up to 250 customers effectively and efficiently and produce significantly superior overall performances over two representative heuristic methods and two state-of-the-art DRL models. Especially, compared with a recent tabu search method for TDVRPs, our models can reduce computation time by up to 3,500 times and improve the solution performance by up to 20%, and they have a good generalization performance. The model, trained for the 30-customer TDVRP with time windows, can be used directly to solve problems with up to 250 customers effectively, by generating superior solutions over those generated by four benchmarking methods.

2 - Assessing the effect of consolidation of freight transport: A case study in Norway
Mario Guajardo, *Cosku Can Orhan*, *Julio C. Góez*, *Stein W. Wallace*

The growing urban population and increasing e-commerce sales cause more and more parcel deliveries within cities. Motivated by these trends, in this project we cooperate with public authorities of a city in Norway to study the effect of consolidation of freight transportation. The effect is measured along metrics on distance and number of stops. To compute these metrics, we deploy a three-stage methodology, involving clustering, capacitated vehicle routing, and split delivery problems. We use data on road network and population from the public authority and on deliveries from a major carrier. We present results for a number of data instances, varying the number of companies, their size and the degree of consolidation. Ultimately, our work aims at providing city authorities with a tool for the assessment of freight transport regulations.

3 - A Multi-Stage Approach for the Two-Echelon Location-Routing Problem Applied to a A Real-World Urban B2B Delivery in Brazil
Claudio B. Cunha, *Hugo Yoshizaki*

With delivery drop sizes decreasing as establishments place orders more frequently, delivery vehicles are often only partially loaded due to time windows and journey length constraints, resulting in increased delivery costs. This problem is particularly evident in the distribution of beverages and foods in highly dense urban areas in Brazil and other developing countries. To address the challenges faced in distribution, a potential solution is to adopt a hybrid two-echelon distribution model. In this model, some delivery routes may start at a satellite facility, served from vehicles departing from a central distribution center. Alternatively, some outlets may have operational characteristics making them better suited for routes in the first tier. Determining the optimal assignment of routes based on outlet characteristics (like small and large clients) is usually a critical aspect of a two-echelon distribution model. On the other hand, clients may present significant variation in drop size per delivery, privileging smaller vehicles for small orders and larger vehicles for larger ones. First, we looked into historical data comprising delivery data with GPS traces for monitoring the vehicles performing the routes. To analyze and compare single and multiple echelon distribution alternatives, we propose a 5-step approach for the two-echelon location-routing problem including a mathematical programming formulation and some heuristics to obtain minimum cost routes. Some different motorized vehicles can be employed in both echelons (e.g. trucks and vans). Motorcycles can be utilized in the second echelon as well as active modes, such as cargo bikes and walking deliveries. We evaluate the performance of our model and heuristic approaches using classic examples from the literature and conduct a case study in the Rio de Janeiro Metropolitan Region to demonstrate the method's potential, yielding promising results. The proportion of small orders is more relevant to optimize the distribution system than the outlet category; additionally, a significant part of these orders are costly to deliver. It would be more appropriate to focus on daily order profiles, rather than a general customer categorization.

4 - E-fulfillment Strategies under Stochastic Orders and Cancellations
Tirui Cao, *Lei Zhao*, *Yang Wang*, *Yiqiang Su*

In the order fulfillment process of an online retailer, holding the received order for a while before dispatching it to a warehouse can help hedge the risk of future order cancellations and reduce the total order fulfillment cost. In this paper, we explicitly consider customers' stochastic order cancellation behavior and study how to design order-holding strategies to reduce the total fulfillment cost, while not significantly disturbing the existing order fulfillment process (e.g. work schedules of the warehouses). We formulate the problem as a Markov Decision Process (MDP), design a cost function approximation (CFA) policy, and apply the optimal computing budget allocation (OCBA) method to search for the optimal policy parameters. We conduct numerical experiments based on the (masked) real data from a major online retailer in China. Preliminary numerical results demonstrate the

proposed CFA policy can better capture the uncertainty in order arrivals and cancellations and, thus, outperform the benchmark policies.

Urban Transportation for the Public Sector

Cluster: Urban Transportation
Invited session
Chair: *Jorge A. Acuna*

1 - Comparing daily networks of Bus Rapid Transit use during different stages of Covid19. The case of Transmilenio, in Bogotá, Colombia
Laura Lotero, *Juan David García-Arteaga*

The Covid19 crisis affected not only the health system, but also economic sectors such as urban transportation systems. This is due to the fear of spreading in public spaces and the strong mobility restrictions in the early stages of quarantines. In Bogotá, the bus rapid transit system, TransMilenio (TM), reduced the number of trips to below 20% of their historical values during the confinement periods, and has not fully recovered to pre-pandemic levels. In order to identify and analyze the effects of the strict quarantines and their subsequent relaxations in the TM system, we used card validation data of entrance to the system, and we build daily origin-destination mobility networks, using as origin node the station where a card ID performed a swipe validation in the morning, and as destination node the validation station of the same card ID in the afternoon. The links were weighted with the number of trips between each OD pair. The daily networks were built with the data available from February to December 2020, released to the community under the covid19 policy measures. In data analysis we need to synthesize the massive data to an actionable size for decision making purposes, therefore, we wanted to compare these daily networks in order to extract spatial-temporal patterns and gain insights into the disruptions of the pandemic in the urban context. Comparing networks is a difficult task, with complexity that grows exponentially with the number of nodes to consider. This is simplified when there is a known node-to-node correspondence between the networks. In this case, since the nodes correspond to stations of the TM system, Vertex Ranking was used, which assumes that two networks are similar if the classifications of their nodes are similar. The network measure used to rank nodes was PageRank. The network clustering method manages to separate groups of mobility patterns. The identified clusters coincide with the base situation (before the Covid19 emergency), strict quarantine, early relaxation of mobility restrictions, subsequent economic recovery policies, as well as weekends and holidays. Results show a promising tool for the analysis of large amounts of networked data, such as in urban mobility networks, and can be used to perform temporal analysis of datasets in different contexts.

2 - Selectively closing recycling centers to meet sustainability goals in Bavaria
Bismark Singh, *Christian Schmitt*, *Malena Schmidt*

Recycling centers - facilities where the population must themselves bring large household waste to recycle - assist in processing waste before the residual material's eventual incineration or disposal, but their operation leads to pollution and emissions of waste in direct conflict to sustainability goals. The German state of Bavaria has seen recycling centers close in the last two decades, forcing some populations to be far from open recycling centers, leading to increased waste dumping in nature. Sensible closures are more important as countries plan to achieve climate neutrality.

We present and apply a quadratic facility location optimization model determining how to selectively close recycling centers, ensuring populations remain within good reach and that open centers are not disproportionately burdened. Within Bavaria, even when a moderate number of recycling centers are closed, large degrees of access can still be ensured. Bavaria suffers from disparity in recycling patterns in rural and urban regions, however, both in terms of motivation to recycle and the locations of the facilities. We promote a policy favoring retention of recycling centers in rural regions, while selectively closing facilities in urban regions, to remove these regional differences.

