28TH INTERNATIONAL CONFERENCE ON MULTIPLE CRITERIA DECISION MAKING

May 25 – 29

Mathematik
Fakultät für Mathematik
und Naturwissenschaften

BERGISCHE
UNIVERSITÄT
WUPPERTAL

	Monday	Tuesday	Wednesday	Thursday	Friday
8:00	Registration, Coffee, Meet and Greet	Registration	Registration	Registration	Registration
8:30					
9:00		Parallel Sessions *4 talks*	Parallel Sessions *4 talks*	Parallel Sessions *4 talks*	
9:30					Award Talks
10:00	Opening				
10:30	Plenary 1 *Salvatore Corrente*				
11:00		Coffee Break	Coffee Break	Coffee Break	Coffee Break
11:30	Parallel Sessions *3 talks*			Parallel Sessions *3 talks*	Award Talks
12:00		Plenary 2 *Andreia Guerreiro*	Plenary 3 *Manuel Bickel*		
12:30	Lunch	Lunch	Lunch	Lunch	Plenary 4 *Stefan Ruzika*
13:00					
13:30					Closing
14:00	Parallel Sessions *4 talks*	Group Photo	Doctoral Dissertation Award	Parallel Sessions *4 talks*	Lunch
14:30		Parallel Sessions *3 talks*			
15:00					
15:30	Coffee Break	Coffee Break	Coffee Break	Coffee Break	
16:00	Parallel Sessions *4 talks*	Parallel Sessions *4 talks*	Outing Intro.	Business Meeting	
16:30			Outing		
17:00					
17:30	Welcome Reception				
18:00					
18:30					
19:00				Conference Dinner *Wuppertaler Brauhaus*	
19:30					
20:00					
20:30					
21:00					

28th International Conference
on Multiple Criteria Decision Making

MCDM 2026: Program

Better Decisions for a Better Tomorrow

May 25–29, 2026
Wuppertal, Germany

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Welcome to MCDM 2026 in Wuppertal

Dear Participants,

it is my great pleasure, as President of the International Society on Multiple Criteria Decision Making (MCDM), together with the organizers Kathrin Klamroth and Michael Stiglmayr, to warmly welcome you to the 28th International Conference of our Society in Wuppertal (Wuppertal MCDM 2026 Conference).

Following the success of our 27th International Conference in Hammamet, Tunisia, it is wonderful to see our community gathering once again, this time in Wuppertal. Our conferences are much more than scientific meetings: they are opportunities to reconnect with colleagues and friends, to welcome new members into our community, and to strengthen the international and interdisciplinary spirit that has always shaped MCDM.

Over the years, our Society has grown into a truly global community, bringing together researchers, practitioners, students, and decision-makers from diverse backgrounds, disciplines, and cultures. This diversity is one of our greatest strengths. It is through the exchange of different perspectives, ideas, and experiences that our field continues to evolve and contribute to addressing increasingly complex societal challenges.

This year's conference theme, "Better Decisions for a Better World" perfectly reflects both the mission of our Society and the growing importance of MCDM in today's world. From sustainability and healthcare to transportation, logistics, energy, finance, and public policy, the methods and approaches developed within our community play an important role in supporting more informed, transparent, and responsible decisions.

The Wuppertal Conference provides an important forum to present new research, exchange ideas, foster collaborations, and inspire future work. I especially encourage students and first-time participants to engage actively in discussions and social activities, as many long-lasting friendships and scientific collaborations within our community began at previous MCDM conferences.

I would also like to express my sincere appreciation to the local organizing committee and all volunteers for their dedication, enthusiasm, and hard work in making this event possible.

I hope you will enjoy not only the scientific program, but also the social program, the discussions between sessions, and the opportunity to experience the welcoming atmosphere of Wuppertal and our MCDM community.

I wish you all a stimulating, productive, and memorable conference.

José Rui Figueira

President of the International Society on Multiple Criteria Decision Making
president@mcdmsociety.org

Dear Participants of MCDM 2026,

as the local organizers, it is our great pleasure to warmly welcome you to Wuppertal. We are honoured to be hosting the 28th edition of this conference series at our university!

Founded in 1972, the University of Wuppertal was established just three years before the first International Conference on MCDM, which was held in Jouy-en-Josas, France, in 1975.

