



MCDM⁻
26 JUNE
1 JULY
2022^x



26th International Conference on Multiple Criteria Decision Making

Conference Programme



**University of Portsmouth, UK
June 26 – July 1, 2022**



Dear members of the International Society on MCDM, dear colleagues, dear friends

It has been a long time since we last met in Istanbul in 2019. In the three years since we have all learned how to teach by talking to a computer screen, how to attend conferences from home. The most important thing I have learned is that online is not the same as in person. Interaction with students and colleagues face to face is essential to our business. Hence, I am very happy to welcome you to Portsmouth, to the 26th edition of our international conference. I am looking forward to an exciting programme of talks on all aspects of the theory and practice of MCDM. I am sure that discussions after the talks and the social programme following the traditions of the society will bring our community closer together again and kindle future collaboration. Of course, we also have important awards to bestow on eminent scholars as well as the PhD award to a young scholar who will help ensure the future of the society. So do not miss these talks or the conference dinner.

On behalf of the society I would like to thank Alessio and his team for their persistence in organising the conference and welcoming us to Portsmouth.

Matthias Ehrgott

President of the International Society on Multiple Criteria Decision Making



Dear Colleagues, Dear Friends,

Finally, it happens! It is my pleasure to welcome you in Portsmouth (United Kingdom) for the 26th Conference on MCDM. The purpose of the MCDM conference is to bring together all the MCDM community every two years. This time, it has been a gap of three years. It has been a very difficult three years, with lockdowns, social distancing and no travel. I did not want a virtual conference last year because the unofficial face-to-face meetings are for me the most valuable. How many new ideas are born during a discussion in the coffee breaks? You can also ask the speaker in the corridors to explain to you more details, the small part you did not understand during the presentation.

This conference will have the same format as the previous MCDM conferences. It has been a long time since we met; enjoy the conference!!

Best wishes,

Alessio Ishizaka

Chair of the 26th MCDM conference

WELCOME



On behalf of the organizing committee, I am very delighted to welcome you to the 26th International Conference on Multiple Criteria Decision Making (MCDM2022) at the University of Portsmouth.

We are at a time when businesses are facing complex questions about efficiency, sustainability and innovation, so effective decision-making sits at the heart of operational resilience. MCDM2022 brings together academics, researchers, practitioners and other professionals from around the world. It is a great opportunity for the delegates to present, discuss, network, and hear about the recent advances in MCDM. We are honoured to have distinguished plenary speakers: Professor Salvatore Greco from the University of Catania, Professor Murat Köksalan from the University of Michigan, and Professor Luis Martínez from the University of Jaén.

I would like to thank all delegates, scientific and organising committee members, stream chairs, and our Business Services & Research Office for their continuous support.

I add my best wishes for a successful and fruitful conference.

Kind regards

Banu Lokman

Co-chair of the 26th MCDM conference

ORGANISING COMMITTEE

- Alessio Ishizaka (Chair)
- Banu Lokman (Co-chair)
- Dylan Jones (Program Chair)
- Ashraf Labib
- Salvatore Greco
- Negar Akbari
- Maria Barbati
- Salem Chakhar

BUSINESS SERVICES & RESEARCH OFFICE (BSRO) TEAM

- Daniel Smith
- Veronika Smetanova

SCIENTIFIC PROGRAMME COMMITTEE

- Matthias Ehrgott, Lancaster University, UK
- Carlos Coello Coello, CINVESTAV-IPN, Mexico
- Kerstin Daechert, Fraunhofer Institute ITWM, Germany
- Michalis Doumpos, Technical University of Crete, Greece
- José Rui Figueira, Technical University of Lisbon, Portugal
- Salvatore Greco, University of Catania, Italy
- Birsen Karpak, Youngstown State University, USA
- Kathrin Klamroth, Bergische Universität Wuppertal, Germany
- Murat Köksalan, Michigan University, USA
- Banu Lokman, University of Portsmouth, UK
- Alessio Ishizaka, University of Portsmouth, UK
- Dylan Jones, University of Portsmouth, UK
- Caroline Mota, University of Pernambuco, Brazil
- Francisco Ruiz, University of Malaga, Spain
- Hsu-Shih Shih, Tamkang University, Taiwan
- Johannes Siebert, Management Center Innsbruck, Austria
- Theo Stewart, University of Cape Town, South Africa
- İlker Topçu, İstanbul Technical University, Turkey
- Jyrki Wallenius, Aalto University, Finland

Stream Chairs

Stream	Chair
Analytic hierarchy / network processes	Enrique Mu, Rozann Saaty
Evolutionary multiobjective optimization	Carlos Fonseca
Multiobjective optimization	Serpil Sayin
Goal programming	Fouad Ben Abdelaziz
Outranking methods	José Figueira, Salvatore Corrente, Yves De Smet
Rule-based methods and artificial intelligence	Salvatore Greco
Value and utility models	Milosz Kadzinski
Data Envelopment Analysis	Ali Emrouznejad
Best-Worst Method	Jafar Rezaei
Interactive MCDM	Jyrki Wallenius
Applications of MCDA	Sarah Ben Amor, Sachin Mangla

ESSENTIAL INFORMATION

Venue

All event sessions, coffee break and lunch will be held in Richmond and Portland Buildings.

Address: University of Portsmouth, Portland Street, Portsmouth, PO1 3DE, UK.

Registration

The registration desk will be located in the Atrium (ground floor), Portland Building, where you will be able to collect your name badge and registration pack for the event.

Your name badge

You should wear your name badge at all times during the event. It is your admission to the venue (includes refreshments and lunch), and social events.

Wi-Fi Access

The University is part of the eduroam community that allows members to connect to Wi-Fi whilst onsite. If you're visiting from another institution that uses eduroam, you can log in with your username and password from your home institution.

For our external guests, wi-fi access is also available at the University of Portsmouth. To connect to 'UoP GUEST', simply select it from the available list of networks on your device. You will be taken to a page to register, simply fill in the details and you will be connected.

Travelling from/to the airport

Nationwide rail strikes have been called by the RMT union at Network Rail to take place on Tuesday 21, Thursday 23 and Saturday 25 June. If you are planning to take the train from London to Portsmouth, it could impact your arrival plans over the weekend of 25th-26th, please see the website below for the latest updates. It is not recommended to travel on the days of strike actions (21st, 23rd and 25th June) but the regular service is expected to run on Sunday, 26 June, (except the trains before 7.15am) <https://www.southernrailway.com/industrialaction>

- **London Heathrow Airport:** If you fly into London Heathrow Airport, we recommend you to take a taxi or coach to Portsmouth Hard or University of Portsmouth, Cambridge Road. If you do choose to take a taxi (takes about 90 minutes), you should book it in advance to get the best offers possible. The coach takes about 3.5 hours. See the National Express website at <https://www.nationalexpress.com/en> for more details about coach times and prices.
- **London Gatwick Airport:** If you arrive at London Gatwick Airport, we recommend you take the direct train to Portsmouth and Southsea Railway Station. The journey takes about 90 minutes. You can find the latest travel times and ticket prices on the National Rail website (<https://www.nationalrail.co.uk/>). Alternatively, you can take a taxi or coach from your terminal at Gatwick to Portsmouth Hard or University of Portsmouth, Cambridge Road. You will find a full timetable and ticket price information on the National Express website at <https://www.nationalexpress.com/en>.
- **Southampton Airport:** If you fly into Southampton Airport, you should take the train from Southampton Airport Parkway to Portsmouth and Southsea Railway Station. You will need to change trains at either Eastleigh, Cosham, Havant or Southampton Central. The journey takes about 60 minutes. Please check the www.nationalrail.co.uk website for the latest travel times and ticket prices.

Transport

- **Trains:** Portsmouth has two main stations, 'Portsmouth & Southsea' and 'Portsmouth Harbour', both of which are within 10-minute walk from the Conference Venue. For details of train services, please visit: www.nationalrail.co.uk

- **Car parking:** We would encourage you to use public transport where possible. Pay & Display parking is available on Hampshire Terrace (PO1 2QF), Cambridge Road (PO1 2EF), Gunwharf Quays Car Park (PO1 3TZ), or Stanhope Road Car Park (PO1 1DU). Most of them cost approximately £10 for parking all day. Parking is restricted at the University of Portsmouth (UoP) car parks, unless you have a valid UoP parking permit. Failure to display a UoP parking permit will result in a Parking Charge Notice (PCN), payable to Portsmouth City Council.
- **Coaches:** University of Portsmouth, Cambridge Road is the closest bus station to the venue (within 5 minute walk). Portsmouth Hard is the main interchange for coach travel to other parts of the country and is within 10-minute walk from the venue. For details, please visit: www.nationalexpress.com
- **Uber:** Use the Mobile app
- **Taxis:** Use the mobile app or call on 02392 654 321

Accommodation

The University offers accommodation on campus to MCDM participants which could be booked through the registration system.

Address: Rees Hall Southsea Terrace, Portsmouth, Southsea, PO5 3AP (Tel: 02392844884)

Website: <https://www.port.ac.uk/student-life/accommodation/our-halls-of-residence/rees-hall>

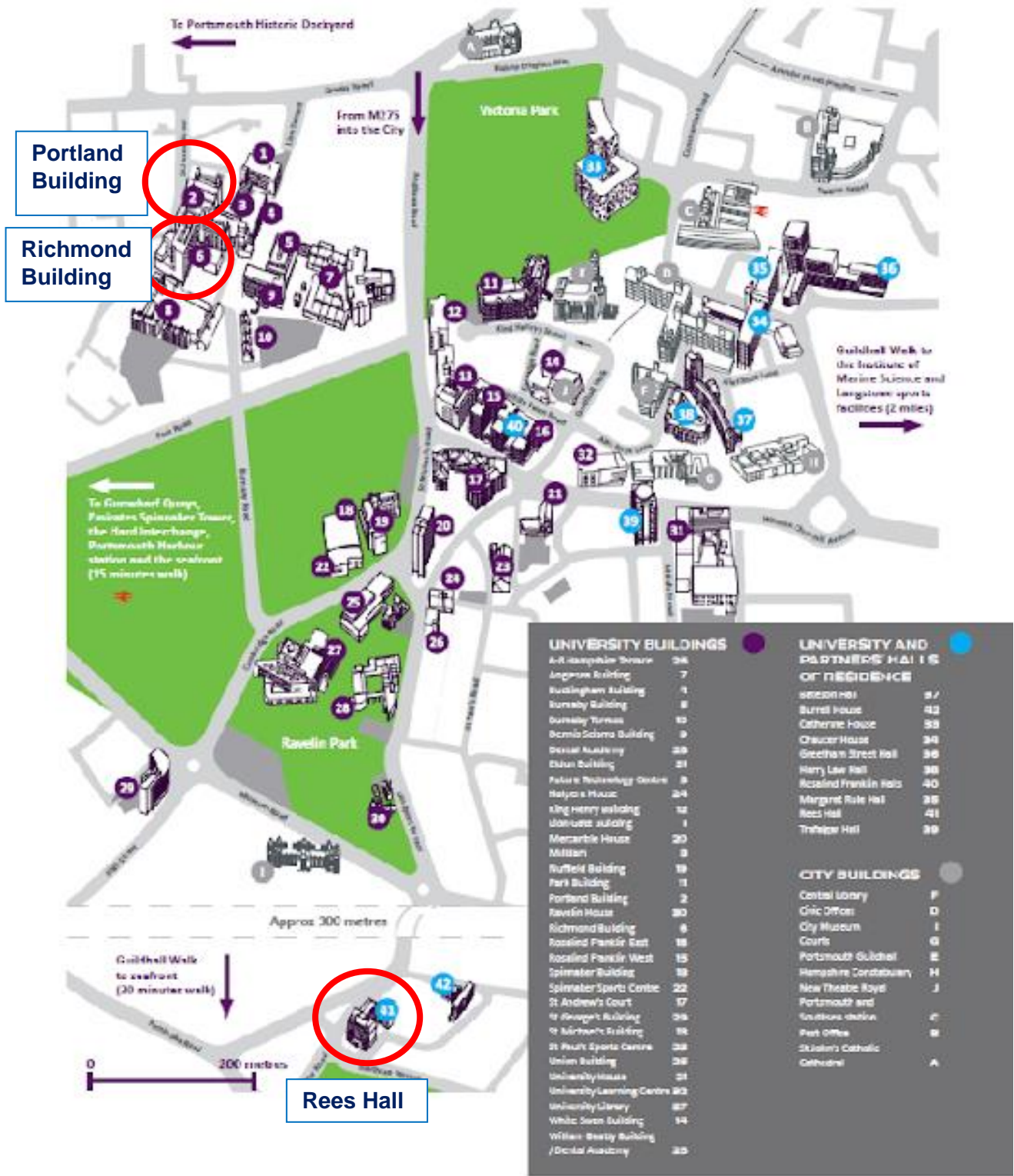
Social Media

We encourage our guests to share event highlights using social media. For those using twitter, please use the hashtag #MCDM2022 and #UniversityofPortsmouth.

Contact

Please e-mail MCDM2022@port.ac.uk for all queries and requests.

MAPS AND DIRECTIONS



PROGRAMME OVERVIEW

Day	Time	Venue	Session Details
Sun	17.00-18.00	PO Atrium	Registration
	18.00-20.00	PO Atrium	Welcome Reception
Mon	08.00-09.00	PO Atrium	Registration
	08.30-09.00	PO Atrium	Tea/Coffee
	09.00-10.00	RB LT1	Opening Welcome
	10.00-10.20	PO Atrium	Tea/Coffee Break
	10.20-12.00	RB LT3, PO 0.28 and PO 0.41	Parallel Sessions
	12.00-13.20	PO Atrium	Lunch
	13.20-15.00	RB LT3, PO 0.28 and PO 0.41	Parallel Sessions
	15.00-15.20	PO Atrium	Tea/Coffee Break
	15.20-17.00	RB LT3, PO 0.28 and PO 0.41	Parallel Sessions
Tue	08.00-09.00	PO Atrium	Registration
	08.30-09.00	PO Atrium	Tea/Coffee
	09.00-10.00	RB LT1	Plenary Session
	10.00-10.20	PO Atrium	Tea/Coffee Break
	10.20-12.00	RB LT3, PO 0.28 and PO 0.41	Parallel Sessions
	12.00-13.20	PO Atrium	Lunch
	13.20-14.20	Group Photo (Meeting Point: PO Atrium)	
	14.20-16.00	RB LT3, PO 0.28 and PO 0.41	Parallel Sessions
	16.00-16.20	PO Atrium	Tea/Coffee Break
16.20-18.00	RB LT1	Doctoral Dissertation Award Session	
Wed	08.00-09.00	PO Atrium	Registration
	08.30-09.00	PO Atrium	Tea/Coffee
	09.00-10.00	RB LT1	Plenary Session
	10.00-10.20	PO Atrium	Tea/Coffee Break
	10.20-12.00	RB LT3, PO 0.28 and PO 0.41	Parallel Sessions
	12.00-13.20	PO Atrium	Lunch
	13.20-15.00	RB LT3, PO 0.28 and PO 0.41	Parallel Sessions
	15.30-19.00	Outing: Boat Cruise & An authentic British pub experience Meeting Point: PO Atrium at 15.20 OR Gunwharf Quays at 15.45	
Thurs	08.00-09.00	PO Atrium	Registration
	08.30-09.00	PO Atrium	Tea/Coffee
	09.00-10.00	RB LT1	Plenary Session
	10.00-10.20	PO Atrium	Tea/Coffee Break
	10.20-12.00	RB LT3, PO 0.28 and PO 0.41	Parallel Sessions
	12.00-13.20	PO Atrium	Lunch
	13.20-15.00	RB LT3, PO 0.28 and PO 0.41	Parallel Sessions
	15.00-15.20	PO Atrium	Tea/Coffee Break
	15.20-16.40	RB LT1	Business Meeting
18.30 - Late Evening	Banquet dinner BoatHouse7, Portsmouth Historic Dockyard		
Fri	09.00-10.00	PO Atrium	Registration
	09.30-10.00	PO Atrium	Tea/Coffee
	10.00-12.00	RB LT1	Award Talks
	12.00-13.00	PO Atrium	Lunch
	13.00-14.40	RB LT3, PO 0.28 and PO 0.41	Parallel Sessions
	14.40-15.00	PO Atrium	Tea/Coffee Break
	15.00-16.00	RB LT1	Closing Session

*Portland Building (PO), Richmond Building (RB)

SOCIAL PROGRAMME

Welcome Reception



Date: Sunday June 26, 2022

Time: 6:00 PM

Location: Portland Building, University of Portsmouth
Portland Street, PO1 3AH

Attire: Business Casual

Afternoon Boat Cruise & An authentic British pub experience



Date: Wednesday June 29, 2022

Time: 4:00 PM

Location: Boat departs at 4.00 PM from Gunwharf Quays, PO1 3TZ (Meeting Point: Portland Building Atrium at 3.20 PM OR Gunwharf Quays at 3.45PM)

Attire: Weather appropriate casual



An authentic British pub experience at a historic Grade I listed building, The Old Customs House, PO1 3TZ

Banquet Dinner at a beautifully restored historic boathouse



Date: Thursday June 30, 2022

Time: 18.30

Location: BoatHouse7, Portsmouth Historic Dockyard, Victory Gate, HM Naval Base, PO1 3LJ

Attire: Semi-formal

SCIENTIFIC PROGRAMME

Monday, 9:00-10:00

MON-1-OPENING

Session: Opening Welcome

Room: Richmond Building LT1

Chair: Alessio Ishizaka

WELCOME AND OPENING REMARKS

Professor Graham Galbraith

Vice-Chancellor, University of Portsmouth

Professor Karen Johnston

*Associate Dean (Research & Innovation),
Faculty of Business and Law, University of Portsmouth*

Professor Matthias Ehrgott

President, International Society on Multiple Criteria Decision Making

Professor Alessio ISHIZAKA

Chair, the 26th International Conference on MCDM

Monday, 10.20-12.00

MON-2-P1

Session: Multi-objective Optimization

Room: Richmond Building LT3

Chair: Serpil Sayın

1. Interactive Algorithms to Solve Biobjective and Triobjective Decision Making Problems.

***Ozlem Karsu** (Bilkent University), **Firdevs Ulus** (Bilkent University), **Tugba Denktas** (Bilkent University) and **Lara Gorur** (Bilkent University)*

We propose interactive algorithms to find the most preferred solution of biobjective and triobjective integer programming problems. The algorithms can be used in any setting where the decision-maker (DM) has a general monotone utility function. They divide the image space into boxes and search them by solving Tchebycheff scalarizations, asking questions to the DM to eliminate boxes whenever possible. We also propose a cone based approach that can be incorporated into both algorithms if the DM has a nondecreasing quasiconcave utility function. We demonstrate the performances of the algorithms and their cone based extensions with computational experiments. The results show that interactive algorithms are useful in terms of solution time compared to algorithms that find the whole Pareto set and that the cone based approach leads to less interaction with the DM.

2. Comparison of Benders decomposition algorithms to solve bi-objective linear programmes

*Ali Sohrabi (The University of Auckland), **Andrea Raith** (The University of Auckland) and Richard Lusby (Technical University of Denmark)*

We present four Benders decomposition algorithms to solve bi-objective linear programmes (BLPs) and compare their performance for the bi-objective fixed charge transportation problem. In three of the algorithms, Benders decomposition is incorporated within the bi-objective simplex algorithm by decomposing the problem into a bi-objective master problem (BM) and a bi-objective sub-problem (BS). Like the bi-objective simplex algorithm, the bi-objective Benders simplex algorithm (BBSA) aims to find a set of extreme efficient solutions by proceeding iteratively from the optimiser of one objective to that of the other. In this algorithm, iteratively, an efficient solution of BM is chosen to be solved with BS - this is called exploring an efficient solution in BS. If BS is infeasible, a feasibility cut is added to BM; otherwise, an optimality cut is generated for each efficient solution of BS and added to BM. The BBSA stops when there is no new non-dominated point in BM that needs to be explored. Since solving BS is a time-consuming step in BBSA, we propose a variant of BBSA where at most two weighted optimality cuts are generated from BS. Another variant of the BBSA proceeds in a bidirectional fashion, where the problem is solved by simultaneously starting from the minimisers of the first and second objectives. The algorithm proceeds similarly to the second algorithm in two directions until the same non-dominated point is found from each direction.

We also present a Benders algorithm to solve a BLP, where a sequence of weighted-sum single-objective problems is solved with Benders decomposition to find a complete set of extreme non-dominated points. We present a new procedure to calculate the value of the next weight using information from the decomposed problem.

3. Relaxations in Multiobjective Integer Programming: The Cases of Linear and Convex Objective Functions

***Serpil Sayın** (Koç University)*

In multiobjective integer linear programming, the linear programming (LP) relaxation of the problem is a well-defined multiobjective linear programming problem. It is known that the

nondominated set of the LP relaxation constitutes a lower bounding set for the original problem and this lower bounding set has been utilized in some branch and bound approaches. Another well-studied relaxation is the convex hull relaxation of the problem, which is expected to deliver better lower bounding sets than LP relaxation. We provide quality comparisons of the two type of bounding sets on selected types of stylized problems with differing number of objective functions and decision variables.

When a generalization to convex objective functions is considered while the feasible set is still polyhedral, we observe that relaxations in the decision space and objective space are differentiated in a way that is not valid in the case of linear objective functions. We study some basic aspects of a number of relaxations and demonstrate them on illustrative examples. We note that tighter relaxations are expensive to compute. We then focus on improving the lower bound sets delivered by relatively inexpensive relaxations. Preliminary computational results for concept verification are provided.

Monday, 10.20-12.00

MON-2-P2

Session: Applications of MCDA

Room: Portland Building 0.28

Chair: Khoirunurrofik Khoirunurrofik

1. Using FITradeoff Method for Priorities Assignment of special operations for Brazilian Federal Police

Carla Cunha (Polícia Federal), **Caroline Mota** (UFPE - Departamento de Engenharia de Produção), **Eduarda Frej** (UFPE - Departamento de Engenharia de Produção), **Lúcia Roselli** (UFPE - Departamento de Engenharia de Produção) and **Adiel de Almeida** (UFPE - Departamento de Engenharia de Produção)

This study addresses a decision-making model for the Brazilian Federal Police with a view to triggering police operations called special operation. These operations are those that, while demanding more resources and specialized techniques, also promote the effectiveness of police actions in a more ostentatious and direct manner. On the other hand, these are more sensitive operations that expose the Institution more. Through police action, guidelines and values of the organization can be perceived. In view of the dynamics of police activity, the correct structuring of the problem was essential, which allowed, with greater clarity, the choice of appropriate multi-criteria decision support method, which is proposed to be more interactive, more flexible and, above all, that demands less cognitive effort by the decision maker. Therefore, initially, the problem was structured using the Soft Systems Methodology (SSM), which is a problem structuring methodology that adopts a systemic approach to create conceptual models that help to understand problem situations and eventually identify improvement actions. The SSM methodology applied to the problem of prioritizing special operations in the Federal Police, allowed to know and prove that the desirable actions to achieve the objectives are feasible. In a second moment, supported by the Value Focused Thinking (VFT) methodology, was the problem properly structured, as well as the objectives and values of the Federal Police were structured and represented by criteria, which let special police operations be evaluated and prioritized, by a value model.

It was noticed that the application of a combined methodology of problem structuring, during the stages of construction of a multi-criteria model, consolidated the decision-making process beyond an isolated and sometimes limited decision. In fact, a profile of the organization was outlined and a set of objectives that represent its values was mapped, allowing, ultimately, greater knowledge and organizational enrichment. Having overcome the complex but essential phase of structuring the problem all carried out with the support of the FITradeoff method. The Flexible and Interactive Tradeoff method was applied to elicit the Decision Maker's (DM's) preferences regarding the multiple criteria with respect to which the operations were evaluated. By using a partial information-based multicriteria method, the DM makes less cognitive effort when his/her preferences are elicited, in such a way that a reduction in the inconsistencies rate is expected. The innovative methodology proposed here uses the junction between the SSM and the VFT to structure the problem and, later, the FITradeoff, as a decision support method. As will be shown, the new methodology, in addition to providing a panoramic and strategic view of the Institution, helped in the best decision choices, in a relatively simple, coherent and efficient way.

Corresponding Author

*Caroline Maria de Miranda Mota, Departamento de Engenharia de Produção, Universidade Federal de Pernambuco, Av. da Arquitetura - Cidade Universitária, Recife, PE, Brazil, +558138795574. E-mail address: caroline.mota@ufpe.br

ACKNOWLEDGMENTS: This research was support by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPQ) and the Academia Nacional de Policia (ANP) da Policia Federal.

2. Developing an Integrated MCDM Approach for Ready Mixed Concrete Supplier Selection

Befrin Neval Bingol (Sirnak University) and Mizgin Ozalp (Sirnak University)

In the construction sector, ready mixed concrete is one of the most crucial materials for construction various structures. In the last thirty years, Turkey's ready mixed concrete production has expanded by 67%. In accordance with this growth performance, Turkey has been the leading country in concrete production in Europe since 2009, and the world's third largest ready mixed concrete producer after China and the USA. Ready-mixed concrete is a tailor-made material that is usually batched before being supplied to the job site. The suppliers must produce in accordance with the standards and fully comply with the technical, environmental, legal, and ethical criteria in all of their plants. Therefore, the technical, environmental, legal, and ethical criteria play a critical role in both the production and delivery standards of ready mixed concrete.

Selecting a supplier for ready mixed concrete is inherently a multi-criteria problem and a decision of strategic importance. Due to its complex and unstructured nature, decision-making techniques can be useful for addressing solutions to this problem.

This paper aims to propose an integrated approach which combines two multi-decision criteria making techniques to select the most appropriate ready mixed concrete supplier for the construction companies. The AHP (Analytical Hierarchy Process) and COPRAS (Complex Proportional Assessment) methods are combined to identify the most appropriate ready mixed concrete supplier based on evaluation criteria. The purchasing managers of construction companies in Turkey were interviewed to identify the most important evaluation criteria while selecting their ready mixed concrete suppliers via a questionnaire. In the proposed approach, the AHP method is used to calculate the weights of the evaluation criteria, whereas the COPRAS method is used to rank the ready mixed concrete supplier alternatives.

A case study is used to show how professionals can utilize an integrated approach to select the most appropriate ready mixed concrete supplier. The findings of this study will assist any decision-makers in selecting the most appropriate ready mixed concrete supplier, ensuring better supply quality and delivery performance.

3. Using the AHP-Express Model and Regression Analysis for Expert Recommendations on Energy Trading Market Models.

Jorre Vannieuwenhuyze (imec-SMIT, Vrije Universiteit Brussel) and Mehdi Montakhabi (imec-SMIT, Vrije Universiteit Brussel)

We investigate how experts evaluate peer-to-peer (P2P), community self-consumption (CSC), and transactive energy (TE) market models for energy transactions compared to a traditional market model, using the Analytic Hierarchy Process (AHP; Saaty 1987, 2003). Continuing on preceding qualitative research, the different market models are evaluated on their capacities to generate different types of values in the electricity market. More specific, twelve criteria are put forward for evaluating the different transaction models. These criteria are the amount of autarky, autonomy, green energy, reduction in electricity costs, increase in positive attitudes towards regionality, increase in sense of community identity, responsibility to future generations, sustainable lifestyle, desire for greater agency in energy transition, social comparison, perceived importance of shared generation/consumption, ease of implementation. So far, the AHP has not yet been applied in the context of energy transaction markets.

However, given the large amount of evaluation criteria, applying a full AHP model would render the number of pairwise comparisons overwhelmingly large. As a result, filling in the questionnaire becomes a daunting task for the experts. In order to cope with this problem, we propose two adaptations.

First, we apply the AHP-express strategy of Leal (2020) in order to reduce reducing the number of evaluations. This strategy first requires the responding experts to select their most preferred attribute. Subsequently, they are asked to compare the other attributes to the most preferred one. This strategy has the advantage of reducing the total amount of comparison judgements as well as simplifying the response scale from bidirectional to unidirectional.

Second, a disadvantage of the AHP-express method is its inability to assess intra-respondent inconsistencies. Nonetheless, regular stochastic regression models allow evaluating inter-respondent inconsistencies. To our knowledge, such regression models have seldom been applied for the analysis of AHP data, especially not in the context of reduced questionnaires like AHP-express.

Results show that experts prefer the community self-consumption and transactive energy market models because they might be most successful in generating green energy. These results help policy makers to better understand the heterogeneous capacities of the market models.

4. Cost-Benefit Analysis of Trans-Sumatera Toll Road using Analytical Hierarchy process: An Ex-Ante Project Evaluation

Khoirunurrofik Khoirunurrofik (Faculty of Economics and Business, University of Indonesia)

To support increased economic growth through infrastructure development in Indonesia, the Indonesian government has attempted to accelerate national projects with strategic value and tremendous economic impact. The Trans-Sumatera Toll Road (JTTS) is a part of the National Strategic Projects Government of Indonesia 2020-2024, laid from the eastern part of the island, located in Lampung Province, stretched through the western part of the island in Aceh Province, with 2,704 km. Cost-benefit analysis (CBA) is commonly used to determine a development project's economic impact and added value. Nevertheless, the analytical method of public infrastructure assessment can include some qualitative criteria by incorporating the views of local and regional stakeholders and the quantitative analysis. Therefore, this study will be necessary to analyze Indonesia's infrastructure assessments from public perspectives as consideration for decision-making. The multi-criteria method of the Analytic Hierarchy Process (AHP) framework is utilized to calculate the cost-benefit analysis of the Trans-Sumatera Toll Road Development. The paper would like to offer a shred of empirical evidence for project appraisal and contribute to the growing literature on public officials' opinions and the general public expressed regarding large-scale projects. It is essential to know the views expressed by public actors (such as the community, public officials, non-government organizations, and academics) concerning the implementation of government development programs in infrastructure development. The target respondents of this AHP method are resource persons at local government offices who are considered capable of providing information to answer questions asked regarding the benefits and costs of the existence of this JTTS. The study concludes that the development of JTTS has a more significant impact, especially on the agricultural sector, compared to other sectors. Nationally, the construction of JTTS will facilitate the flow of commodities between regions, especially between production areas and marketing areas or with ports. This smooth operation will ultimately support non-oil and gas exports, especially in the plantation sector. For the regions themselves, the existence of JTTS is expected to support further the agricultural sector, which is still the prima donna for these regions. The increase in inter-regional trade is a direct impact that turns out to be very influential on the economy of each region around the JTTS.