This presentation is based on two works currently under peer-review.

3 - A multistage stochastic programming model for ambulance allocation to emergency departments
Jorge A. Acuna, *Daniela Cantariño*, *Jose Zayas-Castro*, *Michael Lozano Jr.*

Emergency department (ED) overcrowding is a widespread crisis for the US healthcare system and a significant contributor to adverse patient outcomes. Despite being recognized as the most expensive source of care, ED visits have increased by over 60% since 1997, surpassing 130 million per year. Consequently, the past decade has witnessed a national trend of constructing free-standing EDs. However, the transfer and redirection of patients between on-campus and free-standing EDs exacerbate challenges such as ambulance diversion and prolonged wait times experienced by emergency medical services (EMS). While the efficiency of ED and hospital operations can greatly influence patients' waiting times, overcrowding cannot be solely attributed to individual efficiencies; rather, it is a result of a dysfunctional healthcare system. To address this issue, we propose a multistage stochastic mixed-integer programming (MSSMIP) formulation for allocating ambulance emergencies to on-campus and free-standing EDs over a finite planning horizon. The model takes into account patients' conditions, priorities, real-time route determination, and the capabilities and occupancy levels of EDs to minimize travel and waiting times. Given the computational complexity of MSSMIP problems, we have developed an enhanced progressive hedging algorithm (EPHA) to analyze a real-size scenario in Hillsborough County, Florida. While commercial solvers may achieve optimality faster than the EPHA for small instances, they struggle with larger (real) scenarios even after hours of processing. In contrast, the EPHA achieves smaller gaps and near-optimal solutions in less than 15 minutes for real scenarios. Failure of EMS decision-makers to consider current and future utilization levels can result in free-standing EDs becoming bottlenecks in the system. In contrast to a myopic approach, implementing a centralized decision system for allocation policies should reduce the average patient waiting time by up to 45% (27 minutes), enhance the efficiency of EMS and EDs, and provide robust alternatives during demand fluctuations. Furthermore, properly utilizing the combined capacity of free-standing and on-campus EDs should be sufficient to deliver prompt patient care, even in high-demand scenarios. Lastly, we conducted a sensitivity analysis on primal and dual multipliers, highlighting the penalty update method's significance in improving the EPHA's accuracy and computation time.

Urban Logistics

Cluster: Urban Transportation
Invited session
Chair: *Sabine Limbourg*

1 - The Vehicle Routing Problem with Transfers
Maichel M. Aguayo, *Francisco Avilés*, *Subhash Sarin*

In the vehicle routing problem (VRP), a fleet of capacitated vehicles serve a set of customers with known demands at minimum cost. The VRP with split delivery (VRP-SD), a variant of VRP, permits customer demands to be served by different vehicles, resulting in a significant cost reduction. In this work, we study the VRP with transfers (VRP-T), where customer locations can be used as transfer locations to exchange load among vehicles. Routing costs can potentially be reduced by at least 50% by allowing transfers in the VRP. We develop a two-index mixed-integer programming model and a direct solution method with advanced start (DSM-AS) for solving this problem. Computational results show substantial savings in the costs incurred and the number of vehicles required when transfers are allowed and suggest transfers are at least as effective in reducing the cost as split delivery.

2 - Algorithmics for fleets of connected, geo-localized and cybersecure vehicles: a real-world case-study
Mattia Demidio, *Gabriele DiStefano*

Innovation in 5G high-throughput technologies has enabled the possibility of building new classes of information systems and developing new applications previously impossible to implement, mostly due to limitations in terms of bandwidth and reliability of transmission channels. One of the most interesting examples, highly promising in terms of positive impact on urban environments and their societal and economical welfare, is systems of autonomous or semi-autonomous fleets of connected vehicles, where IoT devices are combined with communication and computational technologies into heterogeneous and distributed infrastructures, unifying hardware, networks and software. These systems are typically characterized by the exchange, among involved computational entities, of large amounts of data, e.g. sensor data, needing to be properly collected and timely processed to support various services, e.g. network optimization, task allocation, coordination, and route planning.

As well documented in the literature, to efficiently provide most of these services, especially in a real-time context, the most effective way is to adopt a graph model of the data (e.g. to model communication networks, roads, or interactions between vehicles) and to employ suited graph algorithms to solve properly defined computational problems on graph datasets (e.g. shortest paths or distributed consensus).

While research in this context has been extensive from a theoretical perspective (in both computer science and engineering fields, due to the large set of applications relying on graph-based modeling and processing), studies and investigations of an experimental and practical nature on implementations of graph algorithms, to establish their performance and assess their deployment in real-world contexts, are rather scarce.

In this talk, we showcase the main phases of the prototyping of an information system employing fleets of semi-autonomous connected vehicles, currently under testing in the city of L'Aquila (Italy), and highlight the most important design and deployment choices adopted with respect to the algorithmic component of the system.

This work is partially supported by project EMERGE: innovation agreement between Ministry of Economical Development, Abruzzo Region, Radiolabs, Elital, Leonardo, Telespazio, University of L'Aquila and Centre of EXcellence EX-Emerge, funded by Italian Government under CIPE n. 70/2017 (Aug. 7, 2017).

3 - Integrating logistics operations for sustainable last-mile deliveries with a consolidation-based assignment heuristic
Sabine Limbourg, *Fatima Ezzahra Achamrah*, *Tanguy Baiwir*, *Florian Peters*

The City Line project aims to promote collaboration between logistics operators and to ensure low emissions for last-mile deliveries in cities. This collaboration involves sharing existing assets and capacities, logistics facilities, and services with competitors to save costs, improve global transport efficiency, and extend one's service zone; it is based on negotiating framework contracts with transport providers, occurring before collaboration. An algorithm uses a depth-first search strategy for each commodity, starting from a set of services to pick up the delivery request at its origin and within the pickup time window and continuing by appending services to drop off at the destination location within the drop-off time window. The search terminates when no more services are to be appended or when the maximum number of intermediate stops is reached; it results in a set of feasible paths, each a sequence of services. Then, for each period within the rolling horizon, the algorithm selects the path with the minimum score, depending on cost and environmental impacts, and assigns the delivery request to this path, updating the capacities of the services in the path, accordingly. Delivery requests for subsequent periods within the rolling horizon are assigned to the used paths accommodating the new request with the least additional capacity requirement using the BestFit algorithm. The potential impacts of collaboration and low-emission zones are analyzed in Belgium through four scenarios. Six types of vehicles, each with its characteristics and emissions, are included, and costs are computed considering the weight and volume of parcels. The results show that increased collaboration among logistics service providers leads to higher loading rates, greater acceptance of delivery requests, and more diverse use of vehicles, significantly reducing CO2 and NOX emissions. These findings offer promising implications for adopting collaborative transport and sustainable logistics, contributing to developing the Physical Internet concept. The study's results could also provide valuable insights for policymakers in developing decision-support tools to promote sustainable logistics practices.

This research was funded by the Walloon Region, grant number 8294, in the framework of the City Line project.