The city of Wuppertal was formed in 1929 by merging the towns Barmen, Elberfeld, Cronenberg, Ronsdorf and Vohwinkel, all of which have much longer histories. Wuppertal is internationally known for its Skytrain, which came into operation in 1901; its zoo, founded in 1879; and the Wuppertal Institute for Climate, Environment and Energy, which began its research work in 1991. You will have the opportunity to experience all of these during our conference: As an efficient mode of public transport; as the destination of our excursion on Wednesday afternoon; and as a source of scientific inspiration during the plenary talk on Wednesday morning.

The University of Wuppertal is research-oriented and offers a wide range of subjects to over 20,000 students. Teaching and research are characterised by interdisciplinarity, team spirit and a capacity for innovation. These qualities also characterise the local organising team, who have devoted themselves to preparing a welcoming, open and inspiring environment. We would like to express our sincere gratitude to the local organising team and the program committee for making this conference possible! We acknowledge financial support from the University of Wuppertal, the European Working Group on Multiple Criteria Decision Aiding (EWG MCDA), the German Operations Research Society (GOR), and the German Research Foundation (DFG).

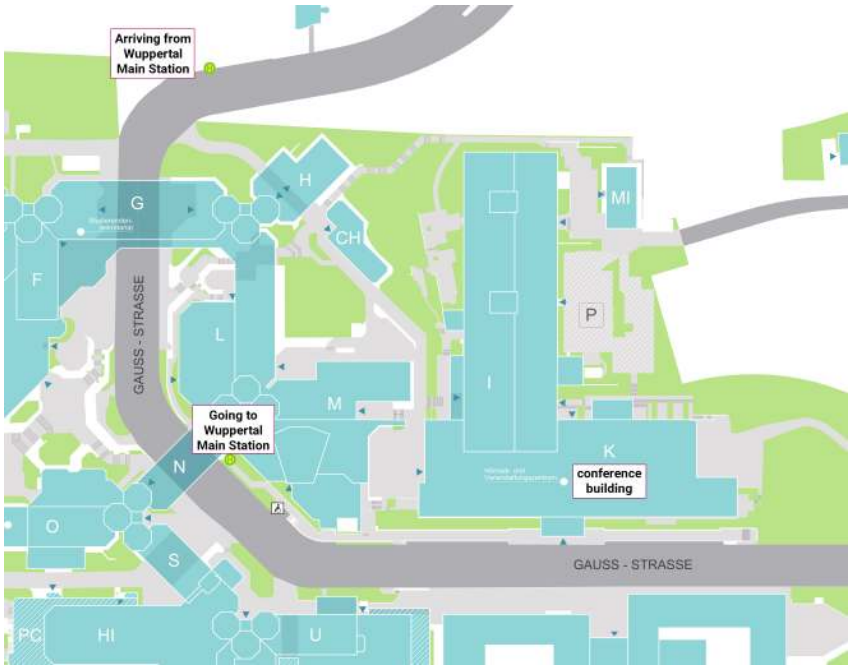
We wish you an enlighting, remarkable and enjoyable conference!

Kathrin Klamroth and Michael Stiglmayr

Chairs of MCDM 2026

Venue

All events, including the coffee break, lunch, and the Welcome Reception, will take place at the University of Wuppertal, Campus Grifflenberg (main campus), Building K (Gaußstraße 20, 42119 Wuppertal).



The university can be reached from Wuppertal Main Station either by a 30-minute walk uphill or by taking one of the following bus lines from bus platform 3 (marked on the map):

- 645 – Wuppertal Schulzentrum Süd
- 615 – Remscheid
- Uni-Express

Please get off at the stop “Universität”. From there, follow the signs to Building K.

About Wuppertal

With a population almost 360,000, Wuppertal is the largest city and the industrial, economic, educational, and cultural centre of the “Bergisches Land”, the region around Wuppertal, Solingen and Remscheid, in western Germany. The cityscape is distinguished by its Wilhelminian and Art Nouveau architecture, as well as its numerous staircases, some of which are vibrantly painted and add a unique charm to the urban landscape. Wuppertal is most famous for its unique public transportation system – the “Schwebebahn” – a 125 year old suspension railway line traversing Wuppertal from west to east. If you have some time to spare, exploring the city is highly recommended. Below you will find a selection of highlights and inviting places to linger.