Monday, 10.20-12.00

MON-2-P3

Session: Rule-based Methods and Artificial Intelligence

Room: Portland Building 0.41

Chair: Salvatore Greco

1. Decision Rules Aggregation

Inès Saad (*MIS-University Jules Verne Picardie*) and **Salem Chakhar** (*Portsmouth Business School*).

The Dominance-based Rough Set Approach (DRSA) is a multicriteria sorting method that uses a set of assignment examples as input to infer a set of if-then decision rules. The conventional DRSA assumes a single decision maker. This may be restrictive mainly when the decision problem needs to take into account different opinions arising from different decision makers. The objective of this paper is thus to propose an approach to coherently combine different sets of decision rules obtained by multiple decision makers. The proposed approach contains four steps: (i) transformation of overlapping rules, (ii) eliminating of redundant rules, (iii) computing of a minimal set of decision rules, and (iv) sorting of decision rules. The objective of the first step is to transform overlapped decisions rules into non-overlapping ones by removing conflicting constraints. The objective of the second step is to eliminate redundant rules, i.e. rules that exist more than one time, or rules fully covered in other - more general - rules. The objective of the third step is to generate a minimal set of decision rules. The objective of the fourth and final step is to sort decision rules from the most relevant to the least relevant based on the qualitative characteristics of decision rules. In addition, the paper proposes extended version the contingency table for a collection of decision rules as well as extended versions of the basic qualitative characteristics of decision rules such as strength, accuracy and coverage and confirmation. The proposed approach has been used in the management of health Knowledge projects.

2. Graph-based Representation of Decision Rules

Simona Panaro (*University of Portsmouth*), **Salem Chakhar** (*University of Portsmouth*), **Salvatore Greco** (*University of Catania*), **Alessio Ishizaka** (*NEOMA Business School*) and **Sajid Siraj** (*University of Leeds*)

Dominance-based Rough Set Approach (DRSA) is a recent decision rule preference model which is an arguably the most general preference modelling method based on aggregation. The output of the DRSA is a collection of if-then decision rules, which is easy to understand for decision makers, however, if the number of rules is high, there is a risk of information overload. To address this issue, this paper proposes a graph-based approach to visually represent the if-then decision rules. The approach first needs a pre-processing phase to construct a binary table where rows are decision rules and columns correspond to elementary conditions. This table is then used to a construct a tree-based representation of decision rules (by maximising the information gain). The usefulness of the proposed approach is demonstrated through a real-life data related to culture heritage in Europe. This is a work in progress so the presentation will be open for feedback and suggestions.

3. TSMAA-TRI: A temporal multi-criteria sorting approach under uncertainty

Anissa Frini (*Université du Québec à Rimouski*) and **Youness Mouhib** (*Université du Québec à Rimouski*)

In recent years, the Quebec government has highlighted the importance of making decisions that are both sustainable and robust under climate change uncertainties. This paper aims to answer the following question: How to sort the alternatives according to their degree of sustainability achievement while evaluations are uncertain and temporal? The general objective of the paper is to propose a temporal sorting method under stochastic uncertainty. The proposed method, called TSMAA-Tri, will assign each alternative to a predefined category

based on a generalization of SMAA-Tri to a temporal context (multi-period evaluation of alternatives) where alternative evaluations are stochastic. The method starts performing Monte Carlo simulations to generate stochastic evaluation values. Each simulation (scenario of uncertainty) will generate a specific value for each criterion using the corresponding probability distribution. Then, aggregation consists in applying SMAA Tri at each period and performing a triple aggregation: i) uncertainty aggregation; ii) multi-criteria aggregation; and iii) temporal aggregation. Multi-criteria aggregation consists in applying the SMAA-TRI method at each period. Then, two ways of temporal aggregation are proposed, based either on acceptability index or on outranking index of boundary profile. The proposed method is illustrated for sustainable forest management to show its applicability.

4. Modelling optimism and pessimism in Stochastic Multicriteria Acceptability Analysis.

Salvatore Greco (*University of Catania and University of Portsmouth*), **Sally Arcidiacono** (*University of Catania*) and **Salvatore Corrente** (*University of Catania*)

We propose a methodology to take into account optimism and pessimism of a Decision Maker that, using Stochastic Multicriteria Acceptability Analysis, evaluates alternatives based on a plurality of weight vectors. With this aim we consider specific families of probability distributions in the space of the feasible weight vectors discussing the results they provide. We also propose a methodology to elicit the probability distributions. We discuss the results obtained through our methodology in the domain of composite indicators.

Monday, 13.20-15.00

MON-3-P1

Session: Multi-objective Optimization

Room: Richmond Building LT3

Chair: Alexander Engau

1. PaMILO: A Solver for Multi-Objective Mixed Integer Linear Programming.

Fritz Bökler (Osnabrueck University), Levin Nemesch (Osnabrueck University) and Mirko H. Wagner (Osnabrueck University)

Finding the non-dominated extreme points of a multi-objective mixed integer linear program (MOMILP) is a computationally hard problem. While solvers for similar problems exist, there are none known for MOMILPs. We present PaMILO, the first solver for finding non-dominated extreme points of MOMILPs. PaMILO provides an easy to use interface implemented in C++17. It solves occurring subproblems employing IBM ILOG CPLEX. Input problems are formulated in the well known .lp file format also used by CPLEX and output is written in an easy to read .json format.

PaMILOs approach is an adaption of the dual-benson algorithm for multi-objective linear programming (MOLP). As the dual-benson algorithm was previously only defined for MOLPs, we describe how to adapt it for MOMILPs.

2. Providing lower and upper bounds on components of Pareto optimal outcomes for large-scale bi and three-criteria MIP problems

Grzegorz Filcek (Wrocław University of Science and Technology) and Janusz Miroforidis (Systems Research Institute, Polish Academy of Sciences)

Despite the rapid development of optimization techniques, there are still multiobjective optimization problems for which the derivation of Pareto optimal solutions can be time and memory-consuming or even beyond allotted limits. This applies, for example, to multiobjective MIP problems, where the 'curse of dimensionality' hits even top-class commercial MIP solvers. In our previous work, we proposed a general methodology for multiobjective optimization to provide lower and upper bounds on objective function values of a Pareto optimal solution obtained by the Chebyshev scalarization of a multiobjective MIP problem, whenever this solution cannot be derived within a reasonable optimization time limit. In our approach, the outcome of the Pareto optimal solution is represented by intervals of possible objective function values. The source of the bounds is a pair composed of a lower shell and an upper shell, which forms a finite two-sided approximation of the Pareto front. When the approximation is provided by a MIP solver, bounds on Pareto optimal outcomes can be calculated. When the bounds are sufficiently tight, an analyst can use interval representations of Pareto outcomes to navigate the Pareto front.

However, in our previous work, no mechanism has been proposed to determine the so-called local upper shell that is the source of upper bounds for a specific Pareto optimal outcome given by a vector of weights of the Chebyshev scalarizing function. In this work, we propose a method of derivation of local upper shells for multiobjective MIP problems with two and three objective functions under limited optimization time. This method is based on systematically changing the vector of weights and solving the Chebyshev scalarization of a relaxed multiobjective MIP problem with the new vector of weights. As in our previous work, the best feasible solution to the Chebyshev scalarization of the multiobjective MIP problem derived by a MIP solver within a given time limit forms the lower shell. The lower shell and local upper shell derived this way are used to calculate lower and upper bounds on components of the implicitly given Pareto optimal outcome. To illustrate the viability of our approach, we present the results of several numerical experiments with selected large-scale multiobjective MIP problems under different optimization time limits.

3. Algorithms for robust bi-objective optimization

Fabian Chlumsky-Hartmann (TU Kaiserslautern), Marie Schmidt (Erasmus University Rotterdam) and Anita Schöbel (TU-Kaiserslautern)

Many real-world optimization problems not only involve multiple conflicting objective functions, but also a degree of uncertainty in these functions. Our work considers problems where the outcome of any chosen solution from the decision space is not known exactly. For example, this may be due to measurement errors or to unknown future developments.

As usual in robust optimization we consider objective functions that depend on a scenario from a so-called uncertainty set which contains the possible scenarios which may realize. In recent years, existing robustness concepts from single-objective optimization such as minmax robustness have been generalized to multi-objective optimization (e.g., Ehrgott, Ide & Schöbel (2014), Ide & Schöbel (2016), Wiecek & Dranichak (2016)) but algorithms for finding robust solutions to multi-objective optimization problems are scarce. The goal of this work is to provide methods for solving uncertain multi-objective optimization problems, i.e., to determine a set of minmax robust efficient solutions. We focus on the robustness concept of point-based minmax robust efficient solutions introduced by Kuroiwa and Lee (2012). This concept looks at the worst cases for each of the objective functions independently, i.e., it involves a maximum in each of the objectives.

The goal is to determine not only one robust efficient solution but - if possible - the complete front of them. We apply the concept of Kuroiwa and Lee (2012) to linear mixed-integer biobjective robust optimization problems for which we determine all extreme supported non-dominated solutions. For the case of linear robust biobjective problems this is enough to construct the set of all robust efficient solutions.

Our approach is to combine Dichotomic Search from multi-objective optimization with a cutting-plane approach called optimization-pessimization from robust optimization in two different ways.

The first idea is to interpret the robust biobjective optimization problem as deterministic optimization problem with a minmax objective function. This leaves us with a piecewise linear objective function for which we are able to generalize Dichotomic search. Dichotomic search requires to solve the scalarized version of the problem in every iteration. The scalarized version of the robust bi-objective problem at hand is a single-objective robust optimization problem which can then be solved by methods of this area, e.g., by the optimization-pessimization approach. For purely linear biobjective optimization (i.e., in the case without integer variables) we also develop an approach where we solve the scalarized version by its dual formulation.

The second idea is to directly start with the optimization-pessimization approach from (single-objective) uncertain optimization. The idea of this approach is to start with a small set of relevant scenarios assuming that the problem can be solved in this case. In the optimization step the problem is solved for the small uncertainty set. In the pessimization step, this solution is evaluated by looking at the complete uncertainty set and a worst-case scenario is identified. This scenario is then added to the relevant scenarios. From optimization and pessimization, a lower and an upper bound is obtained. The procedure stops if the solution quality is good enough. In single-objective optimization, convergence of this method is well understood (e.g., Aissi, Bazgan & Vanderpooten (2009), Pätzold & Schöbel 2020). We are able to generalize the optimization-pessimization method to multi-objective optimization and prove cases in which finite convergence is guaranteed. We then apply this method to biobjective linear optimization using Dichotomic search to solve the problem for small sets of relevant scenarios.

We implemented different versions of these methods and have tested them experimentally on randomly generated instances with varying numbers of variables and constraints for both the feasible set and the uncertainty set. Our numerical results show superiority of the first approach with dualization for purely linear problems. For linear integer or mixed-integer

problems the second approach performed better initially. However, we were able to significantly reduce the runtime of the first approach by strategically using the relevant scenarios from previous scalarized problems instead of starting with one relevant scenario from scratch in each step. The complexity of the resulting algorithm then primarily arises from the optimization problem rather than from the pessimization problem.

4. On Stability and Robustness in Multiple Criteria Decision Making under Uncertainty.

Alexander Engau (Dalhousie University)

This presentation will offer a critical review and share insights related to several notions of Pareto optimality, efficiency, stability, robustness and regret for multicriteria optimization and decision problems under uncertainty. One particular focus will be on the analogous concepts of necessarily or possibly efficient solutions in multiobjective interval programming, and highly or so-called flimsily robust solutions in multicriterion optimization under uncertainty. These definitions, theoretical results and their interpretation for some applications in practice will be compared to alternative concepts of Pareto robustness using either point-based or set-based minimax regret, and some related notions of internal, external and Pareto stability.

Monday, 13.20-15.00

MON-3-P2

Session: Applications of MCDA

Room: Portland Building 0.28

Chair: Sajid Siraj

1. Structuring decision problems involving multiple criteria: investigating the top-down and bottom-up approaches

Barbara Summers (University of Leeds), **Sajid Siraj** (University of Leeds) and **Valerie Belton** (University of Strathclyde)

In a structured decision-making exercise, a hierarchy of criteria is usually developed that must be given consideration for better decision making. In typical decision problems, some criteria are more important than others and therefore it is important to prioritise all criteria based on the decision makers' preferences. In this research, we conducted an online experiment to compare the two common approaches for preference elicitation, that are top-down and the bottom-up approaches. Participants were given real-life decision-making scenarios and data were collected on their activities as well as their feedback. We hope the results will help us identify the potential benefits and limitations of both the top-down and bottom-up approaches and identify situations where each might be best suited. This is a work in progress, we will present our preliminary findings to the MCDM community for analysis and feedback.

2. Comparing PROMETHEE II and ELECTRE III when selecting an offshore wind end-of-life strategy: A sustainable outranking approach

Hasan Altooq (University of Portsmouth), **Graham Wall** (University of Portsmouth), **Maria Barbati** (University of Portsmouth) and **Dylan Jones** (University of Portsmouth)

PROMETHEE II and ELECTRE III are two outranking Multi-Criteria Decision Analysis (MCDA) methods. PROMETHEE II gives a complete ranking of alternatives based on input and output preference flows that calculates the values of net preference flows for individual alternatives. ELECTRE III utilises pseudo-criteria (indifference, preference, and veto thresholds) instead of true criteria to calculate final rankings that can be partial, allowing multiple alternatives to remain incomparable at a certain rank without invalidating the overall ranking.

As wind turbines are typically certified to operate and designed to work up to 25 years, many offshore wind farms are reaching the final stage of the project in which an end-of-life strategy has to be decided. Additionally, countries around the world require a decommissioning plan already at the planning phase of the project. Therefore, sustainable offshore wind end-of-life and decommissioning planning is becoming a very important issue for the industry.

This research utilises PROMETHEE II and ELECTRE III to rank the offshore wind end-of-life alternatives (life extension, refurbishment, repowering, partial decommissioning, and full decommissioning) based on various conflicting sustainability criteria (technical, environmental, social, and economic) and compares the results obtained by the two methods.

The different results obtained by applying the two methods to a pilot offshore wind farm case study indicated that the utilisation of true criteria and pseudo-criteria in the different methods can give different rankings even when the same input parameters are calculated. The results showed that even when the models' parameters are set to favour a certain alternative, changing the preference function in PROMETHEE II or the veto threshold value in ELECTRE III can lead to a ranking where the favoured alternative is not ranked first.

While PROMETHEE II gives a complete ranking of all the alternatives, the partial ranking of ELECTRE III shows that there can be a possibility of combining two or three alternatives from life extension, refurbishment, and repowering to form a project-specific end-of-life strategy in which each turbine is individually assessed to select an appropriate end-of-life turbine-specific alternative based on its technical status and economic viability.

3. Priority-based Multi-actor Multi-criteria Analysis: A Construction Logistics Case Study

He Huang (Vrije Universiteit Brussel), Geert te Boveldt (Vrije Universiteit Brussel) and Cathy Macharis (Vrije Universiteit Brussel - MOBI)

Stakeholder involvement plays an increasingly important role in decision-making. Multi-actor multi-criteria analysis (MAMCA) is a methodology that involves the relevant stakeholders in the decision-making process. By having unique criteria sets for different stakeholder groups, the points of view from them can be confronted at the end of the evaluation.

Stakeholder groups can be defined as groups that are influenced or be influenced by the result of the decision taken. However, in mass-participation applications, such as when involving citizens, the delineation of stakeholder groups is challenging, as stakeholders can be grouped in many different ways, based on different grouping variables.

In this work, we proposed a novel framework, called priority-based MAMCA (PMAMCA). Unlike the conventional MAMCA, the stakeholder analysis is not taken at the beginning of the PMAMCA. Instead, a public criteria pool is defined by considering all the possible criteria that the stakeholders might consider relevant. Then, the stakeholders are asked to weigh the importance level of the criteria, i.e., criteria ranking. Based on the criteria ranking, the stakeholders can be clustered into different groups based on their priorities. Afterward, the clustered stakeholder groups will do multi-criteria group decision-making (MGDM) respectively. Then, the alternative rankings of groups are revealed, and the final solution is sought. This framework is implemented in a construction logistics project. The result shows that the stakeholder groups in PMAMCA can generate a more consensual evaluation output and can better reflect their points of view.

4. How fair were COVID restriction decisions? A data-driven investigation of England using the dominance-based rough sets approach.

Sajid Siraj (University of Leeds) and Edward Abel (University of Southern Denmark)

During the pandemic, the allocation of regional tiered restrictions in the UK has been questioned due to a lack of transparency, leading to accusations of unfair decision making. Using the dominance-based rough set approach, we identify patterns in the data pertaining to the UK government criteria set for tiered allocations. These insights from the analysis are translated into "if-then" type of rules which are easily interpreted by the policy makers. We found differences in the rules extracted from different regions; suggesting inconsistencies in the tier allocations for different regions. We also discovered the north-south divide in a sense that North was assigned higher tiers for significantly lower thresholds for the published criteria such as number of cases, positivity rate, or pressure on healthcare systems. Based on our analysis, we demonstrate the usefulness of dominance-based rough sets approach for investigating the fairness, transparency and explainability in the decisions regarding COVID restrictions. This analysis can be extended to any other nation for investigating the fairness in COVID-related restrictions.

Monday, 13.20-15.00

MON-3-P3

Session: AHP and Applications of MCDA

Room: Portland Building 0.41

Chair: Sarfaraz Hashemkhani Zolfani

1. An innovation framework for the digital era an AHP comparison approach between the UK and Germany

Sameh Saad (Sheffield Hallam University) and Samah Alnuaimi (Sheffield Hallam University)

Digital innovation is increasing momentum through business experts in both government and private sectors and, on the other hand, research and development (R&D). Digital innovation-led industries are increasingly considered a top priority for sustainable competitive advantages in many countries. Furthermore, an upbeat digital innovation practice is a significant global factor in developing novel ideas, products, processes, and technology, promoting positive innovation in an organisation's culture. Thus, many international programmes, such as the United Nations Development Programme (UNDP) and the Global Innovation Index (GII), utilise innovation to enhance service delivery and support national governments cautiously participating in future complex challenges.

Purpose: This paper has three main phases: the first phase focuses on the critique review of the previous innovation models. The second phase illuminates the future brightness of the digital era through the proposal of a digital innovation framework based on two different critical criteria implemented in well industrially developed countries such as the UK and Germany. These are the "Digitalisation-Push" and "Demand-Pull" main criteria and 14 sub-criteria. In the final phase, the Authors proposed a set of innovation processes, which act as an effective interface between "Digitalisation-Push" and "Demand-Pull" to embed an agility dimension into the proposed framework to accelerate the decision-making process.

Research Philosophy/ Methodology/approach

Philosophy: The authors used Ontology research philosophy to deal with the nature of reality needs. However, to explore research philosophy further through the concept; therefore, applying Pragmatism as another perspective could illuminate the innovation management theory and empirical work. Pragmatism includes philosophers taking either objective or subjective views of ontology.

Methodology: The research programme requires qualitative and quantitative analysis; combining these methods introduces testability and context into the investigation. Collecting different kinds of data by various techniques from diverse sources provides a broader range of coverage that may result in a fuller picture. Consequently, using multiple methods increases the robustness named the Triangulation method.

Research Design: This study implemented the theoretical framework in a longitudinal comprising two stages: (1) The study featured an accurate sample size covering the actual innovation situations in two prestigious European countries, the UK and Germany. Both countries have been chosen based on Global Innovation Index (GII). (2) An online pairwise comparisons questionnaire was distributed to 100 participants of manufacturers, academics, organisations, and decision-makers facing the remaining challenges.

Approach: The Analytic Hierarchy Process (AHP) approach is carried out for decision making related to the future demand for innovation, thus making it possible to detect gaps and future research pathways. In addition, that supports decision-makers to deal with equally rational and intuitive judgment to first-rate the best from several alternatives concerning the number of conflicting factors. Moreover, A Sensitivity Analysis was conducted using alternative hierarchical formulations and different assumptions concerning the likely occurrence of the various scenarios.

Findings: The results associated with the UK and Germany show complete prioritisation of the proposed Innovation framework.

The hierarchical structure captured by the UK resulted in a detectable level of the Demand-Pull main criteria, with a percentage of (56%), as opposed to Digitalisation-Push, with (44%). Moreover, the most imperative priority of sub-criteria of demand-pull is User-Demand Innovation, deliberated 10.76%; whereas the recorded results for digital transformation through Industry 4.0 was (8.90%). On the other hand, Germany's results through pairwise comparison show a Digitalisation-Push dominant factor with (56%). In contrast, the Demand-Pull measure was (44%), though, Industry4.0 is the most sub-criteria reported at (12.06%), whereas Sustainable Development Goals accounted for (8.24%) related to the Demand-Pull.

2. Multiple Attribute Decision Making – A Hesitant Fuzzy Set Theoretic Approach

Bhaba Mohanty (Indian Institute of Management, Lucknow)

This paper introduces a new methodology for solving Multiple Attribute Decision Making (MADM) problems under Hesitant Fuzzy Environment. Aggregation of Hesitant Values has received substantial attention in MADM community because of its wide applications in the real world decisions. The present work proposes a procedure that not only transforms a product's hesitant fuzzy values to a single numerical value over the attributes based on its popularity but also fuses them to obtain the final score of the alternative.

Various search engines such as; "Google", "Yahoo", "Microsoft Bing", and "Aol.com" are used in our paper to determine the product popularity. Higher the rank position the more popular product is with respect to the said search engine. As different search engines may carry different rank positions of the same product, the popularity of the product varies from one search engine to another. The proposed work takes the composite view of the search engine results for each product and presents them as Popularity Hesitant Fuzzy Values (PHFVs).

The proposed procedure first calculates the attribute wise product distances from its PHFV and later aggregates them over the attributes to assess the product value holistically. The product corresponding to the minimum aggregated distance is taken as the best product and similarly for the other products.

3. How can existing (licence-free) MCDA software support sustainability assessment? – A literature review

Laura Sofia Mesa Estrada (Karlsruhe Institute of Technology), Martina Haase (Karlsruhe Institute of Technology) and Manuel Baumann (Karlsruhe Institute of Technology)

Sustainability assessment is a methodology that supports complex decision-making processes in a wide range of contexts e.g. energy, landscape management or tourism. Several methods exist to conduct sustainability assessments from which multi-criteria decision analysis stands out given its capability to integrate sustainability criteria, different methods (e.g. life cycle assessment and costing) and relevant stakeholders. Although implementing MCDA methods is seen as a complicated task, especially when the sustainability assessment itself is challenging enough, there is a vast amount of MCDA software available to facilitate this. MCDA software can be found in different formats commercial, licence-free and/or open-source, web-based, standalone or command line applications, etc. In spite of the available MCDA software, its implementation in the context of sustainability assessment is often limited. Some authors prefer to make their own calculations or create their own tool for the specific case study e.g. excel-based tools. This paper aims to assess how the existing licence-free MCDA software can support sustainability assessment and identify the reasons that limit their use by analysts in this context (e.g. missing features). The first part of this paper presents a literature review to identify studies using licence-free MCDA software to support sustainability assessment in different contexts. The second part compares the features of the licence-free MCDA software identified against the MCDA requirements to conduct sustainability assessment. This review reveals that the existing licence-free software need further development to satisfy the

requirements to perform sustainability assessment. Additionally, as sustainability assessments are flexible and adaptable to different contexts, MCDA software (in this context) should have similar characteristics allowing the user to adapt the code to his/her needs. MCDA-based sustainability assessment therefore needs an open source decision support tool in a format that facilitates and simplifies its implementation and allows for further development with respect to individual and changing requirements.

4. Out of its classic structure, MADM framework in the future of PMADM

Sarfaraz Hashemkhani Zolfani (Universidad Catolica del Norte)

Decision-making has been developing in different areas in the new century. Short-term decisions are not critical anymore in the highest level of policymaking. Nowadays, short-term decisions have a defined role from a bigger picture and determination. New decision-making forms need to be flexible enough to consider all the future limitations, opportunities, wild cards, and other unpredictable situations.

Stratified MCDM and Prospective MADM (PMADM) are the two latest approaches in the field that are trying to consider future possibilities and scenarios in the decision-making procedures. PMADM is working as an open platform for researchers and decision-makers to put all types of possibilities, data, and structures inside the classic form of MADM models.

Based on the PMADM approach, current classic MADM methods can adapt to the new flexible models. Although the PMADM approach can work separately from classic models, it can also join the current structures and methods. There is a new possibility in the field to develop new methods beyond the classic form based on the PMADM approach and as a flexible platform.

Since its presentation, PMADM, some contributions in the PMADM approach have been developed. After about six years, there is a brighter perspective from different dimensions of PMADM potentials that can be explained and presented. PMADM and its performance need a summary to sum up what has already been developed and presented.

Background, potential, conceptual model, and future of PMADM and impact of future in the decision-making process will be discussed in detail. All the feedback, achievements, and developments will be presented. Indeed, a new conceptual model will illustrate a big picture of possible PMADM structures and models. In the end, it will be shown how the PMADM approach can work as a sub-field for different multi-disciplinary and related fields. The relationship between these areas and necessities will be discussed.

Monday, 15.20-17.00

MON-4-P1

Session: Interactive MCDM

Room: Richmond Building LT3

Chair: Murat Köksalan

1. Anchoring in interactive Goal Programming: Results from behavioral experiments

Maura Hunt (University of Manchester), **Manuel Lopez-Ibanez** (University of Manchester), **Paul Warren** (University of Manchester) and **George Farmer** (University of Manchester)

In Multicriteria Decision-Making (MCDM), some methods, such as interactive goal programming (iGP), alternate between eliciting preferences from a decision-maker (DM) and using those preferences to find a solution. Humans are a crucial component of this interactive system, yet the impact of cognitive factors on outcomes is often overlooked. Decision-making research has revealed many cognitive biases that affect behavior in estimation and choice tasks. One such bias is anchoring, where estimates of a quantity are robustly biased towards a given value. For example, when determining Everest's height, DMs remain significantly close to an initial value provided by the experimenter. Understandably, such biases could impact more complex tasks like those in MCDM; however, few experiments have considered anchoring in this context.

We present two behavioral experiments investigating anchoring in iGP. The primary benefit of using iGP is that setting goals for the criteria is easy to understand, does not require complex information from the DM, and allows the DM to have complete control of their search. Additionally, we give equal weighting to the iGP application so that the goals set by the DM are the only driver for deriving solutions. In both experiments, we use two decision problems involving two conflicting criteria and 117 predetermined Pareto optimal solutions unknown to the DMs. We decided to initially focus on experiments with two criteria to begin our research from the simplest possible MCDM context and the smallest possible step up from the single-criteria decision problems studied in the classical anchoring literature. Additionally, this highly simplified scenario is deliberate since it is important to minimize the unintended impact of extraneous variables when working with human participants while also maintaining an MCDM context. Subsequent work will conduct further research to investigate how behavior changes when there are more criteria or the causality of such behavior. We also measured the classical anchoring effect using a standard method from the cognitive science literature to consider whether classical anchoring might be related to the anchoring-like effects in MCDM.

We manipulated the starting solutions in the first experiment and examined the chosen solution from interactions. Our analysis suggests that where a DM begins their interaction significantly influences where they end, which persists when accounting for preferences. This finding provides further evidence that DMs may be so influenced by the initial solution that it prevents them from finding their most preferred solution. When comparing the DM's propensity to anchor with classical anchoring questions, we surprisingly did not find evidence that classical anchoring was related to the effect observed in iGP.

We further investigate the role of preferences and anchoring in iGP in the second experiment. Behavioral economics research suggests that the DM's satisfaction with the starting solution causes anchoring in contexts without conflicting criteria. We modified the first experiment to include satisfaction with the starting solution. By including starting satisfaction, we aim to decrease variance and discover to what extent anchoring still occurs in iGP. These findings may provide better insights on where to start iGP applications to minimize iGP anchoring.

2. Measurement and evaluation of multi-function parallel network hierarchical DEA systems

Marios Dominikos Kremantzis (University of Bristol), **Patrick Beullens** (University of Southampton) and **Jonathan Klein** (University of Southampton).

Many organisations are composed of multiple departments connected either in series or in parallel, which may be further decomposed into a number of functions arranged in a hierarchical structure. Several researchers have successfully used appropriate Data Envelopment Analysis (DEA) modelling techniques to assess complex structures. However, to our knowledge, no one has yet examined the case of measuring and evaluating a parallel network structure combined with a hierarchical one. This paper discusses the development of a multi-function parallel system with embedded hierarchical network structures. A linear additive decomposition DEA model and a non-linear multiplicative aggregation DEA model are proposed as alternatives to evaluate the operating performance of such a structure. The system, the sub-systems, and the efficiencies of their internal units, as well as their relationships, are identified. The system efficiency of the additive model is shown to be greater than or equal to that of the multiplicative model. To verify the applicability of our proposed models, we consider a hypothetical example of the measurement and evaluation of the performances of several Business Schools across a number of universities. Other envisaged areas of application of our structure could include supporting the evaluation of the supply chain management of a firm, or the determination of the most desirable ship design considering maintenance issues.

3. Convex cone-based ranking of decision-making units in DEA

Akram Dehnokhalaji (Aston University), **Behjat Hallaji** (Kharazmi University), **Narges Soltani** (York University) and **Jafar Sadeghi** (Ivey Business School, University of Western Ontario)

One of the major research streams in data envelopment analysis (DEA) is ranking decision-making units (DMUs). Utilizing a multicriteria decision-making technique, we develop a novel approach to fully rank all units. Motivated by the convex cone-based total order for multiple criteria alternatives proposed by Dehnokhalaji et al. (Nav Res Logist 61(2):155–163, 2014), we consider DMUs in DEA as multiple criteria alternatives and obtain their total ordering. Initially, some pairwise preference information is provided by the decision maker for units and the concepts of convex cones and polyhedral sets are defined in a DEA framework, correspondingly. We apply a modification of Dehnokhalaji et al. method to extract additional preference information for each pair of units and consequently obtain a full ranking (strict total ordering) of DMUs. The benefit of our approach to their method is that we apply non-radial models to overcome the instability drawback of radial models and their infeasibility occurring in DEA applications. The proposed approach is implemented for two numerical examples, and the accuracy of it is investigated through a computational test.