Urban Transportation Networks

Cluster: Urban Transportation
Invited session
Chair: *Ricardo de la Paz Guala*

1 - Dynamic pricing and dispatching in ride-sharing networks: A deep reinforcement learning approach
Thomas De Munck, *Philippe Chevalier*, *Jean-Sébastien Tancrez*

This work considers the problem of a ride-sharing platform, connecting supply and demand in a network of locations over a finite horizon; it manages the network by making pricing and dispatching decisions. The goal of this research is to understand (i) how pricing and dispatching decisions can interact with each other to generate additional value, and (ii) to what extent customer and driver behaviors influence these two decisions.

To address these questions, we propose an original model formulated as a discrete-time Markov decision process, where the demand is composed of impatient customers, heterogeneous in their willingness to pay. The driver supply can decide where to reposition, according to the platform's prices in different locations. The platform seeks a joint pricing-dispatching policy maximizing revenues, while minimizing repositioning and abandonment costs.

Due to the "curse of dimensionality", the model is not solved with conventional dynamic programming methods; instead, we use a deep reinforcement learning (DRL) framework to find a near-optimal policy. Specifically, we develop an algorithm blending mathematical programming with DRL, proceeding in three steps. First, the algorithm finds a heuristic policy by solving multiple mathematical programs, based on a deterministic relaxation of the model. Second, it trains a DRL agent to replicate the heuristic policy. Third, the algorithm accounts for stochastic components of the environment by using the Proximal Policy Optimization algorithm.

In a numerical study, we demonstrate the efficiency of our algorithm in comparison with other DRL algorithms, both in terms of final performance and computational effort. Then, we explore several managerial insights by applying our model to a case study in New York City. Namely, we study the consequences of optimizing only one of the two decisions (dispatching vs. pricing only), in comparison with optimizing the two decisions jointly. Then, we examine the implications of customer and driver behavior on the algorithm's policy.

2 - A Markovian approach for stochastic dynamic traffic assignment for private transport networks
Ricardo de la Paz Guala, *Cristian E. Cortes*, *Pablo A. Rey*, *Benjamin Heydecker*

We present a Markovian dynamic modelling approach for Stochastic Dynamic Traffic Assignment, where the route choice model the remainder of each journey is assigned probabilistically to the available routes and integrated into a dynamic setting with suitably chosen traffic models to estimate flow-depending costs. Specifically, the route-choice model associated with the Markovian Traffic Equilibrium (MTE) from Baillon and Cominetti (2008) is adapted to the dynamic features of the Dynamic Traffic Assignment (DTA) formulational modeling considerations established by Addison and Heydecker (1996).

We denote this framework as the Markovian Dynamic Traffic Assignment model (MDTA).

The main contributions of our paper are the following:

- The introduction of the concept of reasonable arc towards a destination. Intuitively, the arc takes motorists not farther from their destinations, if minimum cost routes are meant to be used. Then, we assume motorists only travel through reasonable arcs. This approach narrows down the options considered to move forward to each destination. - The formulation of a DTA integrating Baillon and Cominetti's MTE and Addison and Heydecker's modeling framework in an approach respecting the First In, First Out (FIFO) rule. It has three components: an exogenous demand rate profile; a traffic model adapting the deterministic queueing model to represent the behavior of flows within arcs and defining arc cost functions, affected by delays due to queues; and a dynamic adaptation of the arc-choice model of the MTE, using as criterion the expected minimum costs from the current node to each destination, splitting the flow rate among its reasonable outgoing arcs. - The implementation of a solution algorithm inspired by Dial's algorithm (Dial, 1971), but repeated at each time increment, resulting from the discretization of the time period and with a reversed order of the two passes of network scanning. - Insights on the computational implementation of the algorithm. When compared to the SDTA formulation from Han (2003) (a suitable approach given its similar considerations, but with a route-based perspective), our MDTA outperformed when it comes to cost indicators and showed more realistic outputs. This, because in the MDTA not all arcs are assigned with positive flow (as not all of them are reasonable), resulting in the use of only a realistic portion of the transport network.

3 - Public transport reliability and urban transport policy

Fernando Feres, *Ricardo Giesen*, *Luis Rizzi*

Public transport is essential for cities' development, and its role is crucial; for Latin America, the share of public transport usage over the entire urban trip reaches nearly 50% in several major areas. In this region, public transport is commonly affected by reliability problems, however, and the lack of public transport control is common in many developing countries. When fleet management is poor, undesirable effects, such as bus bunching and lateness, are intensified. User satisfaction and comfort are closely related to public transport reliability. Headway variability is a relevant source of service unreliability, generates overcrowding and decreases user satisfaction. We analyze user mode choice and welfare, considering crowding and waiting times when the bus system is unreliable, and the optimal private operation of the public transport system. The headway mean is inversely proportional to the patronage root square, if crowding effects are less significant than waiting time effects. On the other hand, if waiting time effects are less important, then the headway mean is inversely proportional to public transport demand. The novel results come from the optimal headway standard deviation - inversely proportional to the patronage root square, recovering the Mohring effect for the headway standard deviation. The inclusion of a reliability measure for public transport is a major source of economies of scale, and the result is a cornerstone of this model. To analyze the optimal private operation of public transport, we consider a public transport firm maximizing its profit. The results from the first-order conditions show optimal rules for the headway mean and headway standard deviation are the same as in the welfare maximization problem. The optimal result is different, however, because optimal pricing is different; the for-profit firm charges higher prices to public transport users than the welfare maximization price. In general terms, the profit maximization situation reduces welfare due to reduced total transport demand. Finally, we conduct several numerical experiments to assess how bus reliability impacts both user mode choice and welfare, allowing us to exemplify the theoretical results and to show the importance of including reliability issues in public transport optimization.

4 - Application of a three-level Stackelberg model for the design of urban transportation networks in the Bogotá subway system.

Mauricio Cepeda Valero, *Jose Fidel Torres Delgado*, *Andres Gonzalez*

Urban transport planning involves different agents, such as transport users and suppliers. Additionally, the implementation of a transport system in a city can have various impacts on the environment, including the creation of new opportunities for industry or commerce by making certain zones more accessible. The city of Bogota in Colombia is currently facing such a case, with the proposed construction of a first line of subway. The subway would cover 23.9 kilometers, include 16 stations, and have a projected capacity of 72,000 passengers per hour. With this significant project, the use of tools showing the impact on land use and commerce in various zones is highly relevant.

This study focuses on analyzing the dynamics between transportation infrastructure, commerce, and transportation demand for the implementation of the subway in Bogota. A Stackelberg model was designed to relate the agents of interest and to project mobility patterns and location of commercial and residential areas. The model developed is a multilayer network model, consisting of the origin-destination network, the moving network, the transportation system network, and the commercial zone network.

In the model, users decide whether to use the transportation system or another means of transport to minimize their travel costs. The provider of the transportation system seeks to minimize operating costs while satisfying the greatest number of users, and retailers seek to improve profits by locating at points with the greatest flow of potential customers. The models are presented as linear models interacting with each other.