Foto: Marius Becker


Foto: Malte Reiter


Foto: Medienzentrum der Stadt Wuppertal

Foto: Medienzentrum der Stadt Wuppertal


Foto: Simon Wierzba

Wuppertal also offers a wide range of excellent cafés, bars, and restaurants. Please scan the QR code on the right to access a map featuring the local committee's top recommendations. There you will also find a pub crawl route that starts at the university and ends in the popular bar district, the Luisenviertel. Enjoy your time exploring the city. If you have any questions, please do not hesitate to contact the local committee.

About the University of Wuppertal

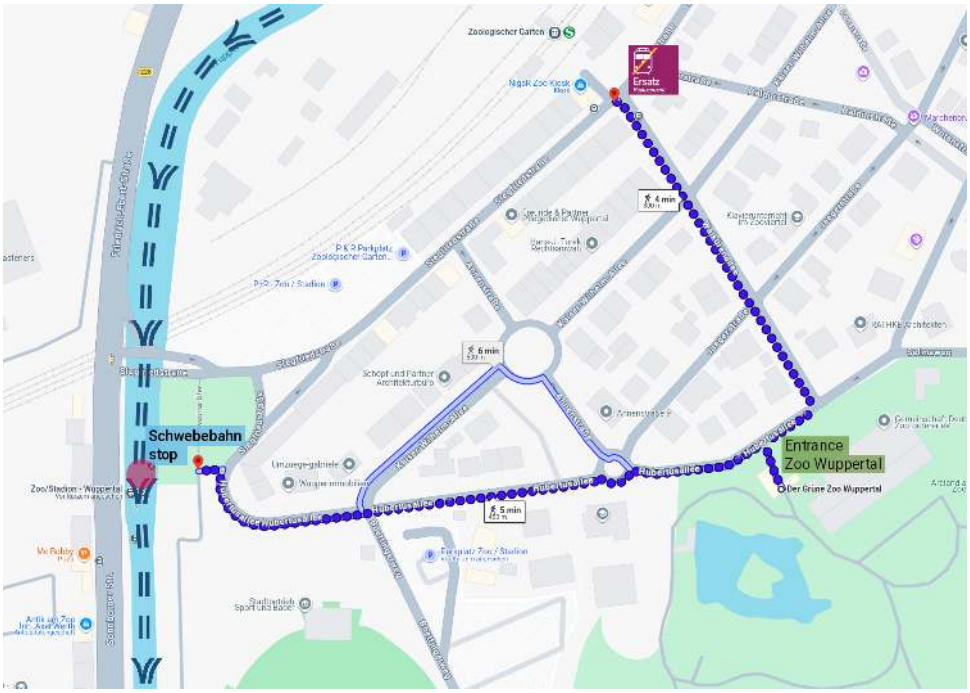
The University of Wuppertal was founded in 1972 as a comprehensive university, bringing together existing academic institutions in Wuppertal, such as engineering schools, the School of Applied Arts, and the College of Education. In 2003, it was reorganized into a university. The student body has grown from 3,473 in its inaugural semester to over 20,000 today. The university's academic programs focus on teacher education, economics, and a wide range of engineering and natural science programs. The humanities, as well as art and design, have also traditionally been strongly represented. Today, the University of Wuppertal offers 84 degree programs and awards approximately 3,139 degrees each year.

Social Program

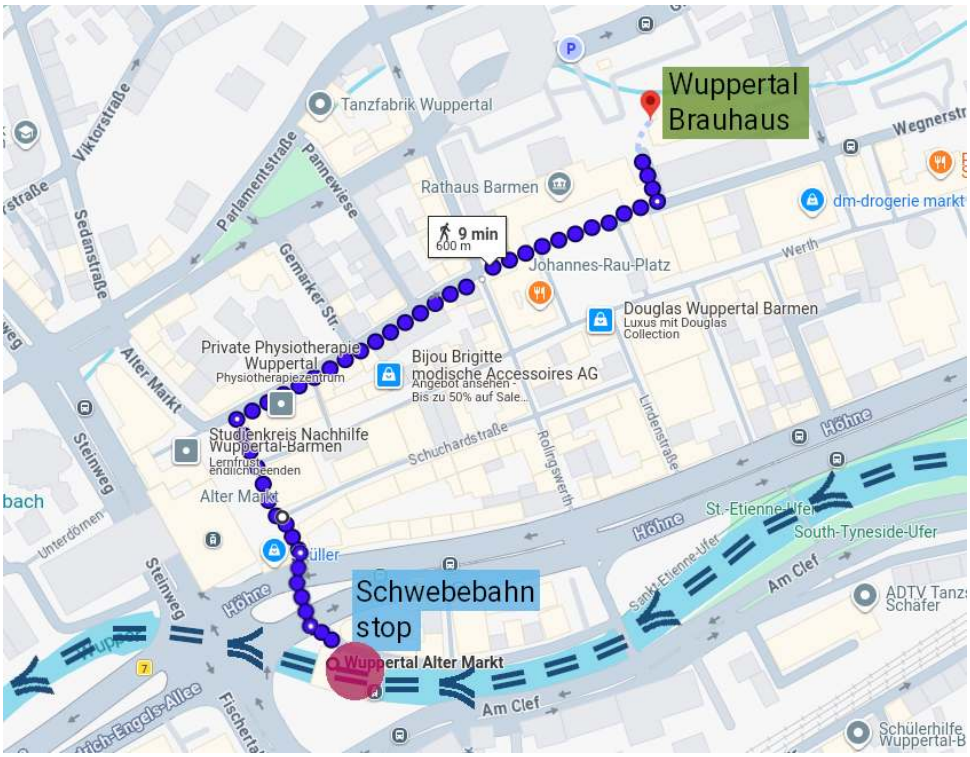
The Welcome Reception will be on campus behind Building K. It takes place on Monday after the parallel sessions starting from 17:30.