4. A new interactive algorithm for multiple criteria sorting problems under a variety of preference functions

Gulsah Karakaya (Middle East Technical University) and **Murat Köksalan** (University of Michigan, Ann Arbor).

Abstract. In this study, we address multiple criteria sorting problems under multiple conflicting criteria. The aim is to place the alternatives in preference-ordered classes of a decision maker. Weighted L_p functions can represent a wide variety of preference structures. These functions include the commonly used linear, Euclidean, and Tchebycheff functions as special cases. We develop an interactive algorithm that utilizes past preferences of a decision maker together with the properties of the assumed preference function to place alternatives into classes. We aim to decrease the preference information gathered from the decision maker throughout the decision process. We test our algorithm on a variety of problems

Monday, 15.20-17.00

MON-4-P2

Session: Applications of MCDA

Room: Portland Building 0.28

Chair: Francisco Ruiz

1. Method for characterizing risk management using multi-criteria

Cecilia Montt (*Universidad de Santiago de Chile*), **Luz Martinez** (*Universidad de Santiago de Chile*), **Luis Quezada** (*Universidad de Santiago de Chile*) and **Astrid Oddershede** (*Universidad de Santiago de Chile*)

Abstract. In this work the risk factors to support the investment in a biomass laboratory are studied. The factors are the elements that influence the investment, operating costs, and the operation of the laboratory itself. A biomass laboratory is where various solid industrial wastes are characterized for their valuation in order to be used as biofuels. The objective of finding these factors is to determine the investment of the laboratory, in order to determine how to implement its operation. The valuation of the factors is based on the costs of the different assets to implement the laboratory and to carry out all the processes, such as whether the waste is used as fuel or not. In order to determine the most influential elements in the characterization of the risk factors, a hierarchical analysis was used to determine the best choice of factors to be used. The results of the hierarchical analysis are input information for the risk assessment method, which is based on the ISO 31000 standard, which indicates that each organization, in this case, the biomass laboratory, can adjust the identification, analysis and assessment of risk to its needs. This method is based on finding the consequence, probability, and risk level matrices, and from these, the risk assessment matrix and the evaluation matrix were obtained. As a result, it was found that the most influential factors are location, laboratory capacity, service process and investment in fixed assets. These factors indicate the risks associated with the factors when investing in them, such as changes in prices and lack of supply.

2. Analysis of Regional Development Performance during Pre and Post Covid-19 period in Indonesia using composite Adjusted Mazziotta-Pareto Index

Akhmad Fauzi (*IPB University Indonesia*), **Hania Rahma** (*IPB University Indonesia*) and **Bhakti Suhendarwan** (*IPB University*)

The Covid-19 pandemic crisis undoubtedly have impacted the social-economics performance of regions and threaten the achievement toward regional sustainable development objective. Studies on the impact of Covid019 mostly have been carried out at the national levels, comparing among countries at the global scale. Nevertheless, the impact of covid-19 crisis will be most likely regional and uneven. Comprehensive comparisons of the pandemic impacts, covering socio-economic aspects, especially in Indonesia are scarce to date. This paper aims to analyze the regional development performance during the pre and post covid-19 using various regional development indicators such as human development index, economic growth, unemployment, poverty, and inequality, covering period of four years data (2018-2021). We employ the non- compensatory Adjusted Mazziotta-Pareto Index, a different type of multi criteria decision making (MCDM), to compare the performance of 34 provinces in Indonesia during the pre-covid-19 and post covid-19 periods. Our results reveal that 30 of 34 provinces (88 %) show a declining trend in the regional performance indicators, indicating that the pandemic crisis have significant impact at the regional levels. This study could be valuable inputs for policy makers in developing countries such as Indonesia to assess the impact of the crisis and draw the policy measures to address the challenges.

3. Efficiency of Spanish Public Universities considering a Multiple Reference Point based Approach and Data Envelopment Analysis

*Samira El Gibari (University of Málaga), Jose M. Cabello (University of Málaga), Trinidad Gómez (University of Málaga) and **Francisco Ruiz** (University of Málaga)*

Higher Education systems are, in general, quite complex, diverse and include different tasks interconnected with each other. Universities play a key role in the construction of knowledge (research), the diffusion of knowledge (teaching) and use of knowledge (service to society). Assessing university performance implies considering all the relevant aspects, and the aim should be to achieve good outputs but also, simultaneously, to make an efficient use of their resources. In this communication, we offer a two-step procedure that combines the Multiple Reference Point methodology for building outcome-oriented composite indicators which, in the second step, are used as outputs in a Data Envelopment Analysis Model. Different scenarios are considered depending on the compensation between indicators. The information provided allows the decision-makers to detect strengths and weakness of the universities and relation it to the input-oriented efficiency.

Tuesday, 9:00-10:00

TUE-1-PLENARY

Plenary Session: Professor Luis Martínez

Room: Richmond Building LT1

Chair: Alessio Ishizaka



Computing with Words in Multi-criteria Decision Making

Professor Luis Martínez

Computer Science Department, University of Jaén, Jaén, Spain

Abstract: The concept of computing usually implies calculation processes either by mathematical means of numbers and symbols or by a computer. Paying attention to computing processes done by human beings, it is noteworthy that they employ frequently words in computing and reasoning, arriving at linguistic results from linguistic premises. Hence, Computing with Words (CW) applies the same view to their computing processes aiming at obtaining linguistic outcomes from linguistic inputs. Due to the fact that words have fuzzy denotations when they are used by human beings, the paradigm of CW was clearly stated as a branch of fuzzy logic by Zadeh in which CW was defined as “A methodology in which words are used in place of numbers for computing and reasoning.” Later on, Zadeh added that “CW is a methodology in which the objects of computation are words and propositions drawn from a natural language.”

Decision makers involved in complex decision making problems usually provide information about their preferences by eliciting their knowledge with different assessments. Usually, the complexity of these decision problems implies uncertainty that in many occasions has been successfully modelled by means of linguistic information, mainly based on fuzzy based linguistic approaches. This talk will provide an overview of the fuzzy linguistic approach used for CW in Multi-Criteria Decision Making and some challenges for future proposals.

Bio: LUIS MARTÍNEZ is currently a Full Professor with the Computer Science Department, University of Jaén, Jaén, Spain. He is also Visiting Professor in University of Technology Sydney, University of Portsmouth (Isambard Kingdom Brunel Fellowship Scheme), and in the Wuhan University of Technology (Chutian Scholar). He has been main researcher in 16 R&D projects, also has published more than 190 papers in journals indexed by the SCI and more than 200 contributions in Inter/national Conferences related to his areas. His current research interests include multi-criteria decision making, fuzzy logic-based systems, computing with words and recommender systems. He was a recipient of the IEEE Transactions on fuzzy systems Outstanding Paper Award 2008 and 2012 (bestowed in 2011 and 2015, respectively). He is a Co-Editor-in-Chief of the International Journal of Computational Intelligence Systems and an Associate Editor of the journals, including the Information Sciences, Knowledge Based Systems, Information Fusion. He is IFSA Fellow 2021, senior member of IEEE and of the European Society for Fuzzy Logic and Technology. Eventually, he has been appointed as Highly Cited Researcher 2017-2021 in Computer sciences.

Tuesday, 10.20-12.00

TUE-2-P1

Session: Interactive MCDM

Room: Richmond Building LT3

Chair: Jyrki Wallenius

1. Special Lines Method: Exploiting Tradeoffs in Integrated Tri-Criterion Sustainable Portfolio Construction.

Ralph Steuer (University of Georgia) and Sebastian Utz (University of St.Gallen).

The paper focuses on investors whose strength of interest in sustainability issues (such as environmental, social, and governance) causes ESG to become a third criterion alongside risk and return in portfolio selection. This causes the efficient frontier to become an efficient surface. This means that an investor's optimal portfolio is no longer the point of most preferred risk/return tradeoff on the mean-variance (M-V) efficient frontier, but is the point of most preferred risk/return/ESG tradeoff on the investor's M-V-ESG efficient surface. However, to find such a point requires non-trivial ESG integration which is the name given to the process of integrating ESG into the portfolio construction process after screening. With the third objective transporting the problem into 3-space, it is almost impossible to search the efficient surface in any kind of comprehensive fashion using M-V based or other bi-criterion techniques as this is akin to a 2-dimensional being trying to view a 3-dimensional object. To remedy the situation, the paper proposes a tri-criterion approach that computes efficient surfaces and special (non-contour) curves so as to dragnet an efficient surface for the points of best ESG integration within it. Using the methodology and data from the S&P500 for parameterization purposes, the paper conducts computational tests on problems with up to 500 securities and under different constraint conditions so as to know what to expect from the new approach over a range of situations.

2. A Bayesian Model for Interactive Multiobjective Optimization with Multiple Reference Points

Theodor Stewart (University of Cape Town)

We propose an interactive method for multiobjective optimization with "many" (typically >3) objectives, that can be viewed in some ways as intermediate between conventional interactive methods (which examine one solution at a time), and EMO methods which seek to provide representations of the Pareto frontier. We demonstrate that the use of multiple widely dispersed reference points can be implemented in a single algorithm, to generate a dispersed set of Pareto optimal solutions. The decision maker can compare these to provide a simple partial ordering, which we recognize as a simple and unambiguous form of preference statement. On this basis, the range of reference points considered is reduced, before the process is repeated to obtain a new set of Pareto optimal solutions for evaluation by the decision maker. The interaction is achieved by generating reference points as linear combinations of the vectors approximating the payoff matrix, where the coefficients are generated from a Dirichlet distribution. Initially this distribution is uniform on the simplex. A pseudo-Bayesian process, analogous to multinomial sampling, is introduced, whereby the distribution is updated on the basis of the classification of the resultant Pareto optimal solutions into preference classes, so that at each new iteration the reference points become more clustered. Numerical experiments on a test problem showed robust performance, with rapid convergence towards an assumed desired goal-point in a matter of 3 or 4 iterations. In confirmation, the approach was also applied to a problem in project portfolio optimization, generating very similar results.

3. Supporting scenario-based decision making with multi-objective optimization

Jyrki Wallenius (Aalto University School of Business), Pekka Korhonen (Aalto University School of Business) and Juuso Liesiö (Aalto University School of Business)

The history of scenario planning can be traced back to Herman Kahn's military applications at the RAND Corporation in the 1950s. More specifically, he developed a technique of describing the future in stories, which he called "scenarios". In the 1960s Kahn expanded his scenario work to social forecasting and public policy (Kahn 1965).

Today scenario planning is widely used to analyze possible futures and to identify the combinations of events and development paths that can lead to these futures. Scenario building has found use in several application areas in military, business, and public policy (recently healthcare) (Hassani 2016). Originally scenario building focused more on identifying the potential futures, but subsequent research has developed methods to provide decision recommendations regarding which actions to take (Karvetski & Lambert 2012, Stewart et al. 2013).

There is disagreement in the literature on how scenarios should be interpreted in the decision theoretical framework. Perhaps the most obvious interpretation is to assume the scenarios form a state-space of mutually exclusive and collectively exhaustive states (Liesiö and Salo 2012; Vilkkumaa et al. 2018). This approach is particularly appealing, as it allows to harness the Subjective Expected Utility model to provide a solid axiomatic basis for the choice. Probabilities are widely used to measure the likelihood of scenarios (Millett 2009). Whether they should be used, has been the subject of a debate. Estimation of subjective probabilities is affected by psychological biases (Tversky & Kahneman 1974).

An alternative approach is to interpret scenarios as decision attributes (or criteria) (Stewart et al. 2013). Multiattribute Value Theory (MAVT) can then be used to build preference models and to identify, which of the available alternatives provides the best overall performance when considering all possible futures. Although intuitive, this approach can be criticized. First, the approach does not avoid making statements on the relative likelihoods of the scenarios, but rather makes these statements implicit or incorporates this information into other model parameters, such as scenario weights (Bunn and Salo 1993; Vilkkumaa et al. 2018). We should also realize that MAVT is concerned with alternatives that, if selected, yield a specific outcome on each of the attributes simultaneously. If one accepts the premise that not all scenarios can realize simultaneously, then they cannot be interpreted as attributes in the sense of MAVT.

We formalize both of these approaches and show how the concept of Pareto optimality is consistent with them and thus offers a non-controversial approach for providing scenario-based decision support under uncertainty. In particular, we develop a decision support model for scenario-based decision making based on interpreting the scenarios as objectives (in the multi-objective sense). However, no explicit probability information regarding the likelihood of the different scenarios is required. Instead, the decision maker implicitly pays attention to the likelihood of different scenarios in her head. Our approach is based on multi-objective optimization and can be used to identify the set of alternatives that includes all possible optimal solutions for SEU- or MAVT-based approaches (see Korhonen & Wallenius, 2020, chapter 13). Our approach is straightforward and much simpler than the one proposed by Durbach and Stewart (2003). Moreover, it avoids MAVT-measurements, presents no interpretation difficulties with attributes, and assumes that one of the scenarios will realize.

To illustrate, consider an investment problem with three scenarios referring to three states of the economy (declining, stable, or improving). We formally treat the scenarios as objectives in Pareto Race (Korhonen & Wallenius, 2020, chapter 11.4). Each of the objective values describes the outcome, given that the economy will decline, remains stable, or improves. If we think that the economy most likely will decline, we put more emphasis on that objective (scenario). The values of the other objectives (scenarios) will tell us the outcome, given that the economy remains stable or improves. At any point, the decision maker can observe the values of the decision variables (in this context, what percentage of total funds is invested in each) leading to the objective values.

References

- Bunn, D., & Salo, A. (1993). Forecasting with Scenarios. *EJOR* 68(3), 291-303.
- Durbach, I., & Stewart, T. J. (2003). Integrating scenario planning and goal programming. *Journal of Multi-Criteria Decision Analysis* 12(4-5), 261-271.
- Hassani B. (2016), *Scenario Analysis in Risk Management*, Springer International, Switzerland.
- Kahn, H. (1965). *Thinking About the Unthinkable*. New York: Horizon Press.
- Karvetski, C., & Lambert, C. W. (2012). Evaluating deep uncertainties in strategic priority-setting with an application to facility energy investments. *Systems Engineering* 15, 483–493.
- Korhonen, P., & Wallenius, J. (2020). *Making Better Decisions: Balancing Conflicting Criteria*, Springer, Switzerland.
- Liesiö, J., & Salo, A. (2012). Scenario-based portfolio selection of investment projects with incomplete probability and utility information. *EJOR* 217(1), 162–172.
- Millett, S. (2009). Should Probabilities Be Used with Scenarios? *Journal of Futures Studies* 13(4), 61-68.
- Stewart, T. J., French, S., & Rios, J. (2013). Integrating multicriteria decision analysis and scenario planning—Review and extension. *Omega* 41(4), 679-688.
- Tversky, A., & D. Kahneman (1974). Judgment under Uncertainty: Heuristics and Biases. *Science* 185, 1124-1131.
- Vilkkumaa, E., Liesiö, J., Salo, A., and Ilmola-Sheppard, L. (2018). "Scenario-based portfolio model for building robust and proactive strategies", *EJOR* 266(1), 205-220.

Tuesday, 10.20-12.00

TUE-2-P2

Session: Applications of MCDA

Room: Portland Building 0.28

Chair: Leonardo Tomazeli Duarte

1. A general interacting space-time model for planning an ecovillage

Maria Barbati (Università Ca' Foscari Venezia), Salvatore Greco (Università di Catania) and Isabella Lami (Politecnico di Torino)

We propose a methodology to support sustainable territorial planning in terms of selecting a portfolio of facilities to be distributed in a given space, during a period of time and taking into account the preferences of the users.

The proposed project portfolio selection procedure is formulated as an interactive multiobjective combinatorial optimization problem in terms of the space-time model introduced in Barbati et al. (2020) with the definition of additional relevant elements with respect to its original formulation. More precisely we integrated the presence of the synergies among facilities and the interaction between the objectives to be optimized. To handle this problem, the Decision Makers (DMs) preferences are elicited through a new user-friendly procedure conjugating the deck of the cards method with the ordinal regression approach permitting to collect preference information in terms of ranking and pairwise comparisons with regard to the intensity of preference of some solutions suggested by the optimization algorithm. With the aim of representing the interaction between criteria, the proposed ordinal regression procedure provides a value function formulated in terms of a Choquet Integral. The value function so obtained is then used to define a multiobjective optimization problem. The new feasible solutions provided by the optimization algorithm are proposed to the DM to verify his appreciation and collect new preference information or new constraints to be integrated in the optimization model. The interaction procedure is iterated until the DM is satisfied with the proposed solution.

Our approach presents several advantages:

- The DM can participate into the decision-making process expressing his preferences in an easy way and with a reduced cognitive burden, thanks to the use of the deck of the cards method;
- The ordinal regression model permits to elicit the preferences of the DM and to deal with interactions among criteria;
- The DM can iteratively build the solutions together with the analyst returning on his preferences at every step of the process;
- The whole process is transparent and simple for the DM to which the interactive optimization procedure supply arguments to explain the selected solutions to other stakeholders in a perspective of a participative decision.

We apply our methodology in a real-world problem to handle the planning procedure of a sustainable ecovillage in the province of Turin (Italy). We interact with the President of the cooperative owning the ecovillage to details what should be the social, economic and cultural facilities of the ecovillage, where they should be located and when they should be scheduled. The choice of applying the space time model for planning of an ecovillage is certainly challenging, because it is a very particular case of territorial transformation, with non-ordinary logics, where, for example, money has a very different value compared to urban transformation contexts where the goal of the developer is to maximise income. We show how the highly interactive methodology proposed was applied to construct the decision model together with the DM, taking conveniently into consideration the specific relevant features of the ecovillage.

2. Multi-criteria Hybrid Approach for Prioritizing Suspected Covid-19 Patients within the Public Emergency Departments: A Case Study

Armando Pérez-Aguilar (Juarez Autonomous University of Tabasco), Pablo Pancardo (Juarez Autonomous University of Tabasco) and Miguel Angel Ortiz-Barrios (Universidad de la Costa CUC)

When patients arrive at the Emergency Departments (EDs) due to suspected Covid-19 and the healthcare resources are not sufficient to meet the demand, physicians are challenged to decide which patient needs to be hospitalized or discharged to home considering an indefinite set of potentially infected people and a wide range of clinical and sociodemographic criteria. These criteria are often conflicting and may entail qualitative or quantitative measures. The prioritization task is even more difficult when the patients have not been tested. Therefore, there is no evidence that better supports medical decision-making regarding the most suitable pathway for Covid-19 management. Also, an important aspect to be deemed is that medical judgments may significantly vary from one doctor to the other based on their perceptions and background. Considering the above-mentioned context, this study aims to develop a Multi-criteria Decision-Making (MCDM) approach for measuring the risk of unfavorable health evolution (risk priority index) in each suspected Covid-19 patient and decide the best discharge/treatment option accordingly. First, Intuitionistic Fuzzy Analytic Hierarchy Process (IF-AHP) was employed to calculate the relative weights of criteria and sub-criteria considering the hesitancy degree of experts and the uncertainty derived from human judgments. Second, Intuitionistic Fuzzy Decision-Making Trial and Evaluation Laboratory (IF-DEMATEL) was used to evaluate the interrelations among clinical and non-clinical factors affecting the patient evolution when suffering from Covid-19. Finally, the Combined Compromise Solution (CoCoSo) was implemented to compute a risk priority index per each suspected Covid-19 patient and identify which aspects need to be intervened for improving the overall health condition. A case study in a public Mexican hospital is presented to validate the proposed approach. As a result, an MCDM network model comprising 6 criteria (Close contact with Covid-19 patients, Comorbidities, Duration, Covid-19 symptoms, Vaccination background, and Sociodemographic profile) and 31 sub-criteria was defined for prioritizing the patients. In addition, "Close contact with Covid-19 patients" (overall weight = 0.175), "Comorbidities" (overall weight = 0.174), and "Duration" (overall weight = 0.173) were found to be the most important factors when defining the risk of unfavorable health evolution in Covid-19 patients. "Covid-19 symptoms" (overall weight = 0.168) and "Vaccination background" (overall weight = 0.163) are also highly contributing to this risk and can be hence considered for effective diagnosis. These results are highly appreciated in public EDs where the healthcare resources need to be properly allocated due to financial restrictions. Likewise, it is a useful tool for decreasing the mortality probability and sequels in patients with an immediate need for specialized care.

3. Decision support for classifying farmers in relation to rural credit: can participatory development of tools help?

Adolfo Vicente Araújo (Universidade Federal de Pernambuco - UFPE), Caroline Mota (Universidade Federal de Pernambuco - UFPE) and Sajid Siraj (University of Leeds)

Family farmer establishments are responsible for a large part of the food production that is on the table of many families. Therefore, rural credit needs greater availability for family farming, so that it can be used to invest, grow and develop agriculture. Another even greater challenge is to present family farming and the rural environment as a place of opportunities and growth, portraying the rural life as a sustainable option. In this context, a decision support tool can help farmers understand the criteria that they need to improve to have a better credit and whether they are eligible for credit approval or not. Theoretically, the traditional classification methods used in approving farmers for credit are still challenging. Because traditional methods have difficulties in dealing with incomparability and another important difference in relation to traditional classification evaluation methods is the independence of the use of the result in relation to the numerical value of the classification judgment scale. This research proposes an innovative methodology to the decision-making process of credit appraisers. The issue of incomparability is unprecedented, noting that it is not always caused by incomparability in

modeling or performance evaluations. In addition, a new methodology for estimating the p and q parameters (preference and indifference limits, respectively) is incorporated into the modeling, incorporating greater robustness. Through the analysis of data produced, referring to an open access platform, in which it has real information about rural establishments in relation to credit, we developed a table with real data that was introduced into the model to test and validate. For this research, we used 10% of the data for testing. We propose the use of ELECTRE TRI for classification and demonstrate how the proposed assessment process favours the inclusion of new criteria that can expand the scope of the valuation of family farmers in relation to rural credit.

4. A fair multicriteria decision making method: an approach based on the optimization of the aggregation operator parameters

*Pedro Cardoso Ishara (University of Campinas (UNICAMP)), Guilherme Dean Pelegrina (University of Campinas (UNICAMP)) and **Leonardo Tomazeli Duarte** (University of Campinas (UNICAMP))*

In machine learning, the search for fair classification and regression methods basically consists in the development of strategies to avoid algorithmic bias towards sensitive groups, which can be characterized by, for instance, gender or ethnicity. While such a topic has been a central issue in the field of machine learning in the last few years, the derivation of fair methods in the context of Multicriteria Decision Making (MCDM) is still an incipient topic of research. Notwithstanding this absence of research, it is worth mentioning that MCDM methods address several problematics, such as the ranking of alternatives, in which the alternatives are given by individuals which can belong to different groups. For instance, consider the application of MCDM methods to rank a set of employees for promotion. It is well known that, in some countries, the promotion rates are smaller for women with respect to men. Such unbalanced rates can be a consequence of certain decision criteria which may introduce bias towards a given sensitive group. While a first strategy to avoid biased rankings is to disregard criteria leading to unfair results, it is not always easy to directly identify which set of criteria is leading to biased solutions.

In view of this problem, we here propose a novel MCDM method that addresses the issue of fairness in ranking problems. Our approach relies on a weighted arithmetic mean (WAM) aggregation operator and the central idea is to optimize the parameters of the aggregation operator, so the resulting ranking is as fair as possible regarding the sensitive group. The implementation of our proposal requires the definition of a cost function, which is accomplished by relying on the notion of top- k rankings. Basically, our method searches for the most balanced ratio between two groups among the first k alternatives (and for several values of k). The balance between these two groups is quantified by the Kullback-Leibler divergence, a well-known measure used to quantify the differences between two probability distributions. Moreover, to optimize the resulting cost function, we apply a metaheuristic known as differential evolution (DE). The use of the DE algorithm allows us to tackle the discontinuities that arise in the adopted cost function due to the use of the notion of top- k rankings.

As attested in numerical experiments, a first feature of our approach is that it becomes possible to automatically counterbalance the influence of criteria which lead to bias, and, thus, by inspecting the resulting parameters of the aggregation operator, to identify the set of criteria that contributes to unfair rankings. Moreover, the resulting ranking in our method still comes from the aggregation process applied on the decision matrix, which means that the search for fairer rankings does not disregard the available data. Our method can be applied in problems in which balanced solutions are sought, while still considering the global values of the alternatives. Finally, it is worth mentioning that our proposal can be easily extended to other MCDM strategies, such as outranking methods.

The authors thank the grants \#2021/11086-0, \#2020/10572-5, \#2020/09838-0 and \#2020/01089-9, São Paulo Research Foundation (FAPESP).

Tuesday, 10.20-12.00

TUE-2-P3

Session: Outranking Methods

Room: Portland Building 0.41

Chair: Tadeusz Trzaskalik

1. Ranking LTE Cells Based on Key Performance Indicators Using MCDM Methods

Pedro Lopes Neto (São Paulo State University UNESP), **José Celso Freire Junior** (São Paulo State University UNESP) and **Celso Eduardo Tuna** (São Paulo State University UNESP)

The growth in worldwide data traffic and user subscriptions in mobile telecommunication networks makes it increasingly difficult to manage network performance in an environment already containing multiple radio access technologies. Despite the rise of 5G, LTE remains the dominant technology, and new cells are installed every day to support traffic growth and new services like voice over LTE. Detecting faulty cells in the network is one of the main concerns of operators. Self-organizing networks have been introduced to deal with this problem, and their self-healing functionality has improved cell fault management. Nonetheless, faulty cell detection remains challenging, and most of the tasks involved are still done manually. This article introduces a new method of faulty cell detection in an LTE radio access network, applying multicriteria decision methods to this problem. The cells are ranked based on selected key performance indicators, using the multi-attribute theory to construct a utility function. The analytic hierarchy process is used to define weights for the criteria.

2. Assessing Regional Resilience in Indonesia: An application of MULTIMOORA method

Hania Rahma (IPB University), **Tini Anggraeni** (Islamic State University Jakarta), **Indri Juliannisa** (UPN Veteran Jakarta) and **Akhmad Fauzi** (IPB University)

Regional resilience has emerged recently as one of the key concepts in understanding the dynamic of regions due to its strong connection with regional adaptability and evolutionary economics. Adverse events such natural disasters, climate change and recently covid-19 pandemic crisis, provide an opportunity to pay more attention to resilience concepts. Measuring regional resilience, however, is still challenges issue since it encompasses many aspects of the regional development. In addition, regional resilience measurement in developing countries such as Indonesia are relatively scarce. This paper attempts to address such an issue using various indicators related to regional development in its resilience contexts. We employ a multi criteria method of MULTIMOORA covering 34 provinces in Indonesia. The results show there are variation in regional resilience among regions. More specifically, regions with low resilience level will be more likely have severe impacts of the crisis such as Covid-19 pandemic than the opposite. This study could be useful inputs for policy makers in developing policy measures to strengthen regional development as well as to overcome constraints that hinders progress toward regional sustainable development.

3. Assessing Socio-economic vulnerability of rural areas in Indonesia: A Multi Criteria Analysis Approach using PROMETHEE

Akhmad Fauzi (IPB University, Indonesia), **Hania Rahma** (IPB University, Indonesia), **Arif Maulana** (IPB University, Indonesia), **Zulfi Nasution** (IPB University, Indonesia) and **Ahmad Syaifullah** (IPB University, Indonesia)

One of the prominent issues in the rural development agendas, especially in developing countries such as Indonesia is the vulnerabilities of rural areas. It is mostly argued that rural communities are relatively more vulnerable when expose to the external shocks due to limited access to economic resources and limited capacity to absorbs the shocks. This paper attempts to assess the socio-economic vulnerabilities at the provincial level using multi criteria analysis. We employ a Promethee method to assess vulnerabilities in rural samples areas using data of 33 provinces covering 26 criteria. The results indicate that provinces that have more rural

areas are more vulnerable than otherwise. The vulnerabilities of the rural areas are mostly determined by exposure and capacity criteria such as exposure to natural hazard, lack of waste treatment, lack of small and medium enterprises and credit facilities, and lack of access and public transportation infrastructure. The results of this study could become valuable inputs for betterment of rural development in developing countries, and improvement of policy measures could be derived from this study.

4. Multistage Bipolar Method

Tadeusz Trzaskalik (University of Economics in Katowice)

The Bipolar method, proposed by E. Konarzewska-Gubała, is an MCDA method; the individual phases of this method use elements of the Electre methodology as well as algorithms of confrontation. The purpose of this presentation is to present its extension, named Multistage Bipolar Method.

A fundamental feature of Bipolar approach is that the decision alternatives are not compared directly with each other, but by means of sets of reference points: objects with desired characteristics, called “good” objects, and objects with undesired characteristics, called “bad” objects.

We will discuss multistage processes with a predefined number of stages. At the beginning of each stage the process is in one of the admissible states. All the states of the process that can occur at the beginning of the consecutive stages form the sets of admissible states for the consecutive stages. Furthermore, for each admissible state at each stage one can determine the possible decisions. The set of all such decisions is called the set of admissible decisions for the given state. If at the beginning of a stage the process is in a certain admissible state and an admissible decision is made, then at the end of this stage the process will be in a final state, determined by the transformation called the transition function. The final state of the process for any stage is at the same time an initial state for the next stage.

In the multistage processes we distinguish two kinds of alternatives: stage and multistage ones. At the beginning of each stage the process is in an admissible state and we can make an admissible decision at this stage. The pair consisting of a state and a decision admissible at this stage will be called a stage alternative. Using the transfer function we perform the transformation of the process to the initial state of the next stage. This action is repeated until the process terminates. Hence, we can talk about sequences of admissible states and decisions which start with a certain admissible state at the first stage and end in an admissible final state of the process. Such sequences are called multistage alternatives. Obviously, each multistage alternative is at the same time a sequence of stage alternatives.