With the implementation of the model in the case study, users prefer to use the system, and, quickly, the system reaches its full capacity. Expanding the system is not easy, however, due to high construction costs. Another significant factor is how commerce is highly incentivized by the implementation of the subway system. This case illustrates the benefits of designing the system as a network model, allowing for easy adaptation of centrality measures to evaluate changes in the networks associated with each of the agents.

Analytics for Prescribed Burning and Firebreaks Location in Forest Fires Prevention

Cluster: Use of Analytics in Forest Fires Management
Invited session
Chair: *Bibiana Granda*

1 - A Risk-Averse Multiobjective Stochastic Approach for the Prescribed Burning Problem

Begoña Vitoriano, *Javier León*, *John Hearne*

Prescribed burning is a widespread practice within forest fire management; it reduces the risk of ignition, but, above all, reduces the risk of fire spreading and makes it easier to control. In this model, the landscape is divided into cells and each cell's vegetation age is used as a proxy. In particular, the connections between old-age cells and their length are defined as high risk spread links, and the cells' areas and their ages as a proxy for ignition and wildfire intensity. Unfortunately, modifying the vegetation of a piece of land can negatively affect the existing fauna. Wild animals need vegetation with certain characteristics, and different species will have different requirements. Vegetation age can also be useful for representing animals' preferences, usually modelled with concave piecewise linear functions. Additionally, the problem of determining where to carry out controlled burnings has great uncertainty, since it is impossible to know in advance how much forest area can be treated during the year, due to the limited time windows when they can occur. To collect all these aspects, a multi-objective stochastic programming model has been developed to determine when and where to carry out prescribed burning, taking into account future plans and landscape evolution. A risk-averse approach is adopted combining CVaR and OWA and solvable by linear programming without adding complexity to the restrictions further than those representing the system itself (following the methodology introduced in León, J., Puerto, J., Vitoriano, B. (2020) 'A risk-aversion approach

for the multiobjective stochastic programming problem', Mathematics 8(11), 2026). The model is applied to a realistic case located in Andalusia, Spain.

2 - Wildfire fuel management: robust optimisation of prescribed burning
Dmytro Matsypura, *Nam Ho-Nguyen*, *Tomas Lagos*, *Oleg Prokopyev*

Wildfires are an integral part of many ecosystems; their severity has been worsening rapidly, however, over the past decade. The intensity and severity of wildfires can be reduced through fuel management activities - the most common and effective being prescribed burning. We propose a multi-period robust optimization framework based on mixed integer programming techniques to determine the optimal spatial allocation of prescribed burning activities over a finite planning horizon. We model fuel accumulation with Olson's equation, and, in contrast with the existing literature, our formulation is linear, significantly improving scalability. To capture potential fire spread along with irregular landscape connectivity, we model the landscape as a graph and exploit graph connectivity measures (e.g. the number of connected components) as optimization objectives. Our computational experiments reveal interesting insights and demonstrate the advantages and limitations of the proposed approach.

3 - Comparison of metaheuristics to solve a simulation-based optimization problem for firebreak allocation
David Palacios, *Jaime Carrasco*, *Sebastián Dávila*, *Andrés Weintraub*

Global warming and the overpopulation of previously uninhabited areas has led to an increase in forest fire episodes; it becomes urgent to control these events. One of the most used techniques are firebreaks - interventions in the vegetation of the forest to prevent the advance of fire. In this work, metaheuristics are studied, implemented and compared to locate firebreaks optimally in the landscape, prior to a forest fire episode and, thus, to reduce the impact of this event. For this purpose, research is carried out in the literature to find similar works using metaheuristics to find any algorithm able to adapt to the problem. Subsequently, Genetic Algorithm, GRASP and Tabu Search are tested in pilot implementations, and a greedy methodology is proposed to perform the local search of the algorithms in a more effective way. Results in the final implementation show good performance of Genetic Algorithm in scenarios of medium- and high-operational capability, as well as in low- and medium-stochasticity scenarios. Finally, these metaheuristics could be useful in the prevention against forest fires in certain geographical areas, such as Chile.

4 - A firebreak location model using two-stage stochastic programming
Matias Vilches, *Jaime Carrasco*, *Sebastián Dávila*, *Franco Quezada*, *David Palacios*

Forest fuel management constitutes a means of fire prevention through the reduction and manipulation of landscape fuels or the application of firebreaks, to decrease or prevent fire progression. The determination of the optimal location and timing of treatments within the landscape is a stochastic combinatorial optimization problem, however, involving the interaction of different management options with the realization possibilities of a random variable representing the spread of fires - not well understood at present. In this study, we propose a two-stage stochastic integer programming (SIP) model for the spatial allocation of firebreaks at the landscape scale. The model takes as input an approximation of the probability distribution of wildfires by choosing a set of weather conditions and initial ignition points, considering historical data of the landscape. The model minimizes the expected loss due to fire by determining the optimal spatial allocation of firebreaks. We use the Cell2Fire simulator and the Canadian Fire Behavior Prediction (FBP) System to re-create fire scenarios, and we present four variations of the model to support different landscape management decisions. The first variation minimizes expected loss due to fire, while the second variation minimizes the burn probability (BP) of the most burned zone. The third variation minimizes the BP of the most burned scenario, and the fourth variation incorporates a risk measure (CVaR) over the set of possible scenarios. Our approach solves the problem for real forests using exact methods and considering the interaction of treatments to the spread of fire; to evaluate the effectiveness of our solutions, we compare them with random solutions on various wildfires. Preliminary numerical results show an average of 7% and 8% improvement in loss due to fire and BP of the most burned zone, respectively, compared with random solutions. By considering the probability distribution of wildfires and using a stochastic optimization approach, our model provides a more effective solution than traditional methods. Results suggest a good performance of our approach to support landscape management decisions and mitigate the impact of wildfires on rural forests.

Analytics for Fire Supression and Protection in Forest Fires Management

Cluster: Use of Analytics in Forest Fires Management
Invited session
Chair: *Begoña Vitoriano*

1 - A novel integrated approach to protect biodiversity values from future fires using fire simulation and optimization
Rodrigo Mahaluf-Recasens, *Jaime Carrasco*, *David Palacios*, *Andrés Weintraub*

One way to mitigate the uncontrolled effect of wildfires and, at the same time, protect our communities and ecological values is through forest fuel management, constituting a means of fire prevention, involving planned changes to living or dead wildland fuels, e.g. prescribed burning, pruning and firebreaks, to lessen fire behaviour potential. In this study, we propose an integrated fire simulation and optimization approach to locate firebreaks on the landscape, so the ecological damage resulting from the removal of vegetation in areas allocated to firebreaks is offset by the preservation of ecological values, as a result of the treatment protective action. We use a prioritization metric - called Downstream Protection Value - identifying crucial cells having a significant influence on the spread of fires on the landscape and the potential for ecological loss. We illustrate our solution on a real landscape, located in the Araucania Region, Chile, whose wildland fuels are classified according to the Chilean KITRAL fire behavior system, and on real animal species observations taken from the Global Biodiversity Information Facility occurrence dataset.