The group photo will be taken on Tuesday at 13:30 in the main lobby of Building K. All participants are kindly invited to join the group photo.

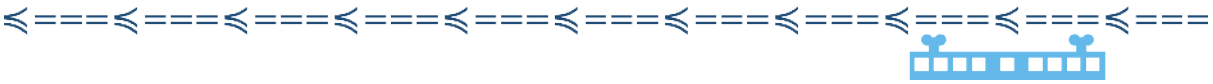
The Outing on Wednesday will start by an Introduction Talk at 15:45 in the Auditorium HS33. Afterwards, we will visit The Green Zoo Wuppertal. You are invited to attend one of the guided tours, after which a small reception will take place.
After the reception you can go back to the city center by either taking the Schwebebahn from the stop "Zoo/Stadion" (5 minutes walk downhill) or the SEV from the stop "Wuppertal Zoologischer Garten" (Schienenersatzverkehr, 4 minutes walk more or less flat).



The Conference Dinner will take place at Wuppertaler Brauhaus. You can go there by Schwebebahn getting off at the station “Alter Markt” and then walk there in nine minutes by taking a stroll through the city center of Wuppertal Barmen.



General Information



Local Organizing Committee

The local organizing committee consists of:

- Kathrin Klamroth (Conference Chair)
- Michael Stiglmayr (Conference Chair)
- Onur Tanil Doganay, Daniela Ebeling, Britta Efkes, Rabea Freese, Fabian Heldmann, Claudia Kamphausen,Renée Lamsfuß, Lara Löhken, Julia Sudhoff Santos, and Chiara Weuste (Local Organizing Team)
- Jakob Dühr, Imran Turan, Tabea Günther, Cansu Kilic, Leonie Walle, and Christina Spiegel (Student Team)

You can recognize us by the black T-shirts with green text “Wuppertal” or a green lion. Please feel free to contact us if you have any questions.

Registration and Conference Office

On Monday morning a large registration desk is located in the main lobby on the 11th floor in Building K Campus Grifflenberg. From Monday afternoon on you can register in the conference office in room K7 (next to the main lobby).

The opening hours of the registration desk are:

- Monday, May 25, from 8:30 to 18:00
- Tuesday, May 26, from 8:30 to 18:00
- Wednesday, May 27, from 8:30 to 16:00
- Thursday, May 28, from 8:30 to 16:00
- Friday, May 29, from 9:00 to 15:00

During that times you can also reach us by phone: +49-202-439 2624 and +49-202-439 3487.

Conference Badge

All participants will receive a badge upon registration at the registration desk and in advance via e-mail. This allows you to use the local transportation (within Wuppertal) between Sunday May, 24th and Saturday May, 30th. If you want to use local transportation before your registration, please make sure that you have a printed version with you. The badge includes your public transport ticket (valid only in combination with a personal ID) and gives you access to the conference dinner and all social activities. You are expected to wear your badge during all events of the conference.

Lunch and Coffee Breaks

Lunches are included in the registration fee from Monday to Friday. They will be served in the main lobby of building K. Moreover, coffee, tea and other snacks will be served there during the conference. Please refer to the program for the scheduled times for lunches and coffee breaks.