We assume that at each stage of the process two reference sets are defined: one containing “good” objects, the other one, “bad” objects. We will call them stage reference sets. At each stage, the reference set of good objects is disjoint with the reference set of bad objects. The reference sets for the entire process are defined as Cartesian products of the good reference sets for the consecutive stages and the corresponding bad ones. Since the process consists of stages, we assume that the position of a multistage alternative with respect to the reference sets for the entire process is evaluated on the basis of the positions of the stage alternatives which form this multistage alternative with respect to the stage reference sets. For this purpose use stage criteria functions assuming, for simplicity (as in the original Bipolar method), that larger values are preferred over smaller values (“more is better”). Of course, it is possible to transform the remaining types of criteria to the form used here. Moreover, we assume that at each stage of the process each good reference object dominates each bad reference object. This assumption allows to avoid the situation in which a stage alternative is at the same time “overgood” (that is, it is evaluated higher than the set of good objects) and “underbad” (that is, it is evaluated lower than the set of bad objects).

An issue that arises here is that of the importance of the criteria at the consecutive stages. In the multistage approach it is possible to have the case in which certain criteria are important in certain stages only, while in other stages other criteria are essential. .

The decision maker determines the importance of each criterion by giving the values of the weights. We assume that the weights have been normalized and that the sum of the values of the weights for all the criteria is equal to 1 for the given stage. The weights of a given criterion can vary depending of the stage. The importance of the criteria and their weights are described in the weight ma-trix. Its rows correspond to the consecutive stages and its columns, to the criteria. If a matrix element is equal to 0, the corresponding criterion is not essential at that stage.

The sorting and ranking procedure consists of three phases. In the first phase we analyze the consecutive stage alternatives from the stage sets of admissible alternatives, comparing them with the elements of the stage reference sets. As a result, we obtain outranking stage indicators. In the second phase we determine the position of a stage alternative with respect to the bipolar stage reference system, assuming that the concordance level is equal to 0.5. For each stage alternative we calculate the stage success achievement and stage failure avoidance degrees. In the third phase we determine the relationships in the set of multistage alternatives, using the values calculated in the second phase. The set of all alternatives is divided into six disjoint classes so that each multistage alternative from a lower-indexed class is evaluated higher than any multistage alternative from a higher-indexed class. Next, we determine a linear ordering in each class.

As regards the possible applications of the Multistage Bipolar Method, it can be applied to create a long-term development strategy, when using the sustainable development approach.

Tuesday, 14.20-16.00

TUE-3-P1

Session: Interactive MCDM

Room: Richmond Building LT3

Chair: Kaisa Miettinen (co-chairs G. Misitano, G. Larrage)

1. Recent Developments in Interactive Multiobjective Optimization Methods in the DESDEO Software Framework

Kaisa Miettinen (University of Jyväskylä), **Bhupinder Singh Saini** (University of Jyväskylä) and **Bekir Afsar** (University of Jyväskylä)

Interactive multiobjective optimization methods incorporate decision maker's (DM's) preference information iteratively in the search for the most preferred Pareto optimal solution. They support the DM in learning about the tradeoffs among the conflicting objectives, what kind of solutions are available as well as what kind of preferences are feasible. The computation and cognitive cost remain manageable since only solutions that are of interest to the DM are considered. Thanks to the learning and insight gained about the problem solved, the DM can adjust the preferences and get convinced of the goodness of the final solution.

We have many different interactive methods, for example, scalarization based (or MCDM based) methods and evolutionary (EMO) methods. They can incorporate various types of preferences. The former use scalarizing functions and appropriate single objective solvers to find a few or a single solution(s) per iteration, while the latter use evolutionary operators to evolve a population to approximate solutions. Importantly, the strengths of both types can be combined. We refer to this as hybridization.

In this talk, we outline some recent developments in interactive methods. We introduce IOPIS that hybridizes scalarizing functions and EMO methods in a novel way and generates a so-called preference incorporated space using different scalarizing functions. A problem in the new space is then solved with an evolutionary method. We also discuss another hybrid method, O-NAUTILUS, which addresses challenges of computationally expensive problems. It is an extension of the NAUTILUS Navigator method enabling the decision maker to navigate in the reachable ranges of objective functions and extending the search to so-called optimistic areas. The method uses computationally expensive function evaluations sparingly.

We also briefly mention some perspectives related to comparing interactive methods involving humans and so-called artificial decision makers. All the methods discussed have been openly implemented in the DESDEO software framework. Aside from enabling comparison, having different methods in the same environment has various advantages. For example, it opens an opportunity to switch the method during the solution process, e.g., when the decision maker wants to change the type of preference information. This kind of adaptability has not been discussed sufficiently in connection with interactive multiobjective optimization methods.

2. Latest advancements in software for interactive multiobjective optimization: introduction to DESDEO

Giovanni Misitano (University of Jyväskylä) and **Bhupinder Singh Saini** (University of Jyväskylä)

In this talk, we introduce DESDEO, an open-source Python framework for interactive multiobjective optimization. DESDEO was developed to address the lack of software libraries implementing interactive multiobjective optimization methods---both scalarization based (or MCDM based) methods and evolutionary (EMO) methods. DESDEO has been developed in a modular way such that, when implementing new methods, various components of existing methods can be reused, replaced, and reorganized. Thus, DESDEO also works as a central hub for implementations of interactive multiobjective optimization methods.

The core structure of the DESDEO framework is composed of four Python packages: `desdeo-problem`, `desdeo-tools`, `desdeo-emo`, and `desdeo-mcdm`. Each package implements a domain of tools for multiobjective optimization in a modular fashion. The `desdeo-problem` package contains Python class definitions to implement various kinds of multiobjective optimization problems, such as surrogate based or analytically defined problems. The `desdeo-tools` package contains implementations of various tools and utilities that are needed across different interactive methods. These include, for instance, implementations of scalarization functions, interaction utilities, and non-dominated sorting. The third package, `desdeo-emo`, contains implementations of evolutionary multiobjective optimization methods, including RVEA, NSGA-III, and MOEA/D, which have interactive and non-interactive variants. Reusable implementations of typical evolutionary operations are also included. Lastly, the `desdeo-mcdm` package contains scalarization based interactive methods, such as synchronous NIMBUS and methods belonging to the NAUTILUS-family of methods.

During the talk, we will also give some simple examples showcasing how DESDEO can be used to define multiobjective optimization problems and solve them interactively. We will also see an example of hybridizing both EMO and MCDM methods. All the code examples shown during the talk will be available for later reference.

As a central hub for implementing interactive multiobjective optimization methods, DESDEO is a promising software resource to aid researchers and practitioners alike. With DESDEO, we aim to raise awareness towards interactive multiobjective optimization methods and encourage researchers to implement their own methods as open-source software. This way, we can reach a critical mass of interactive methods giving us access to the right method for each application at hand. DESDEO is hosted on GitHub, and anybody is welcome to contribute to and utilize DESDEO! Ultimately, DESDEO will aid us in reaching better decisions in multiobjective optimization problems across many different applications.

3. Latest advancements in user interface developments for interactive methods in DESDEO

Giomara Larraga (University of Jyväskylä) and Johanna Silvennoinen (University of Jyväskylä)

Interactive multiobjective optimization methods allow the decision maker to guide the solution process by providing preference information iteratively. During the solution process, the decision maker learns about the problem's tradeoffs and can update the preference information to obtain solutions that meet their expectations. The availability of a user interface is a crucial part of solving real-world optimization problems, as it can ease the interaction between the decision maker and the method. Usually, most implementations of interactive methods lack compelling visualizations, affecting the decision maker's satisfaction in utilizing them. For instance, a bad user interface can prevent the decision maker from using the method despite its good quality solutions).

DESDEO is an open-source framework for interactive multiobjective optimization implemented in Python. This framework eases the implementation of new interactive methods by using a modular structure. In addition, it includes implementations of multiple interactive scalarization-based and evolutionary methods. In this session's previous talks, we presented how to utilize DESDEO's modular structure to implement interactive methods and optimization problems. This talk will introduce three additional packages available in DESDEO: `desdeo-webapi`, `desdeo-components`, and `desdeo-frontend`. These open-source packages ease the implementation of web-based graphical user interfaces for interactive methods.

The package `desdeo-webapi` is a web API (application programming interface) that exposes parts of the DESDEO framework (e.g., utilities to define and store optimization problems, interactive methods) to be utilized in web applications through HTTP calls. It is implemented utilizing Flask, a Python web development framework. The package `desdeo-components` contains implementations of multiple visualization components to be utilized in interactive

methods (e.g., parallel coordinate plots, radar charts, etc.). These components allow the user to interact with them by selecting elements, ranges of values, and other types of interaction. The visualizations are implemented as React components in Typescript utilizing the D3.js library. The package `desdeo-frontend` is a React application that uses the visualizations of `desdeo-components` to build graphical user interfaces for interactive methods. It utilizes `desdeo-webapi` to access the methods and optimization problems available in DESDEO.

This talk will explain the use of these three packages for building a graphical user interface for an interactive method. To this aim, we will present how to define an optimization problem utilizing the graphical user interface. Then, we will solve the defined problem using different interactive methods and visual components. The software examples shown during the talk will be made available for later reference.

The three additional packages discussed during this talk allow anyone to start building their own interface. The web API allows DESDEO to be expanded outside the domain of Python, while the `desdeo-components` and `desdeo-webapi` libraries can help in jumpstarting one's own user interface application to meet a variety of domain specific needs. The examples shown during this talk are just the tip of the iceberg.

Tuesday, 14.20-16.00

TUE-3-P2

Session: Applications of MCDA

Room: Portland Building 0.28

Chair: Matteo Brunelli

1. Including ESG into the multi-criteria analysis of investments

Antonio Lombardi Netto (Sao Paulo State University) and Valerio Salomon (Sao Paulo State University)

The selection of investment portfolios relies on traditional methods, already described in the literature and recognized by the market in terms of risk analysis. However, such methods demand technical knowledge and levels of information not often available to the individual investor. In recent years, the development of ESG (Environment, Social and Governance) practices, considering the evolution of sustainability programs, has been integrated into credit risk analysis (financial market) and asset selection (capital market). The applications of MCDM (Multiple Criteria Decision Making) methods in risk assessment and assets selection make the process simpler, demanding information easily available to the general public. Such applications represent innovation incorporating an ESG-based criteria framework. Automated tools allow any interested parties to evaluate investment opportunities based on criteria that consider the overall performance of assets and their positioning against ESG criteria. This research presents academic benefits to the fields of ESG and MCDM. The research also aims for practical contributions to the financial market. MCDM methods have already been applied for risk assessment in projects. However, the proposal to use them to assess risks related to finance is innovative. As a result, there is an innovative proposal with the potential to add knowledge applied to market realities.

2. Ranking Influential Users in Social Networks by the Evidential Reasoning Algorithm

Tao Wen (The University of Manchester), Yu-wang Chen (The University of Manchester) and Tahir Abbas Syed (The University of Manchester)

In social networks (SNs), influential users can quickly spread misinformation to the entire network. Identifying influential users can be helpful to understand information spreading mechanisms and mitigate any adverse impact potentially caused by misinformation. Several centrality measures have been proposed, for example, the degree centrality counts the number of neighborhoods; the closeness centrality represents the mean geodesic distance from each user; the eigenvector centrality considers both the number and influence abilities of neighborhoods. However, most previous measures have their own limitations, such as the consideration of insufficient information, high time complexity, and limitations of applications in real-world networks. In order to close this important gap, a comprehensive model is proposed to identify influential users by the evidential reasoning (ER) algorithm in this work, which takes into account both the topological structure information around each user and the relationship between several types of centrality measure. The ER approach was proposed for multiple criteria decision analysis (MCDA) based on the Dempster-Shafer (D-S) theory of evidence, which can aggregate several pieces of information in multilevel structure with uncertainty, ignorance, and ambiguity. Our proposed method has 5 steps: (1) The main criterion contains several sub-criteria that consider similar information in SNs to evaluate the importance of users, for example, closeness centrality, betweenness centrality, and information index are mainly based on connections between users. (2) The score of users obtained by each centrality needs to be normalized, followed by determining the belief degree through triangular fuzzy function. In the context of MCDA, the belief distribution represents the importance evaluated by each centrality measure. (3) Weights of attributes are determined by three factors, including (a) conflicts between centralities, (b) differences between the evaluation order, and (c) the overlap of scores. (4) The basic probability assignments are aggregated by the recursive ER algorithm. (5) The influential ability of each user is obtained by the ER rule. Several experiments are conducted to evaluate the performance of our

proposed method in real-world SNs, including (1) the individuation of each method, (2) the Susceptible–Infected model, (3) the relationship between different methods, and (4) Kendall's tau coefficient. This work provides a new perspective for influential user identification and public opinion management in SNs, which can also be further applied as a framework to prevent epidemic spread, cascade failure, and other aspects as needed. The rank of influential users in SNs is helpful to provide a further understanding of Internet rumors spread for the government and social platform operators. At the same time, this method can also be generalized to identify influential users in more complicated SNs according to the needs of the times, including multi-layer SNs and high-order SNs.

3. Exploring the benefits and costs of open innovation for universities by using a stochastic multi-criteria clustering approach: the case of university-industry research collaboration

Javid Zare (*Telfer School of Management / University of Ottawa*) and **Sarah Ben Amor** (*Telfer School of Management / University of Ottawa*)

Abstract. In innovation management, open innovation has become one of the topical issues attracting increasing scholarly attention. Open innovation promotes the usage of the input of outsiders to strengthen internal innovation processes and the search for outside commercialization opportunities for what is developed internally. Open innovation has enabled both academics and practitioners to design innovation strategies based on the reality of our interconnected world. Practicing open innovation has many benefits, including, for example, increased revenue, increased know-how, improved brand reputation, reduced R&D Costs, and improved long-term profitability. In addition, open innovation is also associated with different costs, including, for example, the reduced rarity of knowledge assets, increased possibility of knowledge leakage, loss of focus, and lack of the necessary resources to monitor activities.

Although some studies have identified and explored a variety of the benefits and costs of open innovation in terms of their importance to firm performance, they suffer from a significant shortcoming. Performance is a multidimensional concept and therefore must be evaluated from different dimensions, including financial, customer, business processes, and learning and growth. To the best of our knowledge, none of the studies in the literature allows scholars to compare the benefits and costs of open innovation in terms of different dimensions of performance. In this research, to analyze the benefits and costs of open innovation from different performance dimensions, we use a stochastic multi-criteria clustering method in which the benefits and costs are alternatives, and the different aspects of performance are criteria. Since there is no comprehensive understanding of the nature of the benefits and costs of open innovation, the proposed model aims to cluster them into hierarchical groups in order to help researchers identify the most crucial benefits and costs in relation to different dimensions of performance. In addition, the model is able to deal with uncertainties related to technical parameters such as the criteria weights and preference thresholds.

We applied the model in the context of open innovation for universities concerning their research collaboration with industries. An online survey was conducted to collect experts' opinions on the open-innovation benefits and costs of university-industry research collaboration in view of different dimensions of performance. The results obtained through the cluster analysis indicate that the most important benefits of university-industry research collaboration for universities are increased know-how, being more productive in terms of publication, sensing and seizing new technological trends, and increased agility. In addition, the results show that the most important costs are the lack of necessary resources to monitor activities between university and industry, an increased resistance to change among employees, an increased employees' tendency to avoid using the knowledge that they do not create themselves, paying time costs associated with bureaucracy rules, and loss of focus.

The findings of this study help researchers fundamentally cluster, explore and compare the potential benefits and the potential costs of open innovation for universities regarding their research collaboration with industries. They also enable researchers to analyze issues related

to open innovation for universities more effectively and to define their research projects on these issues in line with the priorities of universities. Meanwhile, the researchers can also make informed decisions about the open innovation projects using their information about the nature and degree of the benefits and costs of open innovation for universities. Finally, the results of this research can help both practitioners and researchers to have a clearer understanding of the benefits and costs of open innovation for organizations such as universities, colleges, teacher-training schools, research centers, institutes of technology, and professional schools providing preparation in specific fields such as medicine, business, and art.

4. An application of preference learning to the selection of blockchain validators

Jonas Gehrlein (Web3 Foundation), Grzegorz Miebs (Institute of Computer Science, Poznań University of Technology), Matteo Brunelli (Department of Industrial Engineering, University of Trento) and Milosz Kadzinski (Institute of Computer Science, Poznań University of Technology)

Polkadot is a novel technology that builds the infrastructure for an interoperable and scalable network of blockchains. It applies a variant of the Proof-Of-Stake (PoS) consensus systems to secure the integrity of the distributed ledger. To achieve this, the economic incentive model at its heart has participants risk significant financial resources (in the form of the network's native token DOT) to earn the right to validate transactions and thereby contribute to the validity of the underlying data structure. This system rewards behavior that adheres to the rules of the network, whereas misconducts result in losing parts or all of the staked funds.

Polkadot uses the Nominated Proof-Of-Stake (NPoS) protocol, with two key network participants - validators and nominators. It allows for the financial stake to be provided by the participants that are running the validation software on dedicated computers (validators) as well as the common users (nominators) of the network. Those can select, or "nominate", their preferred validators and delegate their financial resources to them. The NPoS algorithm then takes those preference lists as input in a daily election to fill the limited slots and determine which validators may participate in block production and which need to stay inactive until they are elected.

This process relieves the burden for validators to acquire the required financial stake (which easily exceed seven-digit figures) by themselves, and skillful and honest node operators get a chance to play a part in the network, regardless of their financial circumstances. This contributes to an inclusive and decentralized network, both desirable properties in the blockchain space. Simultaneously, pooling stakes between validators and their nominators improves the security of the network, because higher stakes mean more incentive to act according to the rules. The incentives of both parties are economically aligned as they share both rewards and punishments. To find suitable validators, nominators need to go through a list of hundreds of candidates (and potentially thousands in the future) with numerous distinct criteria to determine their final nomination preferences. While making a proper selection is economically incentivized, the cognitive resources that need to be spent are significant. For this reason, users might feel overwhelmed processing all of the available data, especially as the underlying set of validators changes constantly, and this process ought to be repeated frequently. The choice of validators is a subjective process and involves conflicting objectives. For example, on the one hand, nominators desire to maximize their return, and on the other hand, very profitable validators might have little stake themselves, indicating a lack of skin-in-the-game. Potential punishment for this validator would mainly affect their nominators, and thereby, the validator might have less incentive to handle and maintain their validator node properly. How this and other trade-offs are solved depends on the subjective preferences of the users. Within this framework, we develop an active learning procedure to aid the selection of validators.

The current procedure asks nominators to choose their validators from a set populated with hundreds of validators, which is certainly cognitively demanding. Conversely, our procedure

asks nominators to answer some pairwise comparisons between validators until a sufficiently unambiguous additive value function - used as the preference model - is found and can support ranking the validators automatically. Six different attributes related to the validator's reliability and profitability are considered. An element of complexity is that such attributes are not necessarily monotonic. For example, for some nominators, the best amount of commission the validator charges for their service is not necessarily zero, because this leaves nominators suspicious of their intentions.

We test the validity of our approach on real nominators in a social experiment, where we further test the objective and subjective performance of two types of pairwise comparisons. First, validators are drawn from the real database, while second, validators are fictitious and created by the algorithm itself to maximize the amount of information that can be learned in the active learning process.

Tuesday, 14.20-16.00

TUE-3-P3

Session: Outranking Methods

Room: Portland Building 0.41

Chair: Luis Dias

1. PrometheeD: a new promethee method for partial ranking based on valued coalitions of monocriterion net flow scores

Gilles Dejaegere (Université libre de Bruxelles) and Yves De Smet (Université libre de Bruxelles)

Multicriteria decision aid consists of helping decision makers to compare (rank, choose, sort, etc.) different alternatives which are evaluated on conflicting criteria. Over the last decades, numerous decision aid methods have been developed. Among them, three main categories are usually considered; the aggregating, interactive and outranking methods. The distinctive feature of outranking methods relies on the fact that some pairs of alternatives can remain incomparable. A well-known family of outranking procedures are the Promethee methods. The aim of this work is first to provide a study of the incomparability relation produced by Promethee I and to highlight what we judge as shortcomings. Indeed, it will be shown the interpretation of the parameters used in Promethee I produce some effects that are not in adequation with the usual definition of an incomparability relation. For instance, increasing the indifference thresholds, which intuitively should make alternatives be considered as more similar together (as larger differences of evaluations become less significant) can have the unexpected effect of increasing the incomparability relation between some pairs of alternatives. To overcome these shortcomings, a new approach will be presented. This is based on weighted coalitions of Promethee unicriterion net flow's scores. This method will be studied and it will be shown that the output incomparability relation is more conforming with the usual definition of incomparability. Finally, a comparison between this new method with the Promethee I method will be performed.

2. Multi-criteria portfolio selection for environmental decision-making using PROMETHEE – The case of the container terminal Tollerort

Erik Pohl (University Duisburg-Essen, Chair of production management) and Jutta Geldermann (University Duisburg-Essen, Chair of production management)

Container terminals are crucial for international trade and supply chains, and port terminal operators strive to reduce the environmental footprint of the terminals to reach carbon neutrality. Environmental decisions are often complex and need to consider various conflicting criteria. PROMETHEE is a family of methods for multi-criteria analysis that has been widely applied in environmental decision-making. To find a preferred alternative from a discrete set of available alternatives, PROMETHEE I and II can be used to determine a partial or complete ranking based on the decision makers (DMs) preference. Some real-world decisions, however, require determining a set or portfolio of alternatives regarding goals and constraints given by the DM. Therefore, we develop a new approach to portfolio selection that incorporates different types of criteria i.e., we develop an approach to find a subset of good alternatives under different constraints considering dependencies among alternatives and different types of criteria.

In this talk, we present a portfolio decision problem concerning energy saving and emission reduction measures in a container terminal. We construct portfolios based on the measure's PROMETHEE assessment under a set of criteria within the ecological, economic, social, and technical categories by using a linear, binary optimization model. To account for non-monotonic and indeterminable criteria, we identify multiple good portfolios and assess these, again, using PROMETHEE. While defining the portfolio, we consider various constraints and

interdependencies. Within the case study, a roadmap towards a more profitable and ecological port operation can be developed.

3. Parametric and non-parametric models to induce a probability distribution in the space of compatible value functions.

Sally Giuseppe Arcidiacono (*University of Catania*), **Salvatore Corrente** (*University of Catania*) and **Salvatore Greco** (*Department of Economics and Business, University of Catania*).

Ordinal Regression (OR) is a popular methodology of multiple criteria decision aiding that induces a value function representing the preferences of a Decision Maker (DM). Based on the remark that, in general, there is an infinite plurality of value functions compatible with the preferences expressed by the DM, Robust Ordinal Regression (ROR) has been proposed extending OR. Conjugating ROR with a Stochastic Multicriteria Acceptability Analysis, a probability distribution has been considered in the space of the value functions compatible with the DM's preferences. In this context, we propose a methodology to induce a probability distribution in the space of the compatible value functions through parametric and nonparametric models. We also test the reliability of the obtained results in a set of experimental computations.

4. Robust conclusions based on qualitatively elicited ELECTRE weights from a panel: methods and an application to rating policies

Luis Dias (*CeBER, Faculty of Economics, University of Coimbra*)

One of the challenges for the application of multi-criteria decision aiding methods is setting the criteria weights. This becomes even more challenging when dealing with a group of decision makers, experts, and/or stakeholders, i.e., when weighting intends to represent the preferences of a panel. Not only panels members might disagree, they also often find it difficult to indicate a precise weighting vector (e.g., due to not knowing the MCDM method, or due to hesitation). A qualitative elicitation approach can then be helpful by not requiring a precise quantification. In particular, for ELECTRE and other methods in which weights represent importance coefficients, such elicitation can be based on ordinal importance levels such as "Not much important", "Moderately important", etc.

This presentation addresses the issue of deriving weight constraints from this type of inputs from a panel, and then deriving robust conclusions from such constraints. The concept of prudent order is suggested as a possible rationale to obtain a ranking of the weights for the panel. From such a ranking, robust conclusions can be derived using well-established optimization and stochastic approaches.

As an application, a case of rating policies for tackling macroplastic and microplastic marine litter is presented. The assessment of the policies involved the participation of a group of experts and stakeholders. This panel assessed the contribution of the policies (six in total) to the a given set of objectives (eight in total), as well as the relative importance of the objectives, on ordinal scales.

For a base case analysis, the median policy assessments provided by the group were considered. A customized version of the ELECTRE TRI multi-criteria decision aiding method was used to aggregate policy assessments into a global assessment expressed in the same scale, allowing communicating the method and its results in a simple way. Results were initially obtained in the form of robust intervals with regards to weighting, which was followed by a ranking of these policies based on a stochastic (SMAA TRI) analysis. The analysis was also repeated considering the 33rd and 67th percentile assessments, corresponding to a more pessimistic and to a more optimistic perspective in relation to the base case analysis.

Tuesday, 16.20-18.00

TUE-4-Doctoral Dissertation Award Session
Room: Richmond Building LT1
Chair: Francisco Ruiz

1. A study of the day-ahead energy market auctions from a multi-objective perspective
Gökhan Ceyhan

**2. A multiple criteria integrated approach for nominal classification problems:
Methods and applications**
Ana Sara Costa

**3. Efficiency and public policy of the Portuguese healthcare sector: A look at the
pressing issues**
Miguel Alves Pereira

Wednesday, 9:00-10:00

WED-1-PLenary

Plenary Session: Professor Murat Köksalan

Room: Richmond Building LT1

Chair: Banu Lokman

Routing Unmanned Air Vehicles under Multiple Objectives

Murat Köksalan

Ross School of Business, University of Michigan, Ann Arbor



Abstract: Unmanned Air Vehicles (UAVs) are widely used for military and civilian purposes. The vehicle typically visits several targets during a mission. Under a single objective, such as minimizing the distance traveled, the UAV routing can be modeled as a traveling salesperson or an orienteering problem. In this talk, we will address the UAV routing problem under multiple objectives. When there are two or more objectives, there can be many efficient trajectories that may be followed between target pairs, each performing better than others in some objectives. There are many efficient tours that use some combinations of these efficient trajectories. Choosing a tour requires making trade-offs between different objectives. We consider traveled distance and detection threat objectives to characterize efficient tours for discrete and continuous terrains. We develop approaches to aid route planners in choosing preferred solutions. We also consider different versions where the UAV needs to be routed in real-time in a dynamic environment and where the set of targets to be visited is also part of the decision to be made, with the additional objective of collected information.

Bio: Murat Köksalan is currently teaching at the Ross School of Business, University of Michigan, Ann Arbor. He has spent most of his career at the Industrial Engineering Department of Middle East Technical University. He held visiting professor positions at Georgetown University, Purdue University, and University of Buffalo in the United States, and Aalto University in Finland. The Young Researcher Award of the Turkish Scientific and Technological Council, The Gold Medal of the International Society on Multiple Criteria Decision Making (MCDM), The Science Award of the Parlar Foundation are among the awards he has received. He won the INFORMS Case Competition several times with different co-authors. He is the founding president of the INFORMS Section on MCDM and the past President of the International Society on MCDM. Methodology and applications of MCDM, multi-objective combinatorial optimization, and heuristic search are among his areas of interest.

Wednesday, 10.20-12.00

WED-2-P1

Session: Multi-objective Optimization

Room: Richmond Building LT3

Chair: Kathrin Klamroth

1. Discrete representations of the non-dominated set

*Lucie Galand (Université Paris-Dauphine, Université PSL, CNRS, LAMSADE, 75016 Paris, France), **Marie Humbert-Ropers** (Université Paris-Dauphine, Université PSL, CNRS, LAMSADE, 75016 Paris, France) and Daniel Vanderpooten (Université Paris-Dauphine, Université PSL, CNRS, LAMSADE, 75016 Paris, France)*

In multi-objective optimization, one of the main difficulties is the large cardinality of the set of non-dominated points, which can be exponential in the size of the instance for multi-objective combinatorial optimization problems or infinite for multi-objective continuous problems.

Therefore, an interesting challenge is to determine a "good representation" of the set of non-dominated points so as to provide decision makers with a tractable set of points describing as well as possible the different choices.

The quality of a representation is assessed through three general properties [Say00, FW10]:

- coverage: the representation must ensure that any non-dominated point is covered by at least one point of the representation
- spacing: the representation must be composed of sufficiently distinct points
- cardinality: the representation must be of reasonable size

To implement the coverage and spacing properties, it is proposed in [BJV17] to use the ε -dominance relation. ε -dominance is a binary relation that approximates Pareto-dominance within a factor ε .

Coverage and spacing can then be expressed through this relation for different ε and ε' values representing the degree of desired requirement for each of these properties.

It is shown in [BJV17] that such a representation can be determined in polynomial time in the bi-objective case but that it is much more difficult with multi-objective problem with at least three objectives. The goal of this work is therefore to propose a general method, not restricted to the bi-objective case, that determines a set satisfying the properties of a good representation.

We focus on the construction of a representation of fixed size for a given discrete set of points. Since the coverage property is essential to the definition of a representation, we propose to optimize it in priority and to consider the spacing property in a second step. We thus define the search for a good representation as a lexicographic optimization problem: under the constraint of cardinality, we lexicographically optimize the ε value ensuring the coverage first, and then the ε' value ensuring spacing.

This problem can be formulated as a linear program with binary variables which is related to the problems of p-center and p-dispersion.

The distance from a point y to a point y' , generally considered in these location problems, is replaced in our case by the minimum ε value needed for y to ε -dominate y' .

Based on known formulations for the p-center problem [Das11, ELP04, CT13] and the p-dispersion problem [Erk90], we propose a method adapted to the specificities of our problem.

Finally, we present some numerical experiments illustrating the performance of the method on large sets of points for different numbers of objectives and different sizes of the representation.

[BJV17] C. Bazgan, F. Jamain, & D. Vanderpooten. Discrete representation of the non-dominated set for multi-objective optimization problems using kernels. *European Journal of Operational Research*, 260(3):814-827, 2017.

[CT13] H. Calik & B.C. Tansel. Double bound method for solving the p-center location problem. *Computers and operations research*, 40(12):2991-2999, 2013.

[Das11] M.S. Daskin. *Network and discrete location: models, algorithms, and applications*. John Wiley & Sons, 2011.

[ELP04] S. Elloumi, M. Labbé, & Y. Pochet. A new formulation and resolution method for the p-center problem. *INFORMS Journal on Computing*, 16(1):84-94, 2004.