2 - A goal programming model for joint evacuation and commodity distribution facing Wildfires.
M. Teresa Ortuno, *Inmaculada Flores*, *Gregorio Tirado*

Wildfires or Forest Fires are unplanned, uncontrolled and unpredictable fires, and they can affect human societies severely, if occurring close to human settlements. In particular, they may require moving people and assets temporarily to safer places to protect them, either before, during or after the occurrence of the fire.

In this work, we address the problem of organizing the supported evacuation of vulnerable people threatened by a wildfire, taking them to previously located shelters, and simultaneously allocating the shelters with the necessary goods. To facilitate the evacuation planning, potential evacuees are classified according to their health condition, so they are taken care of properly. People arrive at the collection points within the risk area over time, in a dynamic way, according to their own susceptibility about the danger, and supplies should arrive at the temporary shelters on time to cover their needs. In the same way, dynamic arrival of potential supplies over time to the distribution points, due to donations, for example, is considered. Different vehicles are available for transportation of people and goods, with limitations regarding the use of some connections due to the fire.

All these factors define a real-life problem formulated as a mixed integer optimization model - dynamic, multi-modal and multicriteria.

There are several criteria to be considered, such as the evacuation of as many people as possible, the time of evacuation of critical and non-critical population, the cost of operation or the arrival of supplies, but there is no trade-off between some of them, so a lexicographical goal programming model is chosen. This model is more flexible than others available in the literature and allows for a joint approach to people evacuation and supply distribution.

Finally, a case study regarding the Saddleridge Fire at San Fernando Valley in Los Angeles County, California, in October 2019, is introduced and used to validate the proposed model. It will also be shown how the model responds to different situations appearing during the spread of the fire.

3 - A new integer programming model for wildfire suppression and resource management: the Team Orienteering Problem with Variable Time Windows
Bibiana Granda, *Begoña Vitoriano*

Wildfire suppression encompasses all the actions taken to put a fire out. In these urgent situations, the decision-making process requires advanced supporting tools to develop the most suitable strategy in a short time. In this regard, operations research provides models not only simulating the fire behavior, leaving the dispatching decisions to the wildfires' manager, but also optimizing management of available resources to contain the fire as soon as possible and minimize the burned area. In this work, a model for wildfire suppression and resource management is presented, leading to a new problem called Team Orienteering Problem with Variable Time Windows (TOPVTW). The solution to this problem is the location of certain controls hindering the fire spread, considering their timing and the paths linking those control locations. These paths and locations are available depending on fire arrival times, modified by the suppression strategy itself. Several researchers have studied the Team Orienteering Problem with Time Windows, where time windows in nodes are known in advance. For the fire suppression problem, time windows are variable, since the availability of nodes and links will depend on the decisions made to control the fire. Other problems, such as those to control disease spread, can also be modeled with this problem, where variable time windows apply only to nodes. The fire suppression problem is more difficult since, not only the nodes, but also links are subject to variable time windows. A mixed integer programming model for the TOPVTW applied to the fire suppression problem and resource management is presented in this work, along with computational results.

Analytics for Forest Fires Prevention and Risk Analysis

Cluster: Use of Analytics in Forest Fires Management
Invited session
Chair: *Rodrigo Mahaluf-Recasens*

1 - Integrated OR and AI systems for fire prevention
Rodrigo Mahaluf-Recasens, *Jaime Carrasco*, *Andrés Weintraub*, *David Palacios*, *Alejandro Miranda*

We present an overview of the work we have been carrying out in designing fuel management to minimize the damage caused by future forest fires. We can view action on fires in three major frameworks: prevention and preparedness, detection and response, and restoration and adaptation. Our work concentrates on prevention. We can define four major phases in this process: data acquisition and management, determination of probabilities of spatial ignitions, stochastic simulations of fire spread, and creating fire breaks or other actions to minimize fire spread to valuable areas. In other talks in these sessions, we will present detailed explanations of each phase, including considerations of carbon emissions and protection of wildlife. A main contribution in our work is the integration of a spread simulation model Cell2Fire, with optimization decision-making using OR and AI approaches. We will present results of real forests in Cataluña and Chile, showing the advantages of applying analytics techniques to fuel management. This work has been supported by institutions in Chile (Fondef) and in Europe (Fire Res). Fire Res is a collaboration of over 30 European institutions (universities, research institutes, and consulting companies) . We will present the importance of this multidisciplinary international collaboration.

2 - Deep Learning-Based Satellite Image Classification for Accurate Deforestation Detection in Romania
Darie Moldovan, *Marian Lucian Cotolan*, *Adina Tilea*, *Bianca Nicoleta Marian*

This research proposes a deep learning framework for monitoring and detecting deforestation in Romania, utilizing two distinct datasets consisting of satellite images - one featuring the Amazon basin and the other featuring four key regions of the Carpathian Mountains, collected by the Sentinel-2 satellite. To achieve accurate classification, the images were pre-processed and resized to serve as input for two classification models: a Convolutional Neural Network (CNN) model implemented using SAS Viya and a fine-tuned ResNet50 model developed in Python. The objective of this research is to predict whether deforestation has taken place, contributing to the preservation and protection of Romania's forests. The findings of this study can have significant implications for the development of effective strategies to combat deforestation and promote sustainable land use practices.

3 - Deep Reinforcement Learning for Fire Prevention
Lucas Murray, *Andrés Weintraub*, *Jaime Carrasco*, *Tatiana Andrea Castillo Jaimes*

Wildfires have increased in severity and frequency, primarily due to climate change, turning them into one of the most destructive forces in nature. Designing and constructing landscapes to withstand fires has become a critical practice, and, therefore, the development of sophisticated tools to support decision-making in this area is increasingly pressing. In this regard, we propose using one of the most novel AI paradigms, Reinforcement Learning, to solve the firebreak allocation problem. Through the use of the fire-spread simulator Cell2Fire and Deep Neural Networks, we programmed an intelligent agent to learn how to position firebreaks in a small forest, achieving near-optimal performance. Furthermore, we generated relatively good solutions using known heuristics and pre-trained the agent with them, resulting in equal or superior performance, suggesting significant potential in the use of intelligent agents to solve OR-tasks, particularly in settings such as fire-prevention. We could solve instances of up to 20x20 cells, demonstrating convergence with good results. This is one of the first times Reinforcement Learning has been used to solve the problem.