We are happy to inform you that this conference is the second conference at Wuppertal university where sustainable coffee mugs are used.
We would like to provide some information to you about the use of these cups:

- You are kindly requested to use your cup throughout the entire week.
- Please mark your cup by writing your name on a piece of tape that you put on the cup. Tape can be found at the registration desk.
- In the restroom of the conference building (K.11) you will find necessary supplies to clean your cup.
- In case you loose or forget your cup somewhere, there are good chances to retrieve it in the conference office (as we will be collecting lonely mugs).

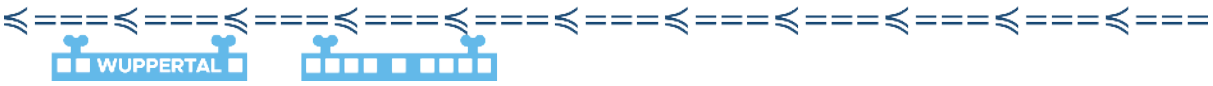
Thanks a lot for your help to avoid lots of waste!

Internet Access

You can connect to wireless internet via “eduroam” using your university credentials.

Meeting Rooms

On the 12th floor of building K are several meeting rooms at your disposal. Please contact the registration desk.



Scientific Committee

The scientific committee consist of

Fouad Ben Abdelaziz
Carlos Coello Coello
Matthias Ehrgott
José Rui Figueira
Salvatore Greco
Gülsah Karakaya
Birsen Karpak
Kathrin Klamroth
Murat Köksalan
Danielle Morais
Andrea Raith
Jafar Rezaei
Francisco Ruiz
Serpil Sayin
Johannes Siebert
Ralph E. Steuer
Michael Stiglmayr
Ilker Topcu

Session Instructions

Information for speakers

- Each contributed talk has a time slot of 25 minutes. Please make sure that you leave 5 minutes for discussion.
- Computers will be available in all lecture rooms (Windows operating system). There will also be black boards in all rooms.
- Please bring your slides on a USB stick, alternatively, you can also use your own device and connect it by HDMI or USB-C.

Information for session chairs

- Please ensure that your sessions start and end on time and that presentations are made in the order shown in the official program.
- In the case of last minute cancellations, please stick to the original program.

Advertising Special Sessions

All special sessions will be held in the Auditorium HS33. Besides the Opening (MA-01, 9:45-10:15) and Closing Session (FD-01, 13:15-13:45), there are four Plenary Talks, three Award Sessions and one exciting talk introducing the Outing on Wednesday.

Plenary Talks The following four distinguished speakers have agreed to give a plenary talk at MCDM 2026:

- Salvatore Corrente (MB-01, 10:15-11:15)
- Andreia Guerreiro (TB-01, 11:30-12:30)
- Manuel Bickel (WB-01, 11:30-12:30)
- Stefan Ruzika (FC-01, 12:15-13:15)

Doctoral Dissertation Award The MCDM Doctoral Dissertation Award recognizes outstanding doctoral dissertation research, completed on January 1, 2024 or later, in the development of theory, methodology, and/or the application of theory or methodology to MCDM. The final decision will be made after the talks of the finalists in the Docotral Dissertation Award Session on Wednesday (WC-01, 13:30-15:15). A warm welcome to everyone to support the young researchers by visiting this session. The finalists are:

- Grzegorz Miebs (Poznan University of Technology): Decision support methods resistant to imper fections of learning data
- Giovanni Misitano (University of Jyväskylä): Enhancing the decision-support capabilities of interactive multiobjective optimization with explainability
- Kathrin Prinz (RPTU in Kaiserslautern): Parallelization in Multi-Objective Optimization based on the Epsilon-Constraint Scalarization
- Yannik Nikolas Zeiträg (CEGIST, Instituto Superior Técnico): A Decision Support Tool for Multi-Objective Production Scheduling and Lot-sizing - Exact, Approximate, and Hybrid Algorithms

Society Awards The awardees of the Society Awards (MCDM Gold Medal, Edgeworth-Pareto Award, Georg Cantor Award) will be announced during the conference dinner on Thursday. Their talks are scheduled on Friday (FA-01, 9:30-11:00 and FB-01, 11:30-12:15).

Outing Introduction Talk The outing will start with a plenary talk by the director of the Wuppertal zoo, Dr. Arne Lawrenz, on “Research for Evidence-Based Decision-Making in Conservation – Examples of