[Erk90] E. Erkut. The discrete p-dispersion problem. *European Journal of Operational Research*, 46(1):48-60, 1990.

[FW10] S.L. Faulkenberg & M.M. Wiecek. On the quality of discrete representations in multiple objective programming. *Optimization and Engineering*, 11(3):423-440, 2010.

[Say00] S. Sayın. Measuring the quality of discrete representations of efficient sets in multiple objective mathematical programming. *Mathematical Programming*, 87(3):543-560, 2000.

2. Using Hypervolume Scalarization for Non-Linear Multiobjective Optimization Problems

Michael Stiglmayr (University of Wuppertal), Johanna Schultes (University of Wuppertal) and Kathrin Klamroth (University of Wuppertal)

The hypervolume indicator has been suggested as a performance indicator in the context of evolutionary multiobjective optimization. In this context it is applied to evaluate the fitness of solutions sets and of individual solutions. Given a reference point in objective space, the hypervolume indicator of a solution set measures the volume that is dominated by the solution set, and dominates the reference point.

In this talk we investigate the hypervolume scalarization method, i.e., finding a solution maximizing its dominated hypervolume. With the hypervolume scalarization also unsupported efficient solutions can be determined without adding constraints to the problem formulation.

This is particularly important when considering problems with PDE constraints, as e.g. multiobjective shape optimization problems, where additional constraints increase the complexity of the problem considerably.

Moreover, maximizing the dominated hypervolume supports the decision maker in identifying good compromise solutions. We investigate the relation of the hypervolume scalarization to the weighted sum scalarization and to multiobjective gradient descent methods. Furthermore, we show numerical results of the hypervolume scalarization for a biobjective shape optimization problem.

3. Variable fixing for multi-objective branch-and-bound

Nicolas Forget (Aarhus BSS) and Sophie Parragh (Johannes Kepler University Linz)

In the bi-objective branch-and-bound literature, a classical way to speed-up the resolution is to perform objective branching, i.e. to create smaller and disjoint sub-problems in the objective space, obtained from the partial dominance of the lower bound set by the upper bound set. When considering three or more objective functions however, applying objective branching becomes more complex, and the benefit is not so clear anymore. Hence, we investigate here whether the objective branching constraints can be further exploited. We focus on multi-objective combinatorial optimization problems, with binary variables only. After performing objective branching, we try to fix variables by identifying values that they cannot take due to infeasibility or dominance in the sub-problems at hand, and show that it significantly reduces the computation time on a set of multi-objective knapsack, and both capacitated and uncapacitated facility location problem instances.

4. Pareto Tracing by Numerical Integration

Kathrin Klamroth (University of Wuppertal), **Matthias Bolten** (University of Wuppertal), **Onur Tanil Doganay** (University of Wuppertal), **Hanno Gottschalk** (University of Wuppertal) and **Lara Löhken** (University of Wuppertal).

We suggest a novel approach for the efficient and reliable approximation of the Pareto front of sufficiently smooth unconstrained bi- and multi-objective optimization problems. Optimality conditions formulated for weighted sum scalarizations of the problem yield a description of (parts of) the Pareto front as a parametric curve, parameterized by the scalarization parameters (i.e., the weights in the weighted sum scalarization). Its sensitivity w.r.t. parameter variations can be described by an ordinary differential equation (ODE). Starting from an arbitrary initial Pareto optimal solution, the Pareto front can then be traced by numerical integration. We provide an error analysis for biobjective problems based on Lipschitz properties and suggest an explicit Runge-Kutta method for the numerical solution of the ODE. The method is validated and compared with a predictor-corrector method on convex quadratic programming problems and on the test function ZDT3, for which the exact solution is explicitly known. We also present numerical results for an engineering application, a biobjective shape optimization problem, that involves finite element discretizations of the state equation.

Wednesday, 10.20-12.00

WED-2-P2

Session: Analytic Hierarchy / Network Processes

Room: Portland Building 0.28

Chair: Fusun Ulengin

1. How to measure the impact of gun laws on lawful owners of guns

Luis Vargas (University of Pittsburgh), **Marcel Minutolo** (Robert Morris University) and **Amos Guiora** (University of Utah)

Balancing public good with individual rights is a difficult task; gun policies attempt to do just this. To ensure public safety, local, state, and federal agencies piece together policies that each entity believes will meet the needs of public welfare. When legislating new gun policies, the impact the policies have on gun owners are perceived as a zero-sum game; some groups are perceived to gain while others think they are losing, but the reality is much more nuanced. Here we present a model based on benefits, opportunities, costs and risks that attempts to assess the impact of gun laws on owners of guns. The impacts of gun control policies are not just monetary (tangible) for some users, but also intangible, like not being able to enjoy hunting, or target shooting, or being afraid if they do not have a way to defend themselves. We are not only trying to understand how gun control policies impact legal gun owners, but also which category of gun owner is more affected.

2. A Framework for Prioritizing Sustainable Third-Party Logistics Service Providers: A Case Study

Ozden Bayazit (Central Washington University), **Birsen Karpak** (Youngstown State University) and **Tacibaht Turel** (Youngstown State University)

The logistics outsourcing industry has been growing rapidly due to its potential to increase efficiencies in the global supply chain. As a result, logistics service providers have assumed a more comprehensive role in response to the increased complexity of global supply chains, which explains why approximately 60% of Fortune 500 companies in the United States turned to Third Party Logistics (3PL) service providers for help. In the retail industry, as the e-commerce market has grown exponentially, so too has the 3PL market, which is forecasted to grow 8% during the period 2021-2026.

In this study, we report the findings from our longitudinal study with an aerospace company in Western Washington in the U.S. Previously, we prioritized three different 3PL service providers and identified prominence of the clusters, namely technical competence, cost, and timeliness using the Analytic Hierarchy Process (AHP.) The decision criteria were identified through a literature search and modified with the interaction by a senior procurement manager for 3PL contracts who delivers logistics services to the company's production systems. Though there was dependency among certain criteria, the manager preferred simplicity over precision at the outset, which is why we employed the AHP for the first study. There were quite a few criteria considered, both qualitative and quantitative. To achieve a manageable list of 3PLs, the candidates were narrowed down based on the criteria such as capacity and capability (range of services) that line up with the company's requirements, demonstrating successful performance to the similar statement of works (SOW) as measured by key performance indicators including turnaround time, inventory accuracy, financial strength and so on. The final list of 3PL providers included a startup minority-owned company, a nationwide company with state-of-the-art technology, and an agile medium enterprise, with an excellent customer relationship management track record. Each provider had a different strength based on the criteria considered. Throughout the process, in-depth interviews have been carried out with the manager. In eliciting judgments, we used verbal mode instead of numerical one since we knew from our own previous research that verbal mode dominates numerical one when perceived ease of use and accuracy are considered. We did an extensive sensitivity analysis

including the two-dimensional one. Our first contender remained at the top though there were rank reversals in the second and third contenders. Our decision-maker selected the Minority-owned 3PL service provider confidently as a result of AHP analysis.

In our second study, the senior procurement manager was ready to implement Analytic Network Process (ANP). Upon implementing the ANP, we compared the preference ratings of alternative 3PL providers derived via AHP versus via ANP and saw that the ranking of the alternative 3PL providers did not change despite a change in the degree of preference. Therefore, there was no reason for the manager to switch to another service provider.

Now, we propose a new framework addressing COVID-19 and its long-term repercussions as well as the Ukraine war and its expected consequences. There are more and more articles asserting that the pandemic has slowed down global sourcing. The mindsets of the employees changed remarkably, with quite a few of them opting for remote working as many of them embraced remote work as the new normal. Another important new mind resetting event has been the war in Ukraine, which is a very different kind of conflict than we are used to. This war got countries thinking about the significance of being self-sufficient as some countries cannot produce certain materials and commodities domestically to be able to meet their own demand.

In the light of these new events, we have decided to add environmental and social sustainability dimensions to our new model. Since the pandemic has made the employees' well-being top-of-mind for employers, the employee well-being of the 3PL provider was included as one of the factors in this new model. Previously, in the technical competence cluster, we included the 3PL provider's ability to meet the company's advanced IT expectations as one factor. In this new model, we also added cyber security as a separate criterion since cybersecurity attacks have become a genuine threat around the world as the Ukrainian war rages on. Moreover, the agility of the 3PL provider is another criterion added to our new framework as agility is key to long-term business survival. With the newly added dimensions and criteria, this model became far more complex, even though we are well aware of the practitioner fatigue problem. For that, we tried to restrict the number of criteria to a manageable level. Clustering also helped reduce the number of pairwise comparisons. We contented with $2n+3$ (n being the number of criteria) pairwise comparisons for each cluster.

In this new model, we have used the implicit intuitionistic Fuzzy Analytic Network Process approach in eliciting judgments and analyzing and proposing alternative solutions to the manager. And then we have discussed the relationship between implicit intuitionistic Fuzzy Analytic Network Process and intuitionistic Fuzzy Analytic Network Process approach to a complex multi-criteria decision problem.

Even though frameworks for Sustainable Third-Party Logistics Service Providers have been reported in the literature, models considering interaction among decision criteria, especially models considering the influences of the alternative 3PL providers on the criteria, are very few. To the best knowledge of the authors, there are no frameworks considering the long-term impact of the pandemic as well as the expected impact of the Ukraine war on global sourcing.

3. AHP/ANP Applications of Big Data Analytics in Supply Chain Management

Ilker Topcu (Istanbul Technical University), Birsen Karpak (Youngstown State University) and Fusun Ulengin (Sabanci University)

Big Data has been attracting not only researchers' but also manufacturers' attention and service business as well. The amount, variety, velocity of data generated, by the external and internal environment of the businesses are significantly increasing and creating great challenges for the organizations who wants extract business insights for competitive advantage. Big Data analytics empower companies to drive valuable knowledge from gigantic structured and unstructured data from multiple sources. We explore Big Data Business Analytics (BDBA) , whether descriptive, predictive, or prescriptive, in supply chain management (SCM). Big Data enabled supply chains have great potential for future research since how to apply bigdata analytics to SCM is still unclear for business and academics though

both business as well as academia have been very keen on this emerging subject. Multiple Criteria Decision Making (MCDM) have been relatively slow attacking big data enabled supply chain management. We have seen very few Analytic Hierarchy Process (AHP) /Analytic Network Process (ANP) study and implementations in this area.

First, we conducted a systematic literature review on BDA in SCM to clarify the issue. We searched the publications published between 2015 and 2021 in the databases of Elsevier Journals (Science direct), Wiley Online Library Journals, Taylor and Francis Online Journals, and Springer Dimensions. We used the query of keywords such as "Big Data Business Analytics" and SCM OR "Big Data Analytics" and SCM OR "Big Data Supply Chain Analytics" OR "Business Analytics" and "big data" and "Supply Chain" OR "Big Data Analytics" and SCM and "decision making" OR "Big Data Analytics" and SCM and Multi-criteria" OR "Big Data Analytics" and SCM and MCDM OR "Big Data Analytics" and SCM and AHP" OR "Big Data Analytics" and SCM and ANP at the title, abstract, and keywords of the publications. We excluded the publications that were conference proceedings, book chapters, or editorials. We also excluded non-English publications. As an inclusion criterion, we searched the research areas of Operations Research / Management Science, Business, Computer Science, Information Science, and Technology. We analyzed the total number of articles published in each year, the frequency distribution of top 10 contributing countries, the frequency distribution of top 10 keywords, the frequency distribution of methods utilized, the frequency distribution of top 10 cited articles in Web of Science, the pageranks of top 10 articles, number of co-authors in each article, the total number of articles published in each journal, the frequency distribution of articles based on journal quartiles, the frequency distribution of articles based on journal indices.

We explore AHP/ANP and extensions applications in big data enabled Supply Chain. Moktadir et al. (2019) use a Delphi-based AHP to evaluate and analyze the barriers and BDA readiness in SCM. They identified that data-related barriers are most influential based on the data obtained from five Bangladeshi manufacturing companies. Khan et al., (2021) evaluate the digital supply chain readiness (DSC). They propose Fuzzy-AHP based knowledge management system (KMS) to establish a link between DSC readiness factors and their impact on DSC readiness score. KMS is validated in an Indian manufacturing company. Dev et al. (2019) use an ANP based evaluation using real-time key performance indicators of the supply chain. Kazancıoğlu et al. (2021) use a fuzzy-based hybrid decision framework to identify barriers to circularity in dairy supply chains through big data solutions. They develop a hybrid decision framework based on the fuzzy ANP and the fuzzy VIKOR to find the weights of the barriers and rank the big data-driven solutions. Economic barrier was identified to be of the most influential barrier, followed by 'technological', 'environmental', then 'social and legal barrier' to circularity in dairy supply chains.

We assert that BDBA and Supply Chain Analytics (SCA) are the strategic assets of an enterprise. After comparing and summarizing the reviewed approaches we identify the primary research opportunities where the deployment and use of 'big data' is likely to have significant impacts in supply chain management. We came up with some future challenges of BDA in SCM for collecting data, storing data, cleaning and verifying data, summarizing data, and modeling with big data. Big data enabled digital supply chains, big data adoption risks involved in sustainable supply chains are among the new research directions we are considering.

Wednesday, 10.20-12.00

WED-2-P3

Session: Evolutionary Multi-objective Optimization

Room: Portland Building 0.41

Chair: Carlos Fonseca

1. New multiobjective strategies to optimize constrained EUD Radiotherapy models

Savíns Puertas Martín (University of Almeria), **Juan José Moreno Riado** (University of Almeria), **Juana López Redondo** (University of Almeria), **Pilar Martínez Ortigosa** (University of Almeria), **Anna Zawadzka** (Maria Skłodowska-Curie National Research Institute of Oncology), **Janusz Miroforidis** (Systems Research Institute, Polish Academy of Sciences), **Ignacy Kaliszewski** (Systems Research Institute, Polish Academy of Sciences) and **Gracia Ester Martín Garzón** (University of Almeria).

Intensity Modulated Radiotherapy (IMRT) is an effective cancer treatment technique to deposit radiation in tumorous tissues while preserving surrounding healthy organs. The design of effective Radiotherapy (RT) plans for IMRT poses a multi-objective problem, whose solutions should exhibit unimprovable trade-offs between doses delivered to the tumour and healthy organs.

The IMRT devices deliver radiation beams to patients from different angles with varied intensities within a beam. Usually, the angles are fixed by the IMRT equipment. To numerically control the radiation dose deposition, each beam is decomposed into a regular grid of beamlets, whose radiation intensity can be individually controlled. Therefore, every RT plan is defined by the specific intensities of all the beamlets over all beams, referred to as the fluency map. When preparing an RT plan, the goal is twofold. On the one hand, plans are sought that ensure depositing the prescribed doses in tumorous cells (the target regions, commonly referred to as PTV regions) and, on the other hand, such plans protect healthy but highly sensitive organs, (Organ(s) At Risk, OAR(s)). These two goals are contradictory and as such have to be traded-off, which means that patient effective and safe RT plans require significant efforts from the planners. This leads the way to multiobjective optimization in IMRT.

To obtain effective RT plans, various optimization models with different statistical and biological criteria have been proposed in the literature, in order to express the different categories of medical prescriptions. However, every model suggested is focused on limited criteria and the RT plans computed by the software need to be improved in relation to all clinical criteria to get feasible RT plans.

The goal of this work is to define new optimization strategies to improve the quality of automatically computed RT plans. With this goal in mind, we have defined a new Multi-Objective Optimization (MOO) model that reflects the statistical constraints and the personalized preferences for each patient. Such MOO model is combined with an EUD (Equivalent Uniform Dose) based model, a widely used biological criterion.

Radiation planning techniques, based on EUD, can provide radiation plans with excellent PTV coverage. The EUD concept enforces the prescribed or recommended radiation doses in PTVs and OARs by a penalty function that itself uses a linear-quadratic cell survival model. For the EUD based optimization model, optimal solutions can be efficiently computed by gradient methods. However, for every PTV region and every OAR, several EUD parameters need to be set by the planner. To account for the additional statistical constraints needed for viable plans, imposed by oncology doctors and medical physicists, the manual tuning of EUD parameters is required. This is a time-consuming and complex task that is hard to accommodate into the clinical workflow on a daily basis.

We propose, as a solution, the deployment of a two-level optimization scheme. On one hand, the optimal solution of the EUD model with a given set of parameters is solved by a gradient algorithm. On the other hand, the MOO model is harnessed to explore the EUD parameter

space in a quest for promising parameter sets, with all statistical constraints enforced. More specifically, to solve the MOO problem, the search over the set of parameters is conducted by the evolutionary optimization principle. Collections of such EUD parameters are evaluated with respect to objectives bearing the corresponding optimal fluency maps, computed by the gradient level. The output of this procedure is a collection of nondominated RT plans. This strategy eliminates manual EUD parameter tuning and replaces it with automatic parameter selection. Moreover, at that level, priorities for the protection of selected OARs are taken into account. To facilitate the analysis of the resulting RT plans, we define decision criteria that assist the planner and the physician in the selection of the final plan.

Our proposed scheme has been evaluated on Head and Neck cancer real data with three sets of priorities. The resulting fluency maps obtained with our automated EUD parameter selection have low dose depositions on the prioritised OARs while maintaining good dose coverage in the PTVs.

The automated EUD parameter selection has shown to be a viable alternative to the current IMRT RT planning clinical practices. This may signify a turning point in IMRT RT planning and, in consequence, a direct improvement for patients' quality of life, as they can receive lower radiation doses in OARs.

2. Use of Data Analysis Techniques for Multi-Objective Optimization of Real Problems: Decision Making

Antonio Gaspar-Cunha (Institute for Polymers and Composites / I3N, University of Minho), Francisco Monaco (Institute of Mathematics and Computer Science, University of São Paulo, Brazil), Paulo Costa (Institute for Polymers and Composites / I3N, University of Minho) and Alexandre Delbem (Institute of Mathematics and Computer Science, University of São Paulo, Brazil)

Most, if not all, real optimization problems can be seen as multi-objective since several objectives are to be satisfied concurrently and are often conflicting. Also, due to the high computation times usually required by the numerical modelling routines available to calculate the values of the objective function, as a function of the decision variables, it is necessary to develop alternative optimization methodologies able to reduce the number of solutions to be evaluated, i.e., if compared with the procedures typically employed, such as evolutionary algorithms. Moreover, in a multi-objective environment, it is also necessary at the end of the optimization process to select a single solution from the pool of optimal non-dominated solutions obtained.

Real industrial processes can be characterized by different types of data that can influence assertively its performance. For example, in the industrial process studied here, polymer processing, variables related to operating conditions of the machine, polymer properties and system geometry affect its operation since the thermomechanical environment developed allows obtaining mathematical relationships between these design variables and the objectives to be accomplished. This enables the direct process optimization using those routines to evaluate the solutions proposed by the optimization algorithms. However, this routine must be run several times, implying high computation times due to the sophistication of the numerical codes

This work aims to apply Artificial Intelligence based on a data analysis technique, designated by DAMICORE, to surpass those limitations, improve the optimization process and help the selection of the best-equilibrated solution at the end. An example from single screw polymer extrusion is used to illustrate the efficient use of a methodology proposed, with a focus on decision making.

Solving Multi-Objective Optimization Problems (MOOP) requires some interaction with a DM, for example, an expert in the field. The aim is to use data analysis techniques to reduce and improve the quality of those interactions, which can be done by integrating optimization methodologies with data analysis tools, i.e., the use of data to drive the optimization. At least,

two different possibilities can be applied by data-driven optimization: i) replacement of the original method of calculating the objectives by a metamodel or surrogate, and 2) helping the computer in deciding about the best solutions to the problem.

The aim here is to use the DAMICORE framework to facilitate the optimization taking into account the limitations/characteristics referred to above. The DAMICORE structure is based on the estimation of distances by compression algorithms called Normalized Compression Distance (NCD). Then, a Feature Sensitivity Optimization based on Phylogram Analysis (FS-OPA) is used to find the set of principal features related to the real problem environment.

The present study focus on two levels of learning, which will be used to study an industrial case study using real data:

First-level learning – the aim is to find clusters of variables sharing information, designated by clades, each representing the set of variables with important interactions. The result of this level is a table with a list of variables with a cluster per row.

Second-level learning – the application of FS-OPA allows the estimation of the contribution of each clade of variables to the objectives, which is made by determining the distance between the clades of objectives (oclade) to each variable clade (vclade) using the phylogram obtained. These distances are an estimation of the influence of a clade to improve an objective. The results of this level are two different matrices, one with the phylogram distances from vclades to oclades and the second with the relative phylograms distances from each variable to each objective.

From a practical point of view, the application of this method to the data of each population of solutions previously obtained during the multi-objective optimization using evolutionary algorithms will allow capturing the interactions between the decision variables and the objectives and, in the end, select the most important objectives to the process. Therefore, the multi-dimensional space, that results from the six objectives existent in the problem solved, can be reduced, which will help the decision maker in selecting in an easy way the solution to be applied in real practice.

The results obtained for this practical example are in agreement with the expected thermomechanical behaviour of the process, which demonstrated that AI techniques can be useful in solving practical engineering problems.

3. Calculating Dominance Move using mixed-integer programming: a new compact formulation

Carlos M. Fonseca (Department of Informatics Engineering, Center for Informatics and Systems of the University of Coimbra (CISUC)), Claudio Lopes (CEFET-MG), Flávio M (Computer Department at the Centro Federal de Educação Tecnológica de Minas Gerais), Elizabeth Wanner (Computer Department at the Centro Federal de Educação Tecnológica de Minas Gerais) and Kalyanmoy Deb (Department of Electrical and Computer Engineering, Michigan State University)

Dominance move (DoM) is a binary quality indicator that can be used in multi-objective and many-objective optimization to compare two solution sets. Although being very intuitive, DoM is hard to calculate. There is a proposed mixed-integer programming model which is complex and highly affected by the number of solutions in the set. This paper presents an efficient and compact formulation that can benefit practitioners interested in using the indicator. Computational experiments show that the formulation has the best overall performance.

Wednesday, 13.20-15.00

WED-3-P1

Session: Multi-objective Optimization

Room: Richmond Building LT3

Chair: Matthias Ehrgott

1. A new two-phase algorithm for the bi-objective minimum spanning tree problem

Lavinia Amorosi (Sapienza University of Rome) and Justo Puerto (University of Seville)

In this talk we present a new two-phase algorithm for the bi-objective minimum spanning tree (BMST) problem. In the first phase it computes the extreme supported efficient solutions resorting to both mathematical programming and algorithmic approaches, while the second phase is devoted to obtaining the remaining efficient solutions (non-extreme supported and non-supported). This latter phase is based on a new recursive procedure capable of generating all the spanning trees of a connected graph through edge interchanges based on increasing evaluation of non-zero reduced costs of associated weighted linear programs. Such a procedure exploits a common property of a wider class of problems to which the minimum spanning tree (MST) problem belongs, that is the spanning tree structure of its basic feasible solutions. Computational experiments conducted on different families of graphs and with different types of cost show the correctness of the algorithm and allow to extract conclusions on the difficulty of finding the entire set of Pareto solutions of the BMST problem depending on the graph topology and the possible correlation of the edge costs.

2. Approximate solutions to multiple-choice knapsack problem by multiobjectivization and Chebyshev scalarization

Ewa Bednarczuk (Systems Research Institute of the Polish Academy of Sciences), Ignacy Kaliszewski (Systems Research Institute of the Polish Academy of Sciences) and Janusz Miroforidis (Systems Research Institute of the Polish Academy of Sciences)

Multiobjectivization, understood as adding additional objective functions to the original ones, is a concept to ease optimization computations. In one form, it reduces to interpreting selected constraints as objective functions, with the purpose to reveal specific constraint structures which otherwise would remain overshadowed, and possibly unnoticed. In the presentation, we follow that concept. Specifically, we apply it to the multiple-choice knapsack problem with nonlinear functions which are additively separable, multiplicatively separable, or additively-multiplicatively separable.

We propose an algorithm to provide approximate solutions to the multiple-choice knapsack problem with that class of functions, together with the optimality gap estimation. The algorithm is based on the multiobjectivization approach combined with the Chebyshev scalarization.

3. Towards a Polynomial Delay Algorithm for Three-Objective Linear Programming

Fritz Böckler (Osnabrück University), Markus Chimani (Osnabrück University) and Alexander Nover (Osnabrück University)

Multiobjective Linear Programming (MOLP) is a corner stone of multiobjective optimization (MOP) and multiobjective combinatorial optimization in particular. In recent years, methods emerged to classify algorithms for MOLP and other MOP as efficient. The state-of-the-art for computing the non-dominated extreme points of an MOLP is an incremental polynomial time algorithm based on the Dual Benson algorithm, now usually called an Inner Approximation (IA) strategy. And the state-of-the-art for computing the non-dominated facets of an MOLP is an incremental polynomial time algorithm based on the original algorithm by Benson, called an Outer Approximation (OA) strategy. For the special case of bi-objective linear programming, the well-known dichotomic approach is capable of finding the extreme points and facets in polynomial delay. A polynomial delay algorithm is not yet known for three and more objective linear programming.

In this talk, we present a new algorithm addressing the weaknesses of the IA and OA methods, namely the non-locality of the vertex enumeration needed in both. We show that the new algorithm can compute the non-dominated extreme points of a three objective LP with polynomial delay. We therefore present the first polynomial delay algorithm for three-objective linear programming. For more than three objectives, we show that the algorithmic strategy is capable of computing the non-dominated extreme points in polynomial delay if certain degree bounds hold for the graph of the upper image.

4. An evaluation of the fairness of railway timetable rescheduling in the presence of competition between train operators

*Edwin Reynolds (Lancaster University), **Matthias Ehrgott** (Lancaster University) and Judith Y. T. Wang (School of Civil Engineering & Institute for Transport Studies, University of Leeds)*

Effective real-time management of railway traffic is crucial to delivering good railway performance. In particular, making changes to the timetable in response to an initial delay can help to reduce the amount of additional delay caused to other trains as a result of the initial incident. This practice is known as timetable rescheduling. The Train Timetable Rescheduling Problem (TTRP) (Cacchiani et al., 2014) can be solved in order to determine the optimal way to reschedule the timetable. A large number of different TTRP problem variants, models, objective functions and solution methods have been studied.

However, the implications for TTRP models of economic competition between railway operators has not been considered. In recent decades, different forms of competition have been introduced in several European railway systems, such as those of Germany, Great Britain and Sweden. Where trains are operated by more than one different company over the same tracks, timetable rescheduling has the potential to impact these operators unequally. In order to be perceived as fair, a TTRP model must not systematically favour some operators over others. A perception of unfairness would be a serious barrier to the practical deployment of TTRP models in competitive railway systems. Therefore, it is essential that the fairness characteristics of such models are understood. This study investigates the fairness of solutions obtained from solving the TTRP.

This paper is organised as follows. We first review the relevant literature on fairness, in particular in relation to the TTRP. We then describe our methodology by defining our notions of fairness and efficiency and how to evaluate them. In our results, we present an analysis of the fairness of efficiency-maximising TTRP solutions. This is supplemented by an analysis of the interactions between pairs of operators, where we also consider the fairness-efficiency trade-off.

Wednesday, 13.20-15.00

WED-3-P2

Session: Analytic Hierarchy / Network Processes

Room: Portland Building 0.28

Chair: Yuji Sato

1. Spherical Fuzzy AHP Based Decision Making Approach for Sustainable Supplier Selection in Manufacturing Sector

Sezin Güleriyüz (*Bartın University*)

According to the "Adaptation Gap Report" published by the UN Environment Program, the financing needed by developing countries for adaptation to climate change can reach \$280-500 billion annually until 2050. According to a new study shared by the World Economic Forum, the global economy may lose 10 percent of its total economic value by 2050 due to climate change. Both countries and the business world have very important responsibilities against the effects of the climate crisis. After signing the Paris Agreement, which aims to limit the global temperature increase to 1.5 degrees by the end of this century, Turkey has made a commitment to reduce its emissions from a 21 percent increase by 2030, in line with the targets it has set. As a first step, it declared that it will become carbon-neutral in 2053 to meet its emission reduction targets in the energy, waste, transportation, construction and agriculture sectors. Sustainability is becoming a crucial concept for numerous industrial sectors because of the increase in environmental protection and social responsibility awareness.

Effective Supply Chain Management (SCM), which contributes to the competitive advantage to enterprises, also significantly determines the social, environmental and economic effects. In this way, it can also lead to sustainable growth. SCM, which supports the productivity, growth and development of enterprises with its many effects, has become an important success factor. Businesses have to consider social, environmental and economic factors in order to gain competitive advantage, differentiate from other businesses and show themselves. These factors are important in order to add value to the product or service in every sense in every process until the products or services reach the customer and businesses can thus make their SCM sustainable.

In recent years, traditional-based studies on supplier selection within the scope of SCM have started to be replaced by approaches based on sustainability perspective. Suppliers, being the component of the supply chain, play a critical role in ensuring its long-term viability. So, Sustainable Supplier Selection (SSS) is an important and challenging issue in SCM. Moreover, SSS provides a basis for forecasting and evaluating the suppliers' ability to form a collaborative partnership. Essentially, as a decision making process, SSS tries to limit the number of potential suppliers until a final selection is made.

Decision making is a situation that people have constantly faced since their existence. Depending on the size and impact of the decision made, it can sometimes be quite difficult to make a decision. In order to overcome such situations, it is to determine the most suitable one among the available alternatives by considering all the factors affecting the decision process in detail. The most effective solution to the decision making problem encountered within the framework of this purpose is to consider this decision in a Multi Criteria Decision Making (MCDM) perspective. MCDM can be defined as prioritizing, selecting or scoring alternatives according to evaluation criteria, when there are more than one alternative for a purpose. SSS considered as complicated MCDM problem under several criteria and experts' evaluation, including uncertainty and subjectivity. Hence Decision Makers (DMs) encounter difficulties when expressing their assessments by numbers since quantitative values are not compatible with everyday thinking. Kutlu Gündoğdu and Kahraman (2019) have recently introduced the spherical fuzzy sets (SFS). These sets are based on the fact that the hesitancy of a DM can be defined independently from membership and nonmembership degrees. SFS enable DMs to reflect independently their hesitations in the decision process with a larger domain by using

a linguistic evaluation scale. The advantage of the proposed method is that SFS brings together scientifically accepted aspects of Pythagorean fuzzy sets and Neutrosophic sets.