Clusters

Agricultural Innovations and OR

Alejandro Mac Cawley
Pontificia Universidad Católica de Chile
amac@ing.puc.cl

Lluís Miquel Plà-Aragonès
University of Lleida
lmpla@matematica.udl.es

Agricultural Innovations and OR

Alejandro Mac Cawley
Pontificia Universidad Católica de Chile
amac@ing.puc.cl

Lluís Miquel Plà-Aragonès
University of Lleida
lmpla@matematica.udl.es

Agrifood Supply Chains

Marcela C. Gonzalez-Araya
Universidad de Talca
mgonzalez@utalca.cl

J. Rene Villalobos
Arizona State University
rene.villalobos@asu.edu

Analytics and Data Science

Dries Benoit
Ghent University
dries.benoit@ugent.be

Kristof Coussement
IESEG School of Management
k.coussement@ieseg.fr

Sebastian Maldonado
University of Chile
sebastianm@fen.uchile.cl

Wouter Verbeke
KU Leuven
wouter.verbeke@kuleuven.be

Richard Weber
University of Chile
richard.weber@uchile.cl

Analytics and Data Science

Dries Benoit
Ghent University
dries.benoit@ugent.be

Kristof Coussement
IESEG School of Management
k.coussement@ieseg.fr

Sebastian Maldonado
University of Chile
sebastianm@fen.uchile.cl

Wouter Verbeke
KU Leuven
wouter.verbeke@kuleuven.be

Richard Weber
University of Chile
richard.weber@uchile.cl

Applied Probability and Statistics

Timothy Matis
Texas Tech University
timothy.matis@ttu.edu

Combinatorial Optimization

Silvano Martello
University of Bologna
silvano.martello@unibo.it

Paolo Toth
University of Bologna
paolo.toth@unibo.it

Combinatorial Optimization

Silvano Martello
University of Bologna
silvano.martello@unibo.it

Paolo Toth
University of Bologna
paolo.toth@unibo.it

Continuous Optimization

Dimitri Papadimitriou
3nLab
dpapadimitriou@3nlab.org

Data Envelopment Analysis and its Applications

Ali Emrouznejad
University of Surrey
a.emrouznejad@surrey.ac.uk

Data Envelopment Analysis and its Applications

Ali Emrouznejad
University of Surrey
a.emrouznejad@surrey.ac.uk

Data Science Meets Optimization

Patrick De Causmaecker
KU Leuven
Patrick.DeCausmaecker@kuleuven.be

Data Science Meets Optimization

Patrick De Causmaecker
KU Leuven
Patrick.DeCausmaecker@kuleuven.be

Discrete Optimization

Rym M'Hallah
Kuwait University
rymmha@yahoo.com

Game Theory and Operations Management

Greys Sosic
University of Southern California
sosic@marshall.usc.edu

Game Theory, Market Design, and Mathematical Economics

Martin Bichler
Technical University of Munich
martin.bichler@in.tum.de

Gerhard-Wilhelm Weber
Poznan University of Technology
gerhard-wilhelm.weber@put.poznan.pl

Healthcare Management

Yong-Hong Kuo
The University of Hong Kong
yhkuo@hku.hk

IFORS Prize for OR in Development Finalist Presentations

Mario Guajardo
NHH Norwegian School of Economics
Mario.Guajardo@nhh.no

Keynote Talks

Alice Smith
Auburn University
smithae@auburn.edu

Keynote Talks

Alice Smith
Auburn University
smithae@auburn.edu

Knowledge, Technology, and Innovation

A. D. Amar
Seton Hall University
ad.amar@shu.edu

Knowledge, Technology, and Innovation

A. D. Amar
Seton Hall University
ad.amar@shu.edu

Location, Network Design, and Routing

Vladimir Marianov
Pontificia Universidad Catolica de Chile
marianov@ing.puc.cl

Location, Network Design, and Routing

Vladimir Marianov
Pontificia Universidad Catolica de Chile
marianov@ing.puc.cl

Location, Network Design, and Routing

Vladimir Marianov
Pontificia Universidad Catolica de Chile
marianov@ing.puc.cl

Logistics

Janny Leung
The University of Macau
jannyleung@um.edu.mo

Maritime Logistics

Rosa G. González-Ramírez
Universidad de Los Andes, Chile
rgonzalez@uandes.cl

Eduardo Lalla-Ruiz
University of Twente
e.a.lalla@utwente.nl

Maritime Logistics

Rosa G. González-Ramírez
Universidad de Los Andes, Chile
rgonzalez@uandes.cl

Eduardo Lalla-Ruiz
University of Twente
e.a.lalla@utwente.nl

Metaheuristics

Celso Ribeiro
Universidade Federal Fluminense
celso.ribeiro@gmail.com

Roger Z. Rios
Universidad Autonoma de Nuevo Leon
roger@yalma.fime.uanl.mx

Mobility and Transportation Systems

Maximilian Schiffer
Technical University of Munich
schiffer@tum.de

Multi-Objective Optimization: Theory, Algorithms, and Applications

Hadi Charkhgard
University of South Florida
hcharkhgard@usf.edu

Multilevel and Stochastic Optimization Methods

Cole Smith
Syracuse University
colesmit@syr.edu

Multiple Criteria Decision Analysis

Salvatore Greco
University of Catania
salgreco@unict.it

Optimization of Power Systems

Ignacio Grossmann
Carnegie Mellon University
grossmann@cmu.edu

Ricardo Pinto de Lima
KAUST - King Abdullah University of Science and Technology
ricardo.lima@kaust.edu.sa

Optimization of Power Systems

Ignacio Grossmann
Carnegie Mellon University
grossmann@cmu.edu

Ricardo Pinto de Lima
KAUST - King Abdullah University of Science and Technology
ricardo.lima@kaust.edu.sa

OR and Food Sourcing and Distribution

Gonzalo Enrique Mejia Delgadillo
Universidad de La Sabana
gonzalo.mejia@unisabana.edu.co

Juan G. Villegas
Universidad de Antioquia
juan.villegas@udea.edu.co

OR Education

Alexander Vinel
Auburn University
azv0019@auburn.edu

Gerhard-Wilhelm Weber
Poznan University of Technology
gerhard-wilhelm.weber@put.poznan.pl

Hulya Julie Yazici
Florida Gulf Coast University
hyazici@fgcu.edu

OR Education

Alexander Vinel
Auburn University
azv0019@auburn.edu

Gerhard-Wilhelm Weber
Poznan University of Technology
gerhard-wilhelm.weber@put.poznan.pl

Hulya Julie Yazici
Florida Gulf Coast University
hyazici@fgcu.edu

OR for Development and Developing Countries

Gerhard-Wilhelm Weber
Poznan University of Technology
gerhard-wilhelm.weber@put.poznan.pl

OR for Development and Developing Countries

Gerhard-Wilhelm Weber
Poznan University of Technology
gerhard-wilhelm.weber@put.poznan.pl

OR in Energy

Rodrigo Moreno
University of Chile
rmorenov@gmail.com

Enzo Sauma
Pontificia Universidad Catolica de Chile
esauma@ing.puc.cl

OR in Energy

Rodrigo Moreno
University of Chile
rmorenov@gmail.com

Enzo Sauma
Pontificia Universidad Catolica de Chile
esauma@ing.puc.cl

OR in Military, Defense, and International Security

Greg Parlier
Colonel, US Army Retired
gparlier@knology.net

OR in Sports

Celso Ribeiro
Universidade Federal Fluminense
celso.ribeiro@gmail.com

OR in Sports

Celso Ribeiro
Universidade Federal Fluminense
celso.ribeiro@gmail.com

Packing and Routing

Rym M'Hallah
Kuwait University
rymmha@yahoo.com

Packing and Routing

Rym M'Hallah
Kuwait University
rymmha@yahoo.com

Plenary Talks

Alice Smith
Auburn University
smithae@auburn.edu

Production Management, Supply Chain Management, and Location

Stefan Nickel
Karlsruhe Institute of Technology (KIT)
stefan.nickel@kit.edu

Scheduling in Logistics

Alena Otto
University of Passau
alena.otto@uni-passau.de

Erwin Pesch
University of Siegen
erwin.pesch@uni-siegen.de

Scheduling in Logistics

Alena Otto
University of Passau
alena.otto@uni-passau.de

Erwin Pesch
University of Siegen
erwin.pesch@uni-siegen.de

Software for Optimization

Robert Fourer
AMPL Optimization Inc.
4er@ampl.com

Software for Optimization

Robert Fourer
AMPL Optimization Inc.
4er@ampl.com

Special Sessions

Alice Smith
Auburn University
smithae@auburn.edu

Special Sessions

Alice Smith
Auburn University
smithae@auburn.edu

Special Sessions

Alice Smith
Auburn University
smithae@auburn.edu

Special Sessions

Alice Smith
Auburn University
smithae@auburn.edu

Special Sessions

Alice Smith
Auburn University
smithae@auburn.edu

Sustainability Analytics and Modeling

Elise Miller-Hooks
George Mason University
miller@gmu.edu

Hulya Julie Yazici
Florida Gulf Coast University
hyazici@fgcu.edu

Sustainability Analytics and Modeling

Elise Miller-Hooks
George Mason University
miller@gmu.edu

Hulya Julie Yazici
Florida Gulf Coast University
hyazici@fgcu.edu

Tutorials

Alice Smith
Auburn University
smithae@auburn.edu

Tutorials

Alice Smith
Auburn University
smithae@auburn.edu

Urban Transportation

Changhyun Kwon
University of South Florida
chkwon@usf.edu

Use of Analytics in Forest Fires Management

Begoña Vitoriano
Universidad Complutense de Madrid
bvitoriano@mat.ucm.es

Andrés Weintraub
University of Chile
aweintra@dii.uchile.cl

Use of Analytics in Forest Fires Management

Begoña Vitoriano
Universidad Complutense de Madrid
bvitoriano@mat.ucm.es

Andrés Weintraub
University of Chile
aweintra@dii.uchile.cl

Author Index

jalarcon@uchile.cl
Universidad de Chile, Chile

Alarcón-Bernal, Zaida Estefanía 122
zaida.alarcon@unam.mx
Biomedical Systems, Universidad Nacional Autónoma de México, México, Distrito Federal, Mexico

Albert, Laura 149
laura@engr.wisc.edu
Industrial & Systems Engineering, University of Wisconsin-Madison, MADISON, WI, United States

Albornoz, Victor M. 4, 5, 75
victor.albornoz@usm.cl
Departamento de Industrias, Universidad Tecnica Federico Santa Maria, Santiago, Región Metropolitana, Chile

Alencar Rolim, Gustavo 88
gustavo.rolim@usp.br
Department of Production Engineering, University of Sao Paulo, São Carlos, São Paulo, Brazil

Alexandre, Rodrigo 107
alvim.rodrigo54@gmail.com
Instituto Alberto Luiz Coimbra de Pós Graduação de Pesquisa de Engenharia, Universidade Federal do Rio de Janeiro, Rio de Janeiro, RJ, Brazil

Alfandari, Laurent 31
alfandari@essec.edu
ESSEC Business School, Cergy-Pontoise Cedex, France

Alhamwi, Alaa 65
Alaa.Alhamwi@dlr.de
Institute of Networked Energy Systems, German Aerospace Center, Oldenburg, Germany

Alirezaei, Mahsa 142
alirezaei@rsm.nl
Rotterdam School of Management, Erasmus University, Rotterdam, Netherlands

Almeida Coco, Amadeu 89
amadeu.almeida-coco@univ-lehavre.fr
University Le Havre Normandy, France

Almeida, Guilherme 19
guilherme.almeida@petrobras.com.br
POCOS/SPO, Petrobras, Macaé, Rio de Janeiro, Brazil

Alonso-Ayuso, Antonio 32
antonio.alonso@urjc.es
Rey Juan Carlos University, Mostoles, Madrid, Spain

Alonso-Meijide, José María 51
josemaria.alonso@usc.es
Statistics and Operations Research, Universidade de Santiago, Lugo, Spain

Alonso-Mora, Javier 81
j.alonsomora@tudelft.nl
Delft University of Technology, Deflt, Netherlands

Alvarez, Alejandro 133
ale.javier.alvarez@gmail.com
University of Buenos Aires, Buenos Aires, Argentina

Alvarez, Pamela P. 68, 69
palvarez@unab.cl
Center for Transportation and Logistics, and Engineering Science, Universidad Andres Bello, santiago, Chile

Alvarez-Tobon, Germán 120
germanalvarez@itm.edu.co
Instituto Tecnológico Metropolitano, Medellín, Antioquia, Colombia

Alves Beirigo, Breno 81, 107
b.alvesbeirigo@utwente.nl
Industrial Engineering and Business Information Systems, University of Twente, Netherlands

Alves Junior, Paulo Nocera 41
pjnocera@yahoo.com.br
Universidad Católica del Norte (UCN), Escuela de Ingeniería de Coquimbo (EIC), Coquimbo, Chile

Amar, A. D. 64
ad.amar@shu.edu
Management Department, Seton Hall University, South Orange, NJ, United States

Amaruchkul, Kannapha 98
kamaruchkul@gmail.com
National Institute of Development Administration, Bang Krapi, Bangkok, Thailand

Amaya, Rene 82
ramaya@uninorte.edu.co
Industrial Engineering, Universidad del Norte, Barranquilla, Atlantico, Colombia

Amel Monirian, Masoud 71
masoudmonirian@gmail.com
Mechanical and Industrial Engineering, Concordia University, Canada

Amen, Matthias 52
Matthias.Amen@uni-bielefeld.de
Chair for Quantitative Accounting & Financial Reporting, Bielefeld University, Bielefeld, Germany

Amorim, Pedro 141
amorim.pedro@fe.up.pt
Industrial Engineering and Management, Faculty of Engineering of University of Porto, Porto, Portugal

Amorosi, Lavinia 104
lavinia.amorosi@uniroma1.it
Statistical Sciences, Sapienza, Rome, Italy

Anaya-Arenas, Ana María 16
AnaMaria.AnayaArenas@cirrelt.ca
Management and Technology, ESG-UQAM, Montréal, Qc, Canada

Andrade, Tiago 148
tiago.cout.andrade@gmail.com
PSR, Brazil

richard.hartl@univie.ac.at
Business Decisions & Analytics, University of Vienna, Vienna, Austria

rachid.hassani@gerad.ca
Department of Mathematical and Industrial Engineering, Polytechnique Montreal, Montreal, Quebec, Canada

u.hasturk@rug.nl
Operations, University of Groningen, Groningen, Groningen, Netherlands

felicien.heche@heig-vd.ch
Haute École spécialisée de Suisse occidentale (HES-SO), Switzerland