AHP method is one of the most preferred MCDM technique due to its simple structure and its ability to deal with complex decision problems. In this study, Spherical Fuzzy Analytic Hierarchy Process (SF-AHP) is employed for evaluating SSS and solving the selection problem. Also, this study presents a framework that provides sustainable ranking of suppliers and a reliable solution for sustainable decisions with a real case study.

2. Assessment of Forest Fire Risk Score: An MCDM Application

Sena Cakmak (*Istanbul Technical University*), **Secil Yurdakul Erol** (*Istanbul University – Cerrahpasa*) and **Ilker Topcu** (*Istanbul Technical University*).

Forests are critical natural resources that serve a key role in sustainable development in terms of their production, socio-economic, and environmental-ecological functions. Wood and non-wood forest products production, tourism, recreation, supporting rural development, providing employment opportunities are among the main production and socio-economic functions of forests. Besides biodiversity conservation, water, and soil protection, creating positive impacts on climate and protecting natural and cultural resources are the main functions of forests regarding ecological and environmental issues. The multifunctionality and critical role of the forests make protecting these resources a privileged aim of the international and national forest policy. Thus forest fires became an essential aspect of the current agenda of forestry. The occurrence of forest fires and the damage caused by them have increased in recent years throughout the world and Turkey due to climate change and growing human impact.

Forest fires are a significant issue in the Mediterranean climate zone, impacting countries like France, Greece, Italy, Portugal, Spain, and Turkey. In Turkey, the coastline, which starts from Hatay and extends through the Mediterranean and Aegean up to Istanbul, has the highest fire risk. The preventing and responding strategies is a significant issue. Forest fire risk determination is important for decreasing forest fire's effect on ecology, economy, and humans. Further, effective wild fire fighting requires a local-based risk assessment. The fundamental purpose of this research is to contribute to ongoing research into preventing forest fires and their consequences.

The danger of forest fires and their spread hazards were analyzed in various studies, and the fire risks of the regions were identified. Furthermore, several researchers appear to aim to optimize fire protection strategies based on risk output. Because of the various aspect of forest fire, researchers have used multi-criteria analysis integrating the artificial neural network (ANN), fuzzy logic methods, Analytic Hierarchy Process (AHP), and Knowledge Discovery in Databases (KDD) with Geographic Information Systems (GIS) to deal with these complex issues and estimate the potential forest fire risk.

The aim of this study is to construct a multi-criteria decision model to compute the fire risk score of a forest area. First, the most relevant criteria are determined based on the previous studies and experts' opinions in the problem structuring stage. We come up with 6 criteria: forest structure and vegetation, topography, climate, forest location, forest facilities, human effects. Forest structure and vegetation criterion group consists of 5 sub-criteria, namely, tree species and species composition, dry cover on the land, forest density, canopy cover, and stand development stage. Topography criterion group has 3 sub-criteria: aspect, slope, and elevation. The 7 sub-criteria of the climate criterion group are climate type, precipitation regime, temperature, wind effect, relative humidity, soil type and humidity, and solar radiation. Forest location group consists of 6 sub-criteria: distance to road network, distance to human settlement, tourism regions and touristic facilities, distance to agricultural land, distance to natural and artificial water resources, distance to power lines and power plants, distance to industrial facilities. Forest facilities criterion group has 3 sub-criteria: existence of facilities established with special permission, existence of forest protection station and fire watchtowers, and existence of recreation areas. Human effects have 2 sub-criteria: population density and literacy rate.

Due to the hierarchic structure of the decision model, at the second stage, we will use Analytic Hierarchy Process (AHP) method to assess the relative importance of these criteria and sub-criteria. We will get in contact with forest management authorities and academicians and conduct a pairwise comparison questionnaire survey to reveal their judgments. As a future study, we will compute the forest fire risk scores of sample forest areas utilizing the AHP-rating approach.

3. Improving the Predictive Power of AHP based Decision Support Systems

Ram Kumar Dhurkari (Indian Institute of Management Sirmaur)

This paper addresses three important questions. First, whether the criterion weight computed using pair-wise comparison in the Analytic Hierarchy Process is context-dependent. Second, if the decision-maker (DM) can define the criterion weight without using any method, then whether such criteria weight resembles the criterion weight computed using the Analytic Hierarchy Process. Third, whether the Analytic Hierarchy Process's predictive power can be improved by adjusting and making the criterion weight context-dependent. Two separate studies were conducted to investigate the prescriptive power of the Analytic Hierarchy Process (AHP). The first study served as a pilot. The second study was conducted relatively on a larger scale. The attention levels of the Attribute Dynamic Attitude Model (ADAM) are used to adjust the relative importance of criterion weight in the AHP method in order to make them context-dependent. Both the studies found that the criterion weight computed using the Analytic Hierarchy Process is not context-dependent. The criteria weight computed using the Analytic Hierarchy Process and the criteria weight collected directly (without using any method) resembled considerably. The Analytic Hierarchy Process's predictive power can be improved by making the criteria weight context-dependent, thus resembling the DM's actual choice behavior. The results are very useful in designing advanced decision support systems and enhancing their prescriptions to resemble actual or real decisions.

4. An Improvement of the Consistency Index in Pairwise Comparison

Yuji Sato (*Graduate School of Management*)

The Consistency Index and the Consistency Ratio of the analytic hierarchy process (AHP) were designed to measure the ratio of inconsistent judgments among pairwise comparisons (PCs), which have been the principal indices for the past four decades. Definitions of inconsistency measures for PCs have yet to be established, however, because of the difficulty in quantifying subjectivity in judgments. Therefore, an empirical review that can take such subjective factors into account is essential. In this paper, the Consistency Ratio is thus reviewed using subjective data, and then a new inconsistency index for PCs is proposed based on the review. The review is based on subjective data obtained from two opinion surveys, which focuses on the relationship between the Consistency Ratio and two indicators: (1) the conformity of the results of the AHP and that of the ranking method, and (2) the goodness-of-fit of weight elicited by the AHP to human perception. A new inconsistency index is then proposed based on the mathematical property of a pairwise comparison matrix and further validated based on the conformity and the goodness-of-fit of weight. The results show that the proposed index detects inconsistency among real-world PCs more sensitively than could the Consistency Ratio; the index might suggest the reliability of the output of a pairwise comparison matrix.

Wednesday, 13.20-15.00

WED-3-P3

Session: Evolutionary Multi-objective Optimization

Room: Portland Building 0.41

Chair: Manuel López-Ibáñez

1. Bi-objective optimization of composite retrieval using NSGA-II

Guillermo Cabrera-Guerrero (*Pontificia Universidad Católica de Valparaíso*), **Mauricio Moyano** (*Pontificia Universidad Católica de Valparaíso*), **Nicolle Ojeda-Ortega** (*Pontificia Universidad Católica de Valparaíso*), **Paula Zabala** (*Universidad de Buenos Aires*) and **Gustavo Gatica** (*Universidad Andres Bello*)

In information retrieval, traditional search strategies only consider one attribute to build up a ranking list of results which depends exclusively on the considered attribute. However, often one needs 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 as a response to this behaviour. Its objective is to group elements into bundles, in which the items are related to each other under both criteria: similarity and complementarity of bundles. These bundles should satisfy users' expectations without needing a new intervention, improving the searching experience. However, to the best of our knowledge, only single-objective models, mainly based on the weighted sum of each criterion, have been proposed in the literature.

In this work, considering the inherent multi-objective nature of this problem, we present a novel bi-objective Composite Retrieval model which considers the existing trade-off between diversity and complementarity of each set of bundles. Given the good performance of multi-objective evolutionary algorithms in combinatorial problems, we implement an NSGA-II algorithm to evaluate our model. We compare the obtained result with those from single objective models previously proposed in the literature.

2. An EMO algorithm combined with Benders Decomposition to Optimizing a Mixed-Integer Linear Optimization over an Efficient Set

Sandra González-Gallardo (*University of Malaga*) and **Victor Blanco** (*University of Granada*)

Abstract. In this work we analyze the problem of optimizing a linear function with mixed-integer variables over the efficient set of a linear multiobjective lower level problem. A new algorithm is proposed based on combining Benders Decomposition (BD) [1] and the EMO approach proposed in [3]. On the one hand, BD is a popular method to solve mixed-integer single-objective problems by projecting out some of the variables of the problem. Integrating BD into an extension of the approach proposed in [2] for pure integer problems allows us to derive an exact (but computationally costly) approach. With the goals of reducing the resolution CPU times and being able to solve larger instances, we combine the above approach with an evolutionary multiobjective optimization (EMO) algorithms in the resolution of the subproblem. Concretely, the EMO algorithm is applied to construct efficiently the approximated Pareto frontier of the linear multiobjective problem. As the dual approach will subsequently use, the decomposition-based EMO algorithm called WASF-GA [3] (Weighting Achievement Scalarizing Function Genetic Algorithm) is introduced into the process with the aim to transform the secondary problem into a set of single-objective linear subproblems. These solutions allow us to derive optimality and feasibility cuts for the BD approach. The methodology is applied to a classical facility location problem in order to test it computationally.

References

[1] J. F. Benders, Partitioning procedures for solving mixed-variables programming problems, *Numerische Mathematik* 4 (1962) 238–252. doi:10.1007/BF01386316.

[2] J. Jorge, A bilinear algorithm for optimizing a linear function over the efficient set of a multiple objective linear programming problem, *Journal of Global Optimization* 31 (2005) 1–16. doi:10.1007/s10898-003-3784-7.

[3] A. B. Ruiz, R. Saborido, M. Luque, A preference-based evolutionary algorithm for multiobjective optimization: The weighting achievement scalarizing function genetic algorithm, *Journal of Global Optimization* 62 (1) (2015) 101–129. DOI: 10.1007/s10898-014-0214-y.

3. Analysis of Interactive Evolutionary Multi-Objective Algorithms based on Reference-Points using Machine Decision Makers with Cognitive Biases

Rubén Saborido (University of Malaga), Maura Hunt (University of Manchester), Manuel López-Ibáñez (University of Malaga) and Mariano Luque (University of Malaga)

Analysing interactive evolutionary multi-objective algorithms (iEMOAs) is particularly challenging due to the difficulty and effort required to conduct empirical studies with human subjects. As a result, most published results rely on simulating behaviour of the decision-maker (DM). In the case of iEMOAs that elicit preferences from the DM by means of reference points or goals, choosing the sequence of reference points that simulates the behaviour of human DMs is particularly challenging. Here we adapt a simulation model proposed by Stewart (2005) in the context of interactive goal programming to create machine DMs for the analysis of iEMOAs based on reference-points. Stewart's simulation model is able to simulate various cognitive biases of the resulting machine DM, such as loss aversion, anchoring, and quantitative errors of judgment. We discuss here the challenges, and our proposed solutions, when adopting Stewart's simulation model as a machine DM that interacts with iEMOAs. Using the proposed machine DM, we empirically analyse some reference-point-based iEMOAs, including R-NSGA-II, WASF-GA, and g-NSGA-II. Preliminary results of this analysis indicate unexpected behaviours of the algorithms caused by the cognitive biases simulated by the machine DM. We hope that our findings will motivate further algorithmic improvements as well as extensions of the machine DM to account for learning and other realistic human behaviours.

Thursday, 9:00-10:00

THU-1- PLENARY

Plenary Session: Professor Salvatore Greco

Room: Richmond Building LT1

Chair: Dylan Jones

The Robust Ordinal Regression and the constructive approach of Multiple Criteria Decision Aiding

Salvatore Greco

Department of Economics and Business,

University of Catania, Corso Italia, 55, 95129 Catania, Italy

*Portsmouth Business School, Centre for Operational Research and Logistics (CORL),
University of Portsmouth, UK*



Abstract: Multiple Criteria Decision Aiding (MCDA) is constituted by a set of concepts, techniques and procedure aiming to provide a recommendation in complex decision contexts. MCDA is based on a constructive approach that aims to build a preference model in cooperation between the analyst and the Decision Maker. A typical MCDA methodology is the ordinal regression aiming to define a decision model in a given class (an additive value function, a Choquet integral, an outranking model such as ELECTRE or PROMETHEE and so on) representing the preference information provided by the DM. Recently ordinal regression has been extended and generalized through Robust Ordinal Regression taking into account the idea that there is a plurality of decision models in a given class compatible with the preferences expressed by the decision maker. Originally, the set of compatible decision models was used to define the necessary and possible preference relations holding when the preference holds for all value functions or for at least one value function, respectively. After, a probability distribution on the set of compatible decision model was introduced to define probabilistic preferences. ROR has been also fruitfully applied to interactive optimization procedures. In this talk, I shall present the basic concepts, the principal models, the main applications and the recent developments of Robust Ordinal Regression taking into consideration its advantages in the context of an MCDA constructive approach.

Bio: Salvatore Greco is full professor at the Department of Economics and Business at the University of Catania where has been teaching Decision Theory, General Mathematics, Financial Mathematics and Actuarial Mathematics. Since 2013 Salvatore Greco has also a part time position at the Business School of Portsmouth University (UK). His research regards preference modeling and multiple criteria decision analysis (MCDA) with a specific attention to application of rough set theory, non-additive integrals, evolutionary multiobjective optimization methodologies, composite indices for sustainable development, wellbeing and innovation, MCDA models for territorial and urban planning. At the 22nd International conference on MCDM held in Malaga June 17-22 2013, he received the MCDM Gold Medal being “the highest honor that the International Society on Multiple Criteria Decision Making bestows upon a scholar who, over a distinguished career, has devoted much of his/her talent, time, and energy to advancing the field of MCDM, and who has markedly contributed to the theory, methodology, and practice of MCDM”. Since 2010, Salvatore Greco is one of the three coordinators of the EURO Working Group in Multiple Criteria Decision Aiding. He has been member of the executive committee of International Society on Multiple Criteria Decision Making for the years 2006-2009, 2011-2013, 2016-2019. In the years 2014-2019 Salvatore Greco was member of the scientific committee of AMASES (Italian Society for mathematics applied to economics and social sciences and in the years 2017-2019 he served as vice president. He is currently the president elect of the MCDM section of INFORMS. Scopus reports 248 publications of Salvatore Greco cited all together 9734 times and an h-index of 51. Google Scholar reports a total of 2223 citations with an h-index of 68.

Thursday, 10.20-12.00

THU-2-P1

Session: Multi-objective Optimization

Room: Richmond Building LT3

Chair: Aric Fowler

1. Solving a Computationally Very Expensive Multiobjective Optimization Pump Design Problem with the Interactive K-RVEA Method

Jana Burkotová (Palacký University Olomouc, Faculty of Science, Czech Republic), Pouya Aghaei Pour (University of Jyväskylä, Faculty of Information Technology, Finland), Tomáš Krátký (Centre of Hydraulic Research, Czech Republic) and Kaisa Miettinen (University of Jyväskylä, Faculty of Information Technology, Finland)

We demonstrate the potential of applying an interactive multiobjective optimization method in solving computationally expensive real-world problems in the pump industry. The considered hydraulic pump model involves very time-consuming CFD (computational fluid dynamics) simulations. In practice, this limits the number of function evaluations and brings challenges to the optimization process. In order to save computation time, the original expensive functions are approximated by surrogate models. To use the limited resources more efficiently, preference information from a domain expert called a decision maker is included in the solution process. In this way, we aim at using time and resources as efficiently as possible. Instead of representing the whole Pareto front, with an interactive method, we focus only on solutions in the decision maker's region of interest.

The aim of the optimization is to find an optimal hydraulic pump design specified by 22 geometric parameters maximizing three expensive objective functions representing pump efficiencies at three different flow rates. The objective functions are conflicting by nature because it is not possible in practice to have high pump efficiencies at lower and higher flow rates simultaneously. Therefore, a good balance in trade-offs is needed. The computation time for running one pump simulation is usually between 16-20 hours and any reduction in computation time is crucial. In the literature, there have been some attempts to solve this problem by using surrogate models and multiobjective evolutionary algorithms to reduce the computation time. However, many of the generated solutions are not interesting to the decision maker. To tackle this challenge, we apply the interactive K-RVEA method that is suited for computationally expensive problems and incorporates decision maker's preferences. The method is based on reference vector guided evolutionary algorithm RVEA. K-RVEA uses Kriging models as surrogates because they provide uncertainty information. In the interactive K-RVEA, the decision maker progressively specifies preference information in the form of a reference point in the objective space to guide the search towards more desirable solutions. The uncertainty information from the Kriging models is utilized in the model management strategy such that solutions with the lowest uncertainty are chosen to ensure the algorithm selects solutions following the decision maker's preferences. A comparison of solutions with interactive K-RVEA and K-RVEA (without preferences) is performed to show the benefits of applying interactive methods in computationally expensive multiobjective optimization problems.

2. Epsilon-constraint algorithms to generate Pareto front representations on multi-objective integer problems

Mariana Mesquita-Cunha (CEG-IST, Instituto Superior Técnico, Universidade de Lisboa), José Rui Figueira (CEG-IST, Instituto Superior Técnico, Universidade de Lisboa) and Ana Barbosa-Póvoa (CEG-IST, Instituto Superior Técnico, Universidade de Lisboa)

Abstract. Although often modelled as single-objective problems, many optimisation problems are, in fact, multi-objective. Nevertheless, people are often hesitant in solving those problems as multi-objective since that poses two main issues: first, their computation is frequently

complicated, having many solutions in the Pareto front; and second, their analysis by the decision maker (DM) to reach a final solution is very demanding. One way to address both issues is to compute, instead of the whole Pareto front, a representation of it. The quality of a Pareto front representation can be assessed using three criteria: coverage, how well the representation covers all regions of the objective space contained in the Pareto front; uniformity, how sparse are the solutions in the representation subset; and cardinality, how many solutions are in the representation subset. Therefore, three algorithms are presented in this work to generate Pareto front representation for multi-objective integer programs. Each algorithm targets one of the measures used to assess the quality of Pareto front representation. The algorithms were tested on an extensive set of instances comprising various problem types. Results show the algorithms are very efficient and effective for their target measure. Furthermore, the cardinality algorithm appears very flexible privileging coverage on lower target cardinalities and uniformity on higher target cardinalities.

3. Sustainability Assessment of European Countries through the Use of Multiple Criteria Decision-Making and Econometric Techniques

Ana B. Ruiz (UNIVERSIDAD DE MALAGA), Francisco Ruiz (UNIVERSIDAD DE MALAGA), Sandra Gonzalez-Gallardo (UNIVERSIDAD DE MALAGA), Mariano Luque (Universidad de Málaga) and Pedro Fernández-Rodero (UNIVERSIDAD DE MALAGA)

Sustainability is commonly defined as “meeting the needs of the present without compromising the ability of future generations to meet their own needs”. The 2030 Agenda for Sustainable Development is a United Nations program that represents a global commitment to achieve economic growth, social inclusion, and environmental sustainability in all countries. Commonly, sustainability is evaluated according to three basic dimensions: social, economic, and environmental. Ideally, the best sustainability situation of a territory would be attained when maximizing the benefits in the economic, social, and environmental dimensions, but there is a natural conflict among these three dimensions since when one is improved, some of the other need to be sacrificed. This makes it clear the multiple criteria decision-making nature of sustainability.

In this work, we propose to study the sustainability performance of European Countries by applying a methodology that combines both multiple criteria decision-making techniques and econometrics. Using individual sustainability development indicators for the European countries available in the EUROSTAT database (from 2010-2019), we first build composite indicators to assess the economic, social, and environmental dimensions of the territories. These composite indicators are built using the Multiple Reference Point Weak and Strong Composite Indicators methodology, which is a technique based on the reference point preferential scheme commonly used in the multiobjective optimization field. According to the information obtained, secondly, we perform an econometric analysis to regress the composite indicators only considering those individual indicators that are somehow controllable by policy makers. The main motivation is to get some insights into the impact that a modification of these controllable individual indicators would have on the overall sustainable development of the territories.

Finally, we focus on the Spanish case, whose sustainability situation can be improved, as this country does not reach the best possible values of the composite indicators of the three dimensions. However, to make a decision about how to improve its situation, further information is needed in order to know the extent of the possible improvement, the trade-offs existing among the dimensions, and how this improvement could be attained. Therefore, we build a multiobjective optimization problem based on the econometric analysis previously performed, which is aimed at identifying the most desired compromise among the three sustainability dimensions to enhance the sustainability situation of Spain. Using preference-based multiobjective optimization techniques, we solve the problem using different preference information to analyze the possible improvements that could be achieved under different scenarios.

4. Optimising for Entertainment in the Vote-Reveal Problem

Aric Fowler (Cardiff University) and Richard Booth (Cardiff University)

In many elections or competitions, a set of voters will either rank a set of candidates from best to worst or will give scores to some of the candidates, with the winner then being the candidate that gets the highest total number of points. When it comes to revealing the result after all votes have been cast, some competitions proceed by having a roll-call of all the voters in which each announces their votes. This is often done for entertainment purposes (e.g., the Eurovision Song Contest), raising the question: Which ordering of voters should be chosen to maximise the entertainment value of the roll-call? This paper explores ways to measure the entertainment value of a ranking and applies combinatorial optimisation techniques to find near-optimal solutions.

With "entertainment value" being a subjective measurement, there is an inherent difficulty in modelling it. Several models for entertainment have been devised over the years and supported by studies, identifying features such as Surprise and Suspense, Hope and Despair, Uncertainty, and the relationship between the enjoyment of watching a competition and whether you support any of the candidates. Given a set of entertaining factors we can derive formulae to measure how well a given ranking scores on an arbitrary scale. These formulae will allow comparison between solutions to find solutions that maximise each concept. In addition to context-free definitions of entertainment, the actual entertainment value of the media depends on contextual information such as the nature of the media and its audience. For the vote-reveal problem, we must consider the fact that audience members may have pre-existing preferences over the set of candidates (e.g. supporting your country's entry). In this paper we consider 'supporters' as audience members who prefer a certain candidate, and 'impartial viewers' as audience members whose interest lies in finding out the overall winner(s).

Several functions are defined to measure each aspect of entertainment value. These include (1) minimising the gap between first and second place to increase the expectation that second place may overtake, (2) maximising the number of times the first-place candidate changes to create uncertainty in the overall outcome, (3) maximising the number of candidates who take first place at any point in the reveal to surprise audience members, and (4) minimising the gaps between candidates to increase uncertainty in outcome during the reveal.

Each of the functions can be used to construct a combinatorial optimisation problem using the voter and candidate data. The functions are non-linear and require a black-box approach to solving. The set of feasible solutions is factorially large, rendering brute-force approaches infeasible. In this paper we apply the Tabu Search algorithm to each function to find near-optimal solutions.

It is more appropriate to consider the functions together to find a solution that scores well across the whole set; rankings developed with multi-objective optimisation are likely to be perceived as more entertaining than solutions that maximise a single factor. To achieve this, the problem must be modelled as a multi-objective optimisation problem where solutions are measured against a set of cost functions. Multi-Objective Tabu Search is applied to this problem, allowing us to generate non-dominated sets of solutions. The non-dominated set can then be sifted through by hand to select candidates for the chosen solution. Given that the choice of "best solution" is subjective choosing by hand seems appropriate in this case, however, the non-dominated set can sometimes be quite large. One of the possibilities for future work is to develop automated methods to highlight preferred solutions within the non-dominated set, aiding in narrowing down the search.

Thursday, 10.20-12.00

THU-2-P2

Session: Value and Utility Models

Room: Portland Building 0.28

Chair: Miłosz Kadziński

1. Deep Preference Learning for Multiple Criteria Decision Analysis

Krzysztof Martyn (*Poznań University of Technology*) and **Miłosz Kadziński** (*Poznań University of Technology*)

We propose preference learning algorithms for inferring the parameters of a threshold-based sorting model from large sets of assignment examples. The introduced framework is adjusted to different scores originally used in Multiple Criteria Decision Analysis (MCDA). They include Ordered Weighted Average, an additive value function, the Choquet integral, a distance from the ideal and anti-ideal alternatives, and Net Flow Scores built on the results of outranking-based pairwise comparisons. As a concrete application of these models, we use Artificial Neural Networks with up to five hidden layers. Their components and architecture are designed to ensure high interpretability, which supports the models' acceptance by domain experts. To learn the most favorable values of all parameters at once, we use a variant of a gradient descent optimization algorithm called AdamW. In this way, we make the MCDA methods suitable for handling vast, inconsistent information. The extensive experiments on various benchmark problems indicate that the introduced algorithms are competitive in predictive accuracy quantified in terms of Area Under Curve and the 0/1 loss. In this regard, some approaches outperform the state-of-the-art algorithms, including generalizations of logistic regression, mathematical programming, rule ensemble and tree induction algorithms, or dedicated heuristics.

2. Interactive co-evolutionary multiple objective optimization algorithm for finding consensus solutions for a committee of Decision Makers

Michał Tomczyk (*Poznan University of Technology*) and **Miłosz Kadziński** (*Poznan University of Technology*)

We introduce an interactive co-evolutionary algorithm for multiple objective optimization, primarily designed for solving group decision problems. It progressively learns the Decision Makers' aspirations during the evolutionary run by asking them to compare pairs of solutions from the population. Their inferred preference models are then aggregated as possible agreements, instantiated as a set of optimization goals in a decomposition-based evolutionary framework. The key novelty of our algorithmic proposal lies in co-evolving two populations. These are the primary population, whose task is to construct relevant consensus solutions, and the supportive population approximating the entire Pareto front. The supportive population reveals possible trade-offs between criteria, allowing to select pairs of solutions for comparisons in a way that maximizes the information gain received from the Decision Makers' feedbacks. Moreover, those of the optimization goals used to steer the supportive population that prove not relevant to any of the Decision Makers are excluded in favor of increasing the primary population's size, providing a more substantial computational budget on constructing consensus solutions. We confirmed the importance of both co-evolution and dynamic resource allocation in a series of extensive experiments. Furthermore, we compared the proposed algorithm with selected existing methods, proving its competitiveness. Lastly, we prove its usability by applying it to a real-world optimization problem of designing an environmentally friendly supply chain.

3. On Scalarization Methods for Multi-task Learning

Gibran Fuentes-Pineda (*IIMAS-UNAM*) and **Carlos Hernández** (*IIMAS-UNAM*)

In learning, one of the current challenges is to an agent that performs several tasks at the same time. For instance, we would like to recognize the sex of a person, ethnicity as well as age. This is the so-called multi-task learning. In this kind of problems, it might be useful to use a single learning model (i.e. a deep learning network) with multiple outputs (one for each task) to benefit from the structure of the problem. Thus, the problem is to tune weights to maximize the accuracy for the given tasks. In this setting, typically the tasks are conflicting. The best weights for one task are not the best for the others and vice versa.

This is clearly a multi-objective optimization problem. In the machine learning literature, most of the works handle the problem by having a loss function for each task and then adding them leading to the weighted sum method. Recently, there have been proposed a few works that solve this problem as a multi-objective optimization problem. Namely using continuation and descent direction methods such as Hillier and Fliege's methods.

In this work, we propose to use the weighted norm scalarization methods to tackle this kind of problems. We chose this kind of methods since they are differentiable and modern machine learning packages can compute the gradient by automatic differentiation. Further, in terms of implementation, they require fewer changes to the machine learning methodologies currently used by the community compared to continuation/descent direction methods and as it is well-known they can handle concave fronts, unlike weighted sum.

We apply the method to the UTKFace problem. In this problem, we have over 23,000 images of people of different ages, sex, and ethnicities. Then, the task is to build a model that is able to determine those characteristics given a new image. For this purpose, we trained a Resnet18, which has 11,696,519 trainable parameters using 21 uniformly distributed weights to approximate the Pareto front. In this case, we divided the dataset into two. 80% for training over 50 epochs where we used stochastic gradient descent as the optimizer. The remaining 20% was used for testing. For our study, we measured the proportion of right answers on each task separately as well as the proportion of right answers in all tasks at the same time.

The results show the existing conflict between the tasks. Next for this three-objective problem, we found a convex front for both training and testing sets. Further, we observe above 70% accuracy in each task separately and around 45% when both predictions are correct at the same time.

In our opinion, on one hand, the work shows how can scalarization methods can be used to tackle multi-task learning problems. On the other hand, it opens the door to large-scale multi-objective optimization problems that could be used by the community to test novel approaches. For future work, we would like to explore other modern deep learning models, apply the methods to other multi-task learning problems as well as design novel methods that exploit the structure of the learning problems.

4. Incorporating the outranking-based approach into the rough set theory

Magdalena Martyn (Poznań University of Technology), Miłosz Kadziński (Poznań University of Technology) and Roman Słowiński (Poznań University of Technology)

We propose a hybrid method combining the rough set theory and the outranking-based approach. We focus on multiple criteria sorting problems concerning the assignment of alternatives to pre-defined preference-ordered classes. The outranking relation is validated when one alternative attains at least as good performances as another alternative on a subset of criteria that are jointly deemed as sufficiently strong. Thus interpreted model replaces the dominance relation incorporated in the traditional Dominance-based Rough Set Approach. However, the user is not required to specify the sufficiently strong coalitions of criteria in advance. In turn, they are discovered from the set of assignment examples specifying the desired class assignments for a subset of reference alternatives. Then, the decision rules are inferred from the approximations of class unions using a suitably adapted variant of the DOMLEM algorithm that is required to refer to all criteria in a sufficiently strong coalition.

The proposed approach can be parameterized on several levels, leading to 32 different variants. First, various class unions can be analyzed jointly or separately. Second, the specific outranking relation needs to be supported by at least one pair of options or only maximize the quality of the classification approximation. Third, one can consider a single outranking relation or a family of relations built on various criteria coalitions. Fourth, it is possible to account for either certain or possible decision rules. Finally, various classification algorithms can be used to determine the recommended assignments for the non-reference alternatives. We illustrate their use in a didactic example concerning the ordinal classification of research units.

Thursday, 10.20-12.00

THU-2-P3

Session: Outranking, Best-Worst and Rule-based Methods

Room: Portland Building 0.41

Chair: Jafar Rezaei

1. A Hybrid Spanning Trees Enumeration and Best-Worst Method for Decision-Making under Uncertainty

Amin Vafadarnikjoo (*Sheffield University Management School, University of Sheffield*) and **Konrad Maliszewski** (*Atheon Analytics*)

In the Best-Worst Method (BWM), a decision maker selects one decision-making criterion as the best criterion and another decision-making criterion as the worst one. The real-world decision-making process necessitates dealing with subjective judgements of human beings and circumstances of the decision-making context. As a result, it is not always straightforward for decision makers applying BWM to confidently identify only one criterion as either the best or the worst criterion. In other words, there might be a set of potential best and a set of potential worst criteria with some level of hesitancy that might make the decision maker unable to confidently choose only one single best or worst criterion. This is likely due to decision makers encountering uncertainty, hesitancy, or lack of information.

In this study, a Spanning Trees Enumeration (STE) method is integrated with the BWM to deal with this type of uncertainty and to capture the hesitancy of decision makers regarding the existence of more than one possible best or worst criteria. In the proposed hybrid approach, STE offers an opportunity for decision makers to suggest more than one best or worst criteria. The STE part of the proposed approach concludes which criterion is actually the best or worst one among the given set of potential best and worst criteria. The STE analysis is based on the data already provided in the form of pairwise comparisons by decision makers. The result of STE then feeds into the BWM to calculate the final weights and prioritised order of criteria.

In order to validate the performance of our proposed hybrid method, we have conducted a set of Monte Carlo simulations under various defined numerical experiments. The simulation analysis has been carried out by running numerical analyses in Python. The Python code is available via open-access and provides a free decision support tool. This tool can be used by researchers and analysts to apply the STE analysis part of the hybrid method to their problem regardless of the scale or size of the decision-making model being analysed. The results indicate a satisfactory success rate of the STE in identifying the unique best or worst criterion in various experiments.

In addition to the numerical analysis, we have also shown the applicability of the proposed STE-BWM in one real-world application. The application was a case study in the UK energy supply chain risk management. In this case study, the six already identified UK energy risks including natural disasters, climate change, industrial action, affordability, political instability, and sabotage/terrorism are prioritised using the STE-BWM.

Overall, it is believed that our research contributes to the multiple criteria decision-making body of knowledge by achieving the aims of the study which are (I) proposing a solution to strengthen the performance of the BWM under explained specific real-world cases where decision makers might struggle to pick only one criterion due to uncertainty, hesitancy, or lack of information; (II) practically applying the hybrid STE-BWM in a real-world case of energy supply chain risks prioritisation model in order to show the applicability of the proposed method as well as verifying the most critical risks in the UK energy supply chain; (III) conducting Monte Carlo simulations under various defined numerical experiments and providing a decision support tool coded in Python to facilitate the STE analysis. This tool can be used by decision

analysts to identify the unique best or worst criteria regardless of the size of their decision-making problem by reducing time and cost of calculation.

2. Representing if-then decision rules through root cause fault tree analysis

Fatima-Zohra Younsi (University of Oran 1, Algeria), Salem Chakhar (Portsmouth Business School) and Ashraf Labib (University of Portsmouth).

Decision rules are powerful knowledge representation support since they (1) explicitly model the relationships between attributes and decisions, (2) have straightforward interpretation which is valuable in real-life application and (3) useful way for policy makers to justify their decision. Decision rules are generated from information tables (e.g. association rules) or decision tables (if-then decision rules). In this paper, we consider the case of if-then decision rules induced from decision tables relying on dominance relation-based rough approximation. The objective is to propose a visual representation of decision rules using concepts arising from root cause analysis, more specifically using Fault Tree Analysis (FTA), which is a well-known deductive safety analysis method. To minimise the size of the tree, similarity and overlapping measures will be used to first cluster decision rules. Then, a mapping procedure is used to transform the collection of if-then decision rules within each cluster into a subtree. The final tree is obtained by adding jump edges between subtrees. The proposed approach will be illustrated and validated using COVID-19 dataset.

3. Interpretable models based on the Choquet integral: An overview and research perspectives in data science

Guilherme Dean Pelegrina (School of Applied Sciences - University of Campinas), Leonardo Tomazeli Duarte (School of Applied Sciences - University of Campinas), Michel Grabisch (University of Paris I Panthéon-Sorbonne) and João Romano (School of Electrical and Computer Engineering - University of Campinas)

Interpretability has been receiving a great deal of attention recently as it plays a key role in the design of more transparent and accountable systems, as well as in the development of complex solutions which can still provide insights to the users (e.g., physicians). Although currently considered a hot topic in data science-related fields (such as signal processing), model interpretability has greatly benefited from classical ideas originated in research communities which are not necessarily oriented towards data analysis. A well-known example is the use of Shapley value, the origins of which can be traced back to the seminal work of Lloyd Shapley in cooperative game theory. Therefore, even if there is an obvious room for novel ideas to tackle the issue of interpretability, the application of existing concepts can also pave the way for efficient and practical solutions equipped with such a feature.

In the same spirit as the Shapley value, the Choquet integral is another classical concept that has been proven useful to deal with the interpretability issue. This non-additive integral, which was introduced by Gustave Choquet in 1954, finds application in many problems, from statistical mechanisms to information fusion. In particular, the idea of using of the Choquet integral as an interpretable model emerged in multiple criteria decision aiding (MCDA), a sub-field of operational research (OR) which aims at supporting decision makers in scenarios where there are conflicting situations, often due to the presence of conflicting decision criteria. The Choquet integral has become a widespread tool in MCDA mainly because of two aspects, which are somehow interconnected and fundamental in real-world decision processes. In addition to providing a nonlinear aggregation operator, which allows one to model complex interactions between the criteria taken into account by the decision makers, the Choquet integral also leads to an efficient way to quantify the contributions that each criterion and each coalition of criteria have on the model response.

Despite its popularity in MCDA/OR, the Choquet integral is still an unexplored tool with great potential of application in data science, including signal processing (SP). A first interesting research opportunity in that regard is to take advantage of the nice aspects of interpretability found in the Choquet integral in order to address important problems in SP that are typically

built upon linear models, such as deconvolution, matrix factorization and convex combination of filters. The application of the Choquet integral in those cases can provide a solution that goes beyond linear models while still preserving a model which admits interpretation.

A second interesting research topic is the use of tools which are familiar to the signal processing community in order to enhance the interpretability and learning aspects of the Choquet integral. To clarify this point, it is worth mentioning that the usual parametrization of the Choquet integral is done with the aid of a set function known as fuzzy measure (or Choquet capacity). While this parametrization based on the fuzzy measure is intimately related to the original motivation underlying the Choquet integral, the interpretability aspect of this model arises by applying transforms that map the fuzzy measure to other domains in which the parameters are straightforward to interpret. In other words, as is usual in SP, it is easier to search the desired information, which in this case regards model interpretability, after the application of a transform. A nice aspect here is that linear transforms are considered to analyze the Choquet integral, which opens the way for applying well-established SP methodologies. For instance, sparse representation tools were considered in with the aim of simplifying the learning process of capacities. Indeed, as interpretability also keeps interesting connections with some principles underlying sparsity, the application of the classical framework originally developed in the context of compressed sensing has the potential of leading to useful properties in a same solution (interpretability, nonlinearity and uniqueness).

In view of these research perspectives, the goal of this paper is to provide an overview of interpretable models based on the Choquet integral. In addition to pointing out examples of applications and futures perspectives involving the Choquet integral as an interpretable model, we shall focus on how data science-related communities can contribute to enhancing the interpretability features associated with such a model.

The authors thank the grants \#2021/11086-0, \#2020/10572-5, \#2020/09838-0 and \#2020/01089-9, São Paulo Research Foundation (FAPESP).

4. A parsimonious extension of the Best-Worst Method

Salvatore Corrente (University of Catania), Salvatore Greco (Portsmouth Business School) and Jafar Rezaei (Delft University of Technology)

Despite its recent introduction in literature, the Best-Worst Method (BWM) is among the most well-known and applied methods in Multicriteria Decision-Making. The method can be used to elicit the relative importance (weight) of the criteria and also to evaluate the alternatives. In this paper, we will present a few extensions of the method making it simpler for a decision-maker (DM) when evaluating a large number of alternatives. Indeed, the new proposal asks the DM to provide a fewer number of pairwise comparisons than the original BWM. Our proposal will be tested on several data sets and its results will be compared with the ones obtained by both the original BWM and the Analytic Hierarchy Process (AHP).

Thursday, 13.20-15.00

THU-3-P1

Session: Multi-objective Optimization

Room: Richmond Building LT3

Chair: Britta Schulze

1. Ordinal Optimization Through Multi-objective Reformulations

Kathrin Klamroth (University of Wuppertal), Michael Stiglmayr (University of Wuppertal) and Julia Sudhoff (University of Wuppertal).

We consider combinatorial optimization problems where the quality of an element (e.g., an edge of a graph representing a street segment) can not be quantified with a real-valued cost coefficient, while it is possible to assign certain quality categories to the elements. For example, a street with a bike lane is safer for a cyclist than a street without a bike lane. While the street with a bike lane would thus be in the category of „safe“ elements, the street without a bike lane would be considered „unsafe“. But it is unclear whether a street with a bike lane is twice, three times or four times safer than one without. To make the situation more complex, there may also be intermediate categories like, e.g., „medium safe“, „mostly safe“, and so on.

Since ordinal costs are in general non-additive, combinatorial optimization problems with ordinal coefficients require novel and tailored optimality concepts and solutions algorithms.

In this talk, we review optimality concepts for ordinal combinatorial optimization problems that were suggested by Schäfer et al. 2020 and 2021 and discuss their similarities and differences. We suggest a reformulation leading to specifically structured multiobjective combinatorial optimization problems with binary costs. Hence, we provide a new perspective on ordinal optimization by transforming ordinal optimization problems into equivalent standard multiobjective problems. Since the transformation preserves all properties of the underlying problem, problem-specific solution methods remain applicable. We extend our results to multiobjective combinatorial optimization problems combining ordinal and real-valued objective functions.

2. A Multi-Objective Perspective on the Cable-Trench Problem.

Lara Löhken (University of Wuppertal) and Michael Stiglmayr (University of Wuppertal)

The Cable-Trench Problem is defined as a combination of the Shortest Path and the Minimum Spanning Tree Problem. In particular, the goal is to find a spanning tree that simultaneously minimizes its total length and the total path length from a pre-defined starting vertex to all other vertices. Both, the Minimum Spanning Tree and the Shortest Path Problem are known to be efficiently solvable. However, a linear combination of these two objectives results in a highly complex problem.

While in the original publication by Vasko et al. (2002) the Cable-Trench Problem is introduced as a linear combination of Minimum Spanning Tree and the Shortest Path objective, we consider it as a bi-objective problem separating the two cost functions. In this sense, the original form of the Cable-Trench Problem corresponds to a weighted sum scalarization of the bi-objective formulation. We use a bi-objective branch-and-bound approach in combination with problem specific cutting planes to determine the set of non-dominated points. We show preliminary numerical results.

3. Augmenting Bi-objective Branch and Bound by Scalarization-Based Information

Julius Bauß (University of Wuppertal) and Michael Stiglmayr (University of Wuppertal)

While branch and bound based algorithms are a standard approach to solve single-objective (mixed-)integer optimization problems, multi-objective branch and bound methods are only rarely applied compared to the predominant objective space methods. Objective space methods benefit from optimized single-objective solvers to solve scalarized subproblems,

while branch and bound methods suffer from the considerably weaker bounding in multiple objectives.

In this talk we propose modifications to improve the performance of bi-objective branch and bound algorithms by utilizing scalarization-based information. We use the hypervolume indicator as a measure for the gap between lower and upper bound set to implement a dynamic bi-objective branching strategy. By adaptively solving scalarizations in the root node to integer optimality we improve both upper and lower bound set. The obtained lower bound can then be integrated into the lower bounds of all active nodes, while the determined solutions are added to the upper bound set. The improved bound sets lead to a higher fathoming rate.

Numerical experiments show that our modifications can reduce the number of investigated nodes significantly by up to 85% and the total computation time by up to 80%.

4. Computing Representations for Combinatorial Optimization Problems Based on the Hypervolume Indicator

Britta Schulze (University of Wuppertal), Luis Paquete (University of Coimbra) and Michael Stiglmayr (University of Wuppertal).

Given a set of feasible points and a reference point in the objective space that is dominated by every point in this set, the hypervolume indicator measures the multidimensional volume of the union of axis-parallel boxes that is spanned between the reference point and the points of the given set. The hypervolume indicator has interesting properties and has shown to be an interesting tool, especially in the field of multiobjective evolutionary algorithms, as, e.g., a selection criterion.

In this talk, we present a scalarization for multiobjective optimization problems that is based on the computation of the hypervolume of feasible points. In particular, we describe a generic solution approach that determines the nondominated set of a biobjective combinatorial optimization problem by solving a sequence of hypervolume scalarizations with appropriate choices of the reference point. We also show how to use this approach to compute a compact representation of the efficient set of combinatorial optimization problems in an a priori manner. Due to the properties of the hypervolume indicator, the representation is guaranteed to be a $(1-1/e)$ -approximation to the optimal representation in terms of the hypervolume.

We discuss applications of this method to particular biobjective combinatorial optimization problems as well as challenges that arise when considering more than two objectives.

Thursday, 13.20-15.00

THU-3-P2

Session: Value and Utility Models

Room: Portland Building 0.28

Chair: José Rui Figueira

1. Aggregation of Expert Information in Multicriteria Group Decision Support with Reference Sets

Andrzej M.J. Skulimowski (*Dept. of Decision Sciences, AGH University of Science and Technology, Kraków*)

This paper proposes an approach to aggregate or correct inconsistent recommendations of experts involved in multicriteria decision support procedures with multiple reference points. The procedure yields a consistent - in the certain sense - set of reference points transformed from an arbitrary collection of them. By assumption, n experts are involved as independent consultants in a decision making process of k other agents termed decision makers. Experts formulate recommendations as reference points of different kind in the criteria space and communicate them simultaneously to the decision makers. This decision situation corresponds to the scheme 'one decision maker – multiple recommending experts' (group decision support) or 'multiple decision makers – multiple experts' (group decision making and support). Each reference point is assigned a certain utility value that should be consistent with this point meaning for the decision maker(s). The independence of experts' judgments may cause different types of recommendation inconsistency. We define the internal, mutual, and plausibility inconsistencies which may occur simultaneously in the same decision problem. We will also assume that experts' recommendations may belong to four predefined characteristic reference sets. Internal inconsistency occurs when a reference class contains comparable recommendations. Mutual inconsistency means that the reference points in different classes cannot be assigned utility values so that the utility function is order representing. The third kind of consistency is the property of a single reference point that determines whether the meaning assigned by an expert to this point is consistent with its situation with respect to the set of attainable criteria values. It is termed the plausibility consistency and may affect the choice of an operation to regularize other inconsistencies. A multi-stage aggregation procedure regularizes the set of reference values pointed out by all experts. The overall verification-aggregation-regularization procedure can be represented as a superposition of operations such as recommendation merging, reference point averaging, splitting the reference classes, moving a reference point between classes, or removing it from the merged class. It is assumed that the aggregation operator applied in a certain step of the procedure to a class or to a pair of reference classes does not alter the remaining recommendations.

Experts are assigned initial credibility coefficients that are decreased when a reference point recommended by an expert is modified or rejected. The operators and the parameters of the regularization procedure are assessed ex-ante with respect to two or more criteria: the total losses of experts' credibility and the quality of the resulting set of reference points. The latter criterion may be expressed in several ways: in terms of the number of inconsistencies that remained after the procedure summed up with a number of weak consistency conditions satisfied by the aggregated reference set. Another plausible measure of ex-ante quality of the regularization process is the minimum number of regularizing operations applied to get a consistent reference set, or the sum of Hausdorff distances between the original and transformed classes of reference points.

Formally, an acceptable aggregation of recommendations is a solution of a multicriteria optimization problem, where the admissible decisions are sequences of aggregation-regularization operations optimized with respect to a selection of least two from the above proposed performance criteria. The constraints may concern the number, the total time, or the total cost of all operations. In addition, the overall process can be assessed ex-post, taking

into account the quality of the compromise solution admitted with the regularized reference set, from the point of view of the decision maker(s). This feedback information is used to learn the regularization parameters within a semi-supervised learning procedure.

The ex-ante assessment are most suitable for the case where the experts and/or decision maker(s) are artificial autonomous decision agents. We will compare two variants of the procedure: the first one applies in each step of the procedure the selected operators to all subsets of reference points independently, creating thus the 'next generation' of reference points as an output of a parallel procedure, similarly as the next generation of cells in classical cellular automata. The second variant analyzes the reference classes sequentially, applying the appropriate aggregation-regularization operators whenever necessary. Moreover, the outcomes of each regularization process in the second variant are assumed to have equal importance. This assumption allows to aggregate the results of each process by constructing the sum of reference classes generated by each process. If the reference set so constructed is inconsistent, the entire procedure is repeated. We will prove that this process is convergent to the unique consistent reference set.

In the discussion section we will analyze the impact of the property that the results of applying aggregation-regularization operators depends on their sequence, on the sequence of reference classes checked for internal or mutual inconsistency and even on the sequence of reference points within a class. It turns out that the order of checking the internal and mutual consistencies does also influence the results of the procedure, so all combinations of consistency checking in an aggregation process can be taken into account as the third dimension of the process. Finally, we will provide an example where n human supervisors provide reference values to a team of autonomous robotic agents performing jointly a complex task modeled as a multicriteria decision process. We will also compare our approach with regression-based preference aggregation methods such as the UTA family.

2. A first multicriteria model to assess the difficulty of single improvement sequences when interactions between criteria exist

Jean-Philippe Hubinont (Université libre de Bruxelles) and Yves de Smet (Université libre de Bruxelles)

The growing amount of data available on companies, cities or any entity, together with the globalization that occurs in most parts of our society, has led to the development of benchmarking models. It consists in finding best practices among a group of compared entities and ultimately, should allow each entity to improve. More particularly, the interest in models that help generating paths of improvement has grown in the strategic decision making literature over these last decades. More recently, specific methods have been proposed in the context of multicriteria decision aid. A core issue is to properly model the difficulty to improve. In existing works, the following assumption is made most of the time: the most preferable, the most difficult. To our point of view, these two concepts have to be de-correlated. In this contribution, a first model is presented to evaluate the difficulty of a sequence of single performance improvement steps when interactions between criteria exist. Moreover, this model could prove to be useful to determine the least difficult sequence of improvements to reach given performances.

3. An automatic-democratic approach to setting weights in multi-criteria performance scoring

Chris Tofallis (University of Hertfordshire)

Non-experts will happily provide weight values without being aware of the implications. It is not reasonable to expect people to have the technical knowledge that experts have spent years acquiring. Methods which avoid issues with weight elicitation are therefore attractive.

We look at the general situation where we wish to generate a set of weights whilst allowing the interests of each 'alternative' to be best represented. This is achieved by firstly finding the

best or optimal score for each alternative. This can be done with DEA (data envelopment analysis).

We then carry out a multiple regression of these optimal scores on the criteria data. The regression coefficients then provide the required weights to attach to the criteria.

In this way the scoring and ranking can be said to have been carried out both democratically and automatically.

4. A multiple criteria approach for constructing a pandemic impact assessment composite indicator: The case of Covid-19 in Portugal

José Rui Figueira (CEGIST, Instituto Superior Técnico, Universidade de Lisboa), Henrique Oliveira (CAMGSD, Instituto Superior Técnico, Universidade de Lisboa), Ana Paula Serro (CQE, Instituto Superior Técnico, Universidade de Lisboa), Rogério Colaço (IDMEC, Instituto Superior Técnico, Universidade de Lisboa), Filipe Froes (GCOM, Ordem dos Médicos, Portugal), Carlos Robalo Cordeiro (GCOM, Ordem dos Médicos, Portugal), António Diniz (GCOM, Ordem dos Médicos, Portugal) and Miguel Guimarães (GCOM, Ordem dos Médicos, Portugal)

The Covid-19 pandemic has caused impressive damages and disruptions in social, economic, and health systems (among others), and posed unprecedented challenges to public health and policy/decision-makers concerning the design and implementation of measures to mitigate its strong negative impacts. The Portuguese health authorities are currently using some decision analysis like techniques to assess the impact of this pandemic and implementing measures for each county, region, or the whole country. Such decision tools led to some criticism and many stakeholders asked for novel approaches, in particular those having in consideration dynamical changes in the pandemic behavior arising, e.g., from new virus variants or vaccines. A multidisciplinary team formed by researchers of the Covid-19 Committee of Instituto Superior Técnico at Universidade de Lisboa (CCIST analysts team) and medical doctors from the Crisis Office of the Portuguese Medical Association (GCOM experts team) gathered efforts and worked together in order to propose a new tool to help politicians and decision-makers in the combat of the pandemic. This paper presents the main steps and elements, which led to the construction of a pandemic impact assessment composite indicator, applied to the particular case of Covid-19 in Portugal. A multiple criteria approach based on an additive multi-attribute value theory (MAVT) aggregation model was used to construct the pandemic assessment composite indicator (PACI). The parameters of the additive model were built through a sociotechnical co-constructive interactive process between CCIST and GCOM team members. The deck of cards method was the technical tool adopted to help in building the value functions and the assessment of the criteria weights. The final tool was presented in a press conference and had a strong impact on Portuguese media, as well as on the main health decision-making stakeholders in the country.

Thursday, 13.20-15.00

THU-3-P3

Session: Goal Programming

Room: Portland Building 0.41

Chair: Dylan Jones

1. The sensitivity of Extended Goal Programmes to the balance between the Manhattan and Chebyshev metrics

John Merchant (*University of Portsmouth*), **Dylan Jones** (*University of Portsmouth*) and **Banu Lokman** (*University of Portsmouth*)

The two principal variants of Goal Programming use either a simple weighted sum of deviations from pre-specified targets (the Manhattan or L1 metric) or a lexicographic ordering of these deviations (the Chebyshev or L ∞ metric). Extended Goal Programming includes both measures and uses a parameter, alpha, to balance the use of each of them so that decision makers can select a mix for themselves. The value of alpha is then one of a number of choices that the decision maker has to make. Explaining the meaning of alpha and its significance and then assisting the decision maker to make the choice can be a time-consuming process. Many previously reported applications have used repeated runs of the model over a wide range of alpha to investigate its importance. It would therefore be helpful to know in advance how sensitive the solution is to this value and hence how much effort needs to be put into its choice.

It is however not obvious how to measure such sensitivity and the paper begins by discussing the options available. By demonstrating the application of these measures to some standard Goal Programming applications it is shown that sensitivity can vary significantly depending on the structure of the model. The paper shows which measures of sensitivity are most helpful and then, by examining general models of increasing complexity, makes a more formal analysis of sensitivity and structure. It shows that the sensitivity of a model to the value of alpha increases both as the number of Goals in the model and the number of a particular kind of constraint increase. Furthermore it shows that sensitivity is not dependent on the total number of variables nor on the sparsity of the matrix of the left-hand side of the constraint equations. It is also demonstrated that, as expected, the sensitivity of the dual of an Extended Goal Programme is the same as the primal version. The paper ends by drawing some general conclusions for predicting the sensitivity of a given Extended Goal Programming model.

2. Adding meaning to multiobjective control in economics and finance

Francisco Salas-Molina (*Universitat Politècnica de València*), **David Pla-Santamaria** (*Universitat Politècnica de València*), **Ana Garcia-Bernabeu** (*Universitat Politècnica de València*) and **Javier Reig-Mullor** (*Universidad Miguel Hernández de Elche*).

Multiple criteria decision making (MCDM) problems are characterised by the presence of several conflicting objectives that are considered simultaneously. We formulate each relevant aspect as an objective function and we use multiobjective optimisation to find the best solutions. MCDM dates back to the works by Pareto at the end of the 19th century, but the field has grown very fast during the last decades.

Within the context of MCDM, there is a group of problems in which time is a key variable in addition to the criteria under consideration. Time is particularly relevant in the field of economics and finance. However, most of the classic approaches to economic problems are static. In this paper, we argue that multiobjective techniques such as goal programming are very useful to control dynamic systems. By dynamic multiobjective problems, we mean multiperiod problems in which we want to optimise a set of objective functions over time. This definition includes problems in which we want to optimise the final or cumulative state of criteria, but also the deviation of the trajectory of these criteria over time with respect to a given reference.

An important research question arises when dealing with multiobjective control problems: which measure should we use to evaluate alternative solutions? If we adhere to dynamic goal programming, we should minimise the sum of deviations for each time step. However, other alternatives suggest the use of maximum absolute deviations or percentage deviations. In this paper, we explore the links between MCDM techniques and multiobjective control and we further elaborate on the use of distances as a function of losses to evaluate alternative solutions.

Although the use of the Minkowski parametric distance function is usually restricted to the selection of alternative solutions in compromise programming, we study the implications of extending its use to dynamic goal programming. We consider the meaning that a key parameter of the Minkowski distance function adds to the characteristics of solutions. We study the implications of the selection of this parameter in the optimisation process. Finally, we reformulate multiobjective control problem as a constrained norm approximation problem. This reformulation presents the advantage of being convex and then solvable for any value of the parameter using state-of-the-art convex optimisation algorithms.

3. Coalition Formation for Horizontal Supply Chain Collaboration: A Multiobjective Approach.

Mirna Abou Mjahed (Neoma Business School), Fouad Ben Abdelaziz (Neoma Business School) and Hussein Tarhini (American University of Beirut).

Companies performing same type of activities are recently leaning to exploit situations to improve their performance. By collaborating horizontally, companies are expected to achieve considerable improvement. Most optimization approaches in coalition-based supply chain collaboration are single objective targeting cost reduction or profit maximization. Real-world decision problems usually require the investigation of more than one criterion to achieve a sustainable progress. When considering multiobjective aspects in decision making, analyzing each aspect separately may not resolve a situation as one may agree to some aspects of cooperation and not to others. Cooperative multiobjective games incorporate in the analysis all the different objectives simultaneously and can be used to realistically model cooperation between players or agents in the problem.

In this paper, we study the collaborative facility and fleet sharing among firms at the same horizontal layer of the supply networks and explore the benefits of forming coalitions. We consider the case of shippers' collaboration in a two-echelon setting and introduce multiple firms operating multiple distribution centers and have multiple retailers. The first echelon represents production allocation and transportation activities between firms and the distribution centers. The second echelon represents transportation activities and deliveries from distribution centers to retailers. This problem assumes that there are enough synergies between firms' activities and there exist some common retailers among the collaborators which enhances the chances of successful collaboration. Such firms have incentives to minimize their operational costs by optimizing inventory levels at warehouses, replenishment process and distribution to retailers. At the same time, firms wish to maintain as much as possible the contact with their own retailers and maximize the number of orders they can fulfill by their privately owned fleets. The quality of logistic service is measured in terms of maximizing the use of firm's own private fleet as possible. The aim is to look at the trade-off between cost of the logistic service (warehousing and transportation) and maintaining customer satisfaction and loyalty by keeping, when possible, delivery service internal to each firm.

By forming coalitions, firms can gain access to more distribution centers. Firms can also cover larger geographic area to operate their distribution services by sharing partners' fleets. In such case, firms may benefit from using better utilized assets' capacities in the shared distribution network. Cooperative game theory has been widely used to model coalition formation and profit distribution. The problem is coalition formation modeled as a cooperative multiobjective game. The contribution of our paper resides in developing a bi-objective model to quantify collaborative savings in cost reduction while maintaining quality logistics and customer loyalty.

The purpose is to help these firms determine whether they should join coalitions and propose the best coalition structure and payoff scheme to distribute savings among the coalition members.

4. Mapping and prioritising Arctic and North Atlantic Maritime Safety and Security Innovation Needs: An application of knapsack-based goal programming

Dylan Jones (University of Portsmouth), Ashraf Labib (University of Portsmouth) and Kevin Willis (University of Portsmouth)

This seminar details work undertaken in order to develop and employ a methodology for assessing needs for innovation across a complex multi-disciplinary field. The research was undertaken in the context of an EU funded project arising from the field of Arctic and North Atlantic maritime safety and security. Firstly, the context of the project and hence the need to classify outstanding areas of need for innovation, applied research, application of knowledge or development of standards or regulation is given. A systematic means of developing a classification of need, and hence a need hierarchy is given. Details of the top level of classification, derived from the Polar Code are first described. These include (i) Navigation, (ii) Vessel related, (iii) Lifesaving equipment and cold and sea survival, (iv) Pollution and incident control (v) Communication and (vi) Training, personal and education. Furthermore, a description of how a series of facilitated stakeholder workshops, semi-structured questionnaires, literature review and past and parallel project results have been used to develop the subsequent three-level need hierarchy will be given. The hierarchy, which comprises of twenty needs and seventy-five sub-needs across the above six categories, will be summarised.

The use of a PICK (Possible, Implement, Challenge, Keep-Back) methodology to classify the above sub-needs according to their level of difficulty of resolution and perceived importance will then be described. The liaison with multiple experts for each of the six polar code categories in order to assign levels of difficulty and importance to each sub-need will be detailed. The sub-needs will then be visualised by a PICK chart which divided them into the four PICK categories. The separation lines of the categories are calculated by the geometric means of level of difficulty and perceived importance across all categories and experts. The significance of sub-needs falling into each of the four (Possible, Implement, Challenge, Keep-Back) categories in the context of the ARCSAR project and the wider context of innovation need mapping will be described.

The development of a goal programming knapsack-based model in order to develop a priority list of sub-needs for the project to give particular emphasis to will then be detailed. According to a broad interpretation of Pareto principles, the priority list will contain approximately twenty percent of the total number of sub-needs. A weighted goal programming model will be developed with three principal goals. The first goal is concerned with the maximisation of the total perceived importance of the set of priority sub-needs. The second goal is concerned with achieving a balance between the representation of the six polar code categories in the priority sub-need set. The third goal is concerned with achieving a balance between sub-needs in the implement and possible (i.e. lower level of difficulty) and challenge (i.e. higher level of difficulty) categories. This is to ensure a balance between shorter- and longer-term innovation needs in the priority set. The above goals are restricted by a knapsack constraint that limits the total level of difficulty of the set of priority sub-needs. Finally, a sensitivity analysis around the weights associated with the three goals and the size of the difficulty knapsack is undertaken and the results presented. Overall conclusions are then drawn with respect to the methodology, the EU project and the overall field of application.