M.He-3@student.tudelft.nl
Delft University of Technology, Delft, Netherlands

xhe@fairfield.edu
Dolan School of Business, Fairfield University, Fairfield, CT, United States

john.hearne@rmit.edu.au
Mathematical Sciences, RMIT University, Melbourne, Victoria, Australia

Carl.Hedenstierna@liverpool.ac.uk
University of Liverpool, Liverpool, United Kingdom

benjamin.heidbrink@uni-bielefeld.de
Chair for Quantitative Accounting & Financial Reporting, Bielefeld University, Bielefeld, Germany

f.javier.heredia@upc.edu
Statistics and Operations Research, Universitat Politècnica de Catalunya - BarcelonaTech, Barcelona, Catalunya, Spain

virgilio.hermoso@gmail.com
Universidad de Sevilla, Sevilla, Spain

carlos.hernandez@iimas.unam.mx
IIMAS, UNAM, Mexico City, Mexico City, Mexico

xhernan5@asu.edu
School of Computing and Augmented Intelligence, Arizona State University, Tempe, AZ, United States

evahgress@tec.mx
Industrial Engineering, Tec de Monterrey, Pachuca, Hidalgo, Mexico

adolfher@ucm.es
Financial & Actuarial Economics & Statistics, Complutense University Madrid, Madrid, Sri Lanka

fhernanb@unal.edu.co
National University of Colombia, Medellín, Colombia

jorge.hernandez.h@uai.cl
Escuela de Negocios, Universidad Adolfo Ibañez, Santiago, Chile

christina.hess@univie.ac.at
Business Decisions and Analytics, University of Vienna, Vienna, Austria

b.heydecker@ucl.ac.uk
Centre for Transport Studies, University College London, London, United Kingdom

niels.hilhorst@uzgent.be
Ghent University Hospital, Department of Dermatology, Ghent, Belgium

ilyas-2.himmich@polymtl.ca
MAGI, Polytechnique Montreal ; Université Mohammed 6 Polytechnique, Montréal, QB, Canada

ihirmas@uc.cl
Industrial and Systems Engineering, Pontificia Universidad Católica de Chile, Santiago, RM, Chile

nam.ho-nguyen@sydney.edu.au
The University of Sydney, Sydney, Australia

michael.hoeck@outlook.de
Lehrstuhl für Industriebetriebslehre, TU Bergakademie Freiberg, Freiberg, Germany

Sally.Hodder@wvu.edu
Department of Medicine, West Virginia University, Morgantown, WV, United States

arild.hoff@himolde.no
Molde University College, Molde, Norway

khoffman@gmu.edu
Department of Systems Engineering and Operations Research, George Mason University, Fairfax, Virginia, United States

aholmes@alumnos.uai.cl

franco.quezada@usach.cl
Industrial Engineering Department, University of Santiago of Chile, Chile

Quezada, Luis 116, 143
luis.quezada@usach.cl
Department of Industrial Engineering, University Of Santiago Of Chile, SANTIAGO, SANTIAGO, Chile

Quila, Daniela 27
dquila6@gmail.com
iNGENIERÍA, UNAB, Melipilla, Region Metropolitana, Chile

Quintairos e Silva, Amanda 17
amandaqsilva@gmail.com
D'Or Institute for Research and Education (IDOR), Rio de Janeiro, Rio de Janeiro, Brazil

Quiroga, Bernardo 61
bernie.quiroga@mail.wvu.edu
John Chambers College of Business and Economics, West Virginia University, Morgantown, WV, United States

Raassens, NÉomie 105
n.raassens@tue.nl
Industrial Engineering and Innovation Science, Eindhoven Univesity of Technology, Eindhoven, Netherlands

Rabelo, Luis 7
luis.rabelo@ucf.edu
Industrial Engineering and Management Sciences, University of Central Florida, Orlando, FL, United States

Racagni, Josefina 115
jracagni@unc.edu.ar
Instituto de Estadística y Matemática, Facultad de Ciencias Económicas - Universidad Nacional de Córdoba, Córdoba, Córdoba, Argentina

Raggio, Raul 75
rragio@udec.cl
Universidad de Concepcion, Concepcion, Chile

Rakhis, Ilyas 61
I.RAKHIS@ocpgroup.ma
OCP Group, Casablanca, Morocco

Rakotonirainy, Rosephine Georgina 137
rosephine.rakotonirainy@uct.ac.za
Department of Statistical Sciences, University of Cape Town, Cape Town, Western Cape, South Africa

Ramalhinho Lourenco, Helena 87, 88
helena.ramalhinho@upf.edu
Universitat Pompeu Fabra, Barcelona, Spain

Ramírez-Ayerbe, Jasone 14
mrayerbe@us.es
Instituto de Matemáticas de la Universidad de Sevilla, Spain

Ramírez-Cobo, Pepa 14
pepa.ramirez@uca.es
Universidad de Cádiz, Cádiz, Spain

Ramik, Jaroslav 112
ramik@opf.slu.cz
Dept. of Informatics and Mathematics, Silesian University, School of Business, Karvina, Czech Republic

Ramón, Nuria 41
nramon@umh.es
Centro de Investigación Operativa, Universidad Miguel Hernández, Elche, Spain

Ramos Tapia, Benjamín 18
benjamin.ramos.t@mail.pucv.cl
Pontificia Universidad Catolica de Valparaiso, Viña del Mar, Valparaíso, Chile

Ramos, Angel Manuel 93
angel@mat.ucm.es
Universidad Complutense de Madrid, Madrid, Spain

Rana, Rupal 145
r.rana@lboro.ac.uk
Business School, Loughborough University, Loughborough, United Kingdom

Rancic, Marko 148
marko.rancic@totalenergies.com
Total Energies, PARIS, France

Rêgo, Fernanda 144
fernanda.rego.100@ufrn.edu.br
Departamento de Engenharia de Produção, Universidade Federal do Rio Grande do Norte, Natal, Rio Grande do Norte, Brazil

Ríos-Fierro, Francisco 55
franrios9930@gmail.com
Departamento de Ingeniería Industrial, Universidad de Concepción, Concepción, Concepción, Chile

Recalde, Diego 32, 35
diego.recalde@epn.edu.ec
Mathematics, Escuela Politécnica Nacional, Quito, Pichincha, Ecuador

Recalde, Fabrizio 72
frecalde@fiuna.edu.py
Ingeniería Industial, Facultad de Ingeniería de la Universidad Nacional de Asunción, Asunción, Central, Paraguay

Recalde, Jorge 3, 72
jlrecalde@uc.cl
Facultad Politécnica, Universidad Nacional de Asunción, San Lorenzo, Paraguay

Redchuk, Andrés 10, 21
andres.redchuk@urjc.es
Rey Juan Carlos University, Fuenlabrada, Spain

Resende, Mauricio 87
mgcr@uw.edu
Industrial and Systems Engineering, University of Washington, Holmdel, New Jersey, United States

Restrepo, Julian 94
juliancamilores@gmail.com

aweintra@dii.uchile.cl
Industrial engineering, University of Chile, Santiago, Chile

dingtony@uci.edu
Institute of Transportation Studies, University of California, Irvine, California, United States

Session Chair Index