Thursday, 15.20-16.40
THU-4-Business Meeting
Room: Richmond Building LT1
Chair: Matthias Ehrgott

**The International Society on MCDM
Business Meeting**



Friday, 10:00-12:00

FRI-1- Award Talks

Room: Richmond Building LT1

Chair: Jyrki Wallenius



The International Society on MCDM Award Talks

The MCDM Gold Medal

This is the highest honour that the International Society on Multiple Criteria Decision Making bestows upon a scholar who, over a distinguished career, has markedly contributed to the theory, methodology, practice and professional development of MCDM.

The MCDM Edgeworth-Pareto Award

This is the highest distinction that the International Society on Multiple Criteria Decision Making bestows upon a researcher or practitioner of MCDM who has demonstrated a high level of creativity in developing novel areas of application of MCDM and associated methodology, markedly influencing the form of MCDM practice.

The Georg Cantor Award

This is the highest form of recognition that the International Society on Multiple Criteria Decision Making bestows upon a researcher who has personified the spirit of independent inquiry in developing innovative ideas in the theory and methodology of MCDM, significantly expanding the tools available to MCDM practice.

Friday, 13.00-14.40

FRI-2-P1

Session: Applications of MCDA

Room: Richmond Building LT3

Chair: Adiel Teixeira de Almeida

1. A preference disaggregation method using time-series-based approach applied to basketball

Betania Campello (UNICAMP), **Sarah Benamor** (University of Ottawa), **Rafael Prochnow** (UNICAMP), **Luciano Mercadante** (UNICAMP), **Leonardo Tomazeli Duarte** (University of Campinas) and **João Romano** (UNICAMP)

Multiple criteria decision aid (MCDA) is a field of decision science that aims to support decisions involving a set of alternatives and multiple criteria. The preference disaggregation approach in MCDA infers preferential information from examples of choices provided by the decision maker (DM). These examples can be a set of the DM's past decisions, a subset of decision alternatives, or a set of fictitious alternatives.

The preference disaggregation analysis in MCDA is usually based on the additive utility function model. Such a model associates a numerical value with each alternative. This numerical value is computed by aggregating the scores of the alternative on the different criteria. For this purpose, well-known MCDA preference disaggregation method is UTA. It uses a linear programming formulation to determine piecewise the linear marginal value functions. Several variants of this method were proposed. These include, for instance, UTASTAR, considered to be an improved version of UTA; UTADIS, which is used to infer decisions related to sorting alternatives into ordered categories; or UTA-poly, which assumes polynomials and splines instead of piecewise linear functions.

These methods have in common that each criterion is associated with a single value, which may be the average of the criterion's performance in a given period of time or some other static data. However, several decisions are made considering the evolution of the criterion over time, its time-series, or some characteristics of these time-series (summary measures such as the average and tendency). For instance, in medium- or long-term investment decisions, the tendency and the variance of the criteria are as relevant as their average. Also, to hire an athlete, many DMs deem it relevant to analyze the athlete's tendency, variance and average on several criteria. Thus, for the model to be representative, it is important to infer the DM's preference while taking into account several characteristics of the criteria's time-series simultaneously.

For this purpose, we propose UTASTAR-T, an extension of UTASTAR, to learn the DM's preferences in a context where some characteristics of the time-series criteria are considered simultaneously. We apply this new method to measure the performance of quintets in basketball, using real data. The UTASTAR-T method allows us to understand the characteristics of a team's quintets, considering some criteria that are called technical performance indicators, such as shot making, rebounding, and assists. Thus, the alternatives are the quintets, and the criteria are the technical indicators. These indicators were analyzed over 26 games of a Brazilian team in the qualifying round of the 2020/2021 season of \textit{Novo Basquete Brasil}.

Our work is an interdisciplinary contribution bringing together decision science and sports. UTASTAR-T is a new MCDA method that takes into account the time-series characteristics of criteria. In basketball, the analysis of coach decisions using UTASTAR-T allows for a dynamic view of these decisions, since games are successive actions that vary over time. In addition, UTASTAR-T provides an analysis of the performance of basketball quintets, rather than an analysis of individual players. The quintets approach can be interesting since, when the coach switches a player, a new relationship is formed between the players, changing the characteristics of the quintet and not only the individual performance induced by the exchange.

2. A data-driven multiple criteria sorting approach to constructing social vulnerability composite indicators using the Choquet integral

Renata Pelissari (UNICAMP), Sarah Ben Amor (University of Ottawa) and Leonardo Tomazeli Duarte (UNICAMP)

Setting weights is a rather challenging issue in the construction of composite indices in many fields. In the literature, weighting methods may be categorized into two main types: statistical weighting methods and participatory weighting methods. In the former, weights of the variables are purely estimated from the data, which may be a welcome feature given the current and increasing availability of data. However, these methods present some limitations such as not taking into consideration decision-makers' preferences and difficulty in capturing possible interactions among input variables. On the other hand, participatory weighting methods address these issues, since they can easily take into consideration expert's preferences and present some techniques, such as the Choquet integral preference model, to model interacting variables.

Given this context, the current paper contributes by proposing a sorting decision-making method that takes into consideration the preferences of decision-makers (DM), which helps in personalizing their decision-making strategies, and allows potentially interacting variables. To take into consideration interaction between variables, we apply the Choquet integral. Although the proposed method is not predominantly a data-driven method, it also relies on statistical algorithms since it learns the Choquet interaction indices from statistical correlations estimated from data. We also apply the SMAA methodology in order to avoid any prior judgment on the importance given to the considered variables. In order to conduct a sorting, the groups are characterized by reference values previously defined by the DM. We propose to classify the alternatives by minimizing the difference between their evaluations and the category reference values. This procedure is possible since the Choquet integral can be proved as a distance measure.

The proposed method is applied to the construction of the São Paulo Social Vulnerability Index that aims to provide the managers of the public sector and the society with a detailed view of the municipality's living conditions in the state of São Paulo, Brazil. As well as in the original IPVS, we intend to categorize census sectors into seven groups from extremely low vulnerability to very high vulnerability. But differently from the original IPVS, here we are able to take the preferences of the DMs into consideration.

3. Selecting the Best Truck for a midsize carrier supported by the FITradeoff Method

Lucia Reis Peixoto Roselli (Center for Decision Systems and Information Development (CDSID), Universidade Federal de Pernambuco), Mariana Wanderley Cyreno (Center for Decision Systems and Information Development (CDSID), Universidade Federal de Pernambuco) and Adiel Teixeira de Almeida (Center for Decision Systems and Information Development (CDSID), Universidade Federal de Pernambuco)

This paper discusses the FITradeoff decision process [1,2] conducted by a Decision-Maker (DM) to select the best trucks for a midsize carrier [3]. The main objective of this problem has been to guarantee the greatest long-term profitability. Hence, to represent this objective, seven criteria have been defined. After that, six trucks have been listed to compose the alternative space.

In this context, the FITradeoff method for choice problematic was used to solve this problem [1]. Using the FITradeoff Decision Support System (DSS), the DM ranks the scaling constants regarding each criteria. After this step, four alternatives have been dominated and two alternatives stay as Potentially Optimal Alternatives (POAs). These alternatives were: Volkswagen 25 420 Constellation and Mercedes-Benz Axor 2544 S Ls.

Hence, at this moment, the DM wishes to evaluate these alternatives in the holistic evaluation. The DM desires to compare these alternatives using the graphical (bar graph, spider graph

and bubble graph) and tabular visualizations presented in the FITradeoff DSS. Thus, after evaluating alternatives performance's in those graphs, the DM do not feel convinced to express a dominance relation between them. In this case, the DM prefers to proceed the decision process in the elicitation by decomposition.

During the elicitation by decomposition, the DM compares pairs of consequences. The DM evaluated eight pairwise comparisons, expressing his preferences for each one of them. After that, a solution has been found. The Volkswagen 25 420 Constellation has been indicated as the best choice for this problem.

Based on the description about the decision process within the FITradeoff DSS, some remarks can be made about the FITradeoff method [1,2]. This method is a method in the context of Multi-Attribute Value Theory [4], with uses additive aggregation of consequences. Also, this method presents the same axiomatic structure of the Tradeoff procedure [4]. However, incorporates partial information concepts, requiring only strict preferences for Decision-Makers (DMs) [1,2].

Another important remark is that FITradeoff integrates the two perspectives for preference modelling during the decision process – the elicitation by decomposition and the holistic evaluation [2]. Thus, using the FITradeoff DSS, DMs can conduct the preference modelling in two ways, expressing preferences between consequences in a pairwise comparison during the elicitation by decomposition, or expressing preferences between alternatives during the holistic evaluation. Moreover, the holistic evaluation has supported by different kind of graphical and tabular visualizations. These visualizations exhibit the performance of the alternatives of the problem. For instance, DMs can compare Potentially Optimal Alternatives (POAs) in choice problematic to express dominance relations between them.

The preferences expressed in both ways are included in a Linear Programming Problem (LPP), which runs after each interaction with DMs. Since this method is considered interactive because after each preference expressed by DMs, the LPP model runs, and DMs can evaluate partial results.

Moreover, this method is flexible since DMs can alternate between the perspectives for preference modeling, using those that they judge as most adequate to continue the decision process. In addition, DMs can stop the process at any moment of the process, considering the partial results as solution. The first paper concerning the FITradeoff method has been proposed to solve choice problems. However, now the FITradeoff method can be used to solve portfolio problematic [5], ranking problematic [6], sorting problematic [7]. Hence, a wide range of application have been presented in the literature using the FITradeoff method. In addition, several behavioral studies have been performed to investigate these two perspectives of preference modeling of the FITradeoff DSS. The FITradeoff DSS is available for free at www.fitradeoff.org.

Acknowledgment

This work had partial support from the Brazilian Research Council (CNPq) [grant 308531/2015-9;312695/2020-9] and the Foundation of Support in Science and Technology of the State of Pernambuco (FACEPE) [APQ-0484-3.08/17].

1. de Almeida, A. T., Almeida, J.A., Costa, A. P. C. S., & Almeida-Filho, A.T. (2016). A New Method for Elicitation of Criteria Weights in Additive Models: Flexible and Inter-active Tradeoff. *European Journal of Operational Research*, 250(1): 179-191
2. de Almeida, AT, Frej, E.A., Roselli, L.R.P. (2021). Combining Holistic and Decomposition Paradigms in Preference Modeling with the Flexibility of FITradeoff. *Central European Journal of Operations Research*. Doi: 10.1007/s10100-020-00728-z.
3. Cyreno, M. W., Roselli, L. R. P., & de Almeida, A. T. (2022). Using FITradeoff Method for solving a truck acquisition problem at a midsize carrier. In: Jason Papathanasiou, Ana Paula Cabral Seixas Costa, Uchitha Jayawickrama and Daouda Kamissoko (eds). *Decision Support*

Systems XII - Decision Support addressing modern Industry, Business and Societal needs. ICDSST 2022. Lecture Notes in Business Information Processing (forthcoming).

4. Keeney RL, Raiffa H.: Decisions with multiple objectives: preferences, and value tradeoffs. Wiley, New York (1976).

5. Frej, E. A., Ekel, P., & de Almeida, A. T. (2021). A Benefit-To-Cost Ratio Based Approach for Portfolio Selection Under Multiple Criteria With Incomplete Preference Information. Information Sciences. v. 545, p. 487-498

6. Frej, E. A.; de Almeida, A.T.; Costa, A. P. C. S.: Using data visualization for ranking alternatives with partial information and interactive tradeoff elicitation. Operational Research, v.2019, 1-23 (2019).

7. Kang, T. H. A., Frej, E. A., & de Almeida, A. T. (2020). Flexible and Interactive Tradeoff Elicitation for Multicriteria Sorting Problems. Asia Pacific Journal of Operational Research, v. 37, p. 2050020.

4. MCDM applications with FITradeoff web based DSS Combining holistic and decomposition paradigms in preference modelling

Adiel Teixeira de Almeida (Federal University of Pernambuco), **Lucia Reis Peixoto Roselli** (UFPE) and **Eduarda Frej** (UFPE)

This work shows MCDM Applications with the web based DSS developed for the FITradeoff method. The presentation focuses on the flexibility feature of the FITradeoff method. It is supported by a web-based DSS for preference modeling, which is freely available in www.fitradeoff.org. The method is based on the additive aggregation of criteria and uses partial or incomplete information from a DM (Decision Maker). The preference modeling is primarily based on the classical tradeoff procedure for elicitation by decomposition. However, it considers also a different perspective based on holistic evaluations. The presentation explores this new feature of combining and integrating these two paradigms (de Almeida et al, 2021). That is, the decision process is illustrated by showing a few applications that explores this combination of both paradigms: Holistic evaluations and elicitation by decomposition. The papers shows how the DSS and its decision process has been improved by using results from behavioral studies, including the use of neuroscience tools. The main aspect to be shown is the improvement in the decision process by supporting the interactions between the DM and the analyst.

Reference:

de Almeida, A.T., Frej, E.A. & Roselli, L.R.P. Combining holistic and decomposition paradigms in preference modeling with the flexibility of FITradeoff. Central European Journal of Operations Research, v. 29, p. 7-47, 2021.

Friday, 13.00-14.40

FRI-2-P2

Session: Analytic Hierarchy / Network Processes

Room: Portland Building 0.28

Chair: Luis Quezada

1. GANP-Fuzzy Sorting II method for the environmental planning and management of the Susa Valley

Vanessa Assumma (Polytechnic University of Turin), **Marta Bottero** (Polytechnic University of Turin) and **Alessio Ishizaka** (NEOMA Business School)

This study aims to support both decision makers and policy makers in the definition and prioritization of complex and uncertain strategies and recommendations. Particularly, this work focuses on MCDA sorting classification to deal with complex spatial systems with interdependences, such as the biocultural landscapes. The contribution starts from an existing sorting method called Group Analytic Network Process Sorting II method (GANPSort II), which was developed in the context of a Ph.D. thesis (Assumma, 2021) and based on the previous extensions ANP Sort (Ishizaka & Pereira, 2017). The GANP-Fuzzy Sorting II is proposed as an extension by integrating the fuzzy logic in the evaluation stage (Ishizaka et al., 2020):

The application of the GANP-Fuzzy Sort II method refers to a biocultural landscape located in Northern Italy and bordering on France: the Susa Valley (Piedmont). The alternatives to classify consist of 39 municipalities. They are characterised, on the one hand, by a high naturalness and outstanding landscape, and on the other hand by social conflicts and environmental injustices that threatened the Susa Valley health status over the last decades. In this sense, the decision-making process requires an urgent need to take into account all the interests of actors and stakeholders in a shared, sustainable and resilient policy strategy.

The GANP-Fuzzy Sorting II method has structured the decision problem following the Analytic Network Process approach (ANP) by identifying a set of indicators according to the logic of Pressure-State-Response (PSR). These indicators are organised into a set of clusters representing the fundamental components of the environment. Four classes are defined to measure the performance of the Susa Valley and its municipalities.

A survey is developed through an online questionnaire that has involved a multidisciplinary panel of experts. The purpose of the GANP-Fuzzy Sorting II method is to identify both valuable and critical municipalities to support both decision makers, policy makers and also environmental bodies to build a set of strategies and recommendations for the environmental planning and management of the Susa Valley.

2. Single expert manipulations in the cardinal pairwise-comparisons method

Konrad Kułakowski (AGH UST) and **Michał Strada** (AGH UST)

The pairwise-comparisons based decision-making methods like AHP rely largely on expert opinions. Experts can be wrong or inconsistent. However, it is widely believed that any mistakes by the experts are not on purpose. In our work, we adopt the opposite assumption. Our experts are dishonest and want to achieve the intended shape of the ranking in the least conspicuous way possible.

In our work, we analyze several possibilities for manipulating the pairwise-based ranking procedure. Understanding and identifying possible attack methods can help decision-makers avoid such threats in practice.

3. AHP model for assessing critical factors impacting stadium security

Astrid Oddershede (University of Santiago of Chile), **Luis Quezada** (UNIVERSITY OF SANTIAGO OF CHILE), **Miguel Angel Rodriguez** (Universidad de Santiago de Chile) and **Cecilia Montt Veas** (Universidad de Santiago de Chile)

A multi-criteria model based on the analytical hierarchy process (AHP) is presented to identify and prioritize the critical factors affecting the safety of a sports venue. The objective is to provide decision-makers with a support tool to act on this issue. A case study on soccer stadium security is presented as an illustration. An exploratory research was conducted by gathering information on previous experiences in Chile and other countries, considering national and international regulatory frameworks. A first AHP model emerged from this study, which was ratified, complemented and evaluated by a panel of experts in the field. The results indicate that, with the use of the multi-criteria approach, it is possible to determine a set of factors that affect the safety of a stadium, as well as to rank them according to their level of importance. This is done in order to improve security in soccer events considering a given horizon. The AHP proved to be a useful tool to obtain the aspects that directly influence the safety of soccer stadiums in Chile. Thus, the AHP model can be used as a guideline for the development of the stadium security system. This study serves as a basis for those who must establish priorities and make decisions on actions to improve the critical situation.

4. A method for designing a strategy map with scenarios using ANP/AHP

Luis Quezada (UNIVERSITY OF SANTIAGO OF CHILE), **Astrid Oddershede** (University of Santiago of Chile), **Pedro Palominos** (Universidad de Santiago de Chile), **Cecilia Montt Veas** (Universidad de Santiago de Chile) and **Miguel Angel Gonzalez** (Universidad de Santiago de Chile)

A method for designing a strategy map with scenarios is presented. A strategy map is a visual description the strategy of a firm. It contains the strategic objectives and the causal relationships between them. The objectives are grouped into the four perspectives of a Balanced Scorecard: Financial, Clients, Internal Processes and Growth & Learning. One of the criticism of the strategy map is that it considers only one scenario. The objective of this work is to provide a strategy map that takes into a count various potential scenarios. First, managers have to identify the scenarios and then build a strategy map for each of them. Then the method estimates the priority of the strategic objectives and the causal relationships using ANP/AHP for each one of the scenarios. A global strategy is built by identifying those strategic objectives and causal relationships with a higher priority. The proposed method allows managers to consider possible futures. The method is illustrated in the case of a service company.

Friday, 15.00-16.00

FRI-3-Closing Session

Room: Richmond Building LT1

Chair: Alessio Ishizaka

Presenter Index (in Alphabetical Order)

Presenter	Session ID	Day	Time	Room
Adiel Teixeira de Almeida	FRI-2-P1	Friday	13.00-14.40	RB LT3
Adolfo Vicente Araújo	TUE-2-P2	Tuesday	10.20-12.00	PO 0.28
Akhmad Fauzi	MON-4-P2	Monday	15.20-17.00	PO 0.28
Akram Dehnokhalaji	MON-4-P1	Monday	15.20-17.00	RB LT3
Alessio Ishizaka	MON-1-OPENING	Monday	09.00-10.00	RB LT1
Alessio Ishizaka	TUE-1-PLENARY	Tuesday	09.00-10.00	RB LT1
Alessio Ishizaka	FRI-3-CLOSING	Friday	15.00-16.00	RB LT1
Alexander Engau	MON-3-P1	Monday	13.20-15.00	RB LT3
Amin Vafadarnikjoo	THU-2-P3	Thursday	10.20-12.00	PO 0.41
Ana B. Ruiz	THU-2-P1	Thursday	10.20-12.00	RB LT3
Ana Sara Costa	TUE-4-Doctoral Dissertation Award	Tuesday	16.20-18.00	RB LT1
Andrea Raith	MON-2-P1	Monday	10.20-12.00	RB LT3
Andrzej M.J. Skulimowski	THU-3-P2	Thursday	13.20-15.00	PO 0.28
Anissa Frini	MON-2-P3	Monday	10.20-12.00	PO 0.41
Antonio Gaspar-Cunha	WED-2-P3	Wednesday	10.20-12.00	PO 0.41
Aric Fowler	THU-2-P1	Thursday	10.20-12.00	RB LT3
Astrid Oddershede	FRI-2-P2	Friday	13.00-14.40	PO 0.28
Banu Lokman	WED-1-PLENARY	Wednesday	09.00-10.00	RB LT1
Barbara Summers	MON-3-P2	Monday	13.20-15.00	PO 0.28
Befrin Neval Bingol	MON-2-P2	Monday	10.20-12.00	PO 0.28
Betania Campello	FRI-2-P1	Friday	13.00-14.40	RB LT3
Bhaba Mohanty	MON-3-P3	Monday	13.20-15.00	PO 0.41
Britta Schulze	THU-3-P1	Thursday	13.20-15.00	RB LT3
Carla Cunha	MON-2-P2	Monday	10.20-12.00	PO 0.28
Carlos Hernández	THU-2-P2	Thursday	10.20-12.00	PO 0.28
Carlos M. Fonseca	WED-2-P3	Wednesday	10.20-12.00	PO 0.41
Cecilia Montt	MON-4-P2	Monday	15.20-17.00	PO 0.28
Chris Tofallis	THU-3-P2	Thursday	13.20-15.00	PO 0.28
Dylan Jones	THU-1-PLENARY	Thursday	09.00-10.00	RB LT1
Dylan Jones	THU-3-P3	Thursday	13.20-15.00	PO 0.41
Erik Pohl	TUE-3-P3	Tuesday	14.20-16.00	PO 0.41
Fabian Chlumsky-Hartmann	MON-3-P1	Monday	13.20-15.00	RB LT3
Francisco Ruiz	MON-4-P2	Monday	15.20-17.00	PO 0.28
Francisco Ruiz	TUE-4-Doctoral Dissertation Award	Tuesday	16.20-18.00	RB LT1
Francisco Salas-Molina	THU-3-P3	Thursday	13.20-15.00	PO 0.41
Fritz Bökler	WED-3-P1	Wednesday	13.20-15.00	RB LT3
Fusun Ulengin	WED-2-P2	Wednesday	10.20-12.00	PO 0.28
Gilles Dejaegere	TUE-3-P3	Tuesday	14.20-16.00	PO 0.41
Giomara Larraga	TUE-3-P1	Tuesday	14.20-16.00	RB LT3
Giovanni Misitano	TUE-3-P1	Tuesday	14.20-16.00	RB LT3
Gökhan Ceyhan	TUE-4-Doctoral Dissertation Award	Tuesday	16.20-18.00	RB LT1

Presenter Index (in Alphabetical Order) (continued)

Presenter	Session ID	Day	Time	Room
Graham Galbraith	MON-1-OPENING	Monday	09.00-10.00	RB LT1
Guilherme Dean Pelegrina	THU-2-P3	Thursday	10.20-12.00	PO 0.41
Guillermo Cabrera-Guerrero	WED-3-P3	Wednesday	13.20-15.00	PO 0.41
Hania Rahma	TUE-2-P3	Tuesday	10.20-12.00	PO 0.41
Hasan Altooq	MON-3-P2	Monday	13.20-15.00	PO 0.28
He Huang	MON-3-P2	Monday	13.20-15.00	PO 0.28
Ignacy Kaliszewski	WED-3-P1	Wednesday	13.20-15.00	RB LT3
Inès Saad	MON-2-P3	Monday	10.20-12.00	PO 0.41
Isabella Lami	TUE-2-P2	Tuesday	10.20-12.00	PO 0.28
Jafar Rezaei	THU-2-P3	Thursday	10.20-12.00	PO 0.41
Jana Burkotová	THU-2-P1	Thursday	10.20-12.00	RB LT3
Janusz Miroforidis	MON-3-P1	Monday	13.20-15.00	RB LT3
Javid Zare	TUE-3-P2	Tuesday	14.20-16.00	PO 0.28
Jean-Philippe Hubinont	THU-3-P2	Thursday	13.20-15.00	PO 0.28
John Merchant	THU-3-P3	Thursday	13.20-15.00	PO 0.41
Jorre Vannieuwenhuyze	MON-2-P2	Monday	10.20-12.00	PO 0.28
José Rui Figueira	THU-3-P2	Thursday	13.20-15.00	PO 0.28
Julia Sudhoff	THU-3-P1	Thursday	13.20-15.00	RB LT3
Julius Bauß	THU-3-P1	Thursday	13.20-15.00	RB LT3
Jyrki Wallenius	TUE-2-P1	Tuesday	10.20-12.00	RB LT3
Jyrki Wallenius	FRI-1- Award Talks	Friday	10.00-12.00	RB LT1
Kaisa Miettinen	TUE-3-P1	Tuesday	14.20-16.00	RB LT3
Karen Johnston	MON-1-OPENING	Monday	09.00-10.00	RB LT1
Kathrin Klamroth	WED-2-P1	Wednesday	10.20-12.00	RB LT3
Khoirunurrofik Khoirunurrofik	MON-2-P2	Monday	10.20-12.00	PO 0.28
Konrad Kułakowski	FRI-2-P2	Friday	13.00-14.40	PO 0.28
Krzysztof Martyn	THU-2-P2	Thursday	10.20-12.00	PO 0.28
Lara Löhken	THU-3-P1	Thursday	13.20-15.00	RB LT3
Laura Sofia Mesa Estrada	MON-3-P3	Monday	13.20-15.00	PO 0.41
Lavinia Amorosi	WED-3-P1	Wednesday	13.20-15.00	RB LT3
Leonardo Tomazeli Duarte	TUE-2-P2	Tuesday	10.20-12.00	PO 0.28
Levin Nemesch	MON-3-P1	Monday	13.20-15.00	RB LT3
Lucia Reis Peixoto Roselli	FRI-2-P1	Friday	13.00-14.40	RB LT3
Luis Dias	TUE-3-P3	Tuesday	14.20-16.00	PO 0.41
Luis Martínez	TUE-1-PLENARY	Tuesday	09.00-10.00	RB LT1
Luis Quezada	FRI-2-P2	Friday	13.00-14.40	PO 0.28
Luis Vargas	WED-2-P2	Wednesday	10.20-12.00	PO 0.28
Magdalena Martyn	THU-2-P2	Thursday	10.20-12.00	PO 0.28
Manuel López-Ibáñez	WED-3-P3	Wednesday	13.20-15.00	PO 0.41
Mariana Mesquita-Cunha	THU-2-P1	Thursday	10.20-12.00	RB LT3
Marie Humbert-Ropers	WED-2-P1	Wednesday	10.20-12.00	RB LT3
Marios Dominikos Kremantzis	MON-4-P1	Monday	15.20-17.00	RB LT3

Presenter Index (in Alphabetical Order) (continued)

Presenter	Session ID	Day	Time	Room
Matteo Brunelli	TUE-3-P2	Tuesday	14.20-16.00	PO 0.28
Matthias Ehr Gott	MON-1-OPENING	Monday	09.00-10.00	RB LT1
Matthias Ehr Gott	WED-3-P1	Wednesday	13.20-15.00	RB LT3
Matthias Ehr Gott	THU-4-Business Meeting	Thursday	15.20-16.40	
Maura Hunt	MON-4-P1	Monday	15.20-17.00	RB LT3
Michael Stiglmayr	WED-2-P1	Wednesday	10.20-12.00	RB LT3
Michał Tomczyk	THU-2-P2	Thursday	10.20-12.00	PO 0.28
Miguel Alves Pereira	TUE-4-Doctoral Dissertation Award	Tuesday	16.20-18.00	RB LT1
Miguel Angel Ortiz-Barrios	TUE-2-P2	Tuesday	10.20-12.00	PO 0.28
Miłosz Kadziński	THU-2-P2	Thursday	10.20-12.00	PO 0.28
Mirna Abou Mjahed	THU-3-P3	Thursday	13.20-15.00	PO 0.41
Murat Köksalan	MON-4-P1	Monday	15.20-17.00	RB LT3
Murat Köksalan	WED-1-PLenary	Wednesday	09.00-10.00	RB LT1
Nicolas Forget	WED-2-P1	Wednesday	10.20-12.00	RB LT3
Ozden Bayazit	WED-2-P2	Wednesday	10.20-12.00	PO 0.28
Ozlem Karsu	MON-2-P1	Monday	10.20-12.00	RB LT3
Pedro Lopes Neto	TUE-2-P3	Tuesday	10.20-12.00	PO 0.41
Ralph Steuer	TUE-2-P1	Tuesday	10.20-12.00	RB LT3
Ram Kumar Dhurkari	WED-3-P2	Wednesday	13.20-15.00	PO 0.28
Renata Pelissari	FRI-2-P1	Friday	13.00-14.40	RB LT3
Sajid Siraj	MON-3-P2	Monday	13.20-15.00	PO 0.28
Salem Chakhar	THU-2-P3	Thursday	10.20-12.00	PO 0.41
Sally Giuseppe Arcidiacono	TUE-3-P3	Tuesday	14.20-16.00	PO 0.41
Salvatore Greco	MON-2-P3	Monday	10.20-12.00	PO 0.41
Salvatore Greco	THU-1-PLenary	Thursday	09.00-10.00	RB LT1
Samah Alnuaimi	MON-3-P3	Monday	13.20-15.00	PO 0.41
Sandra González-Gallardo	WED-3-P3	Wednesday	13.20-15.00	PO 0.41
Sarfaraz Hashemkhani Zolfani	MON-3-P3	Monday	13.20-15.00	PO 0.41
Savíns Puertas Martín	WED-2-P3	Wednesday	10.20-12.00	PO 0.41
Sena Cakmak	WED-3-P2	Wednesday	13.20-15.00	PO 0.28
Serpil Sayin	MON-2-P1	Monday	10.20-12.00	RB LT3
Sezin Güteryüz	WED-3-P2	Wednesday	13.20-15.00	PO 0.28
Simona Panaro	MON-2-P3	Monday	10.20-12.00	PO 0.41
Tadeusz Trzaskalik	TUE-2-P3	Tuesday	10.20-12.00	PO 0.41
Tao Wen	TUE-3-P2	Tuesday	14.20-16.00	PO 0.28
Theodor Stewart	TUE-2-P1	Tuesday	10.20-12.00	RB LT3
Valerio Salomon	TUE-3-P2	Tuesday	14.20-16.00	PO 0.28
Vanessa Assumma	FRI-2-P2	Friday	13.00-14.40	PO 0.28
Yuji Sato	WED-3-P2	Wednesday	13.20-15.00	PO 0.28
Zulfi Nasution	TUE-2-P3	Tuesday	10.20-12.00	PO 0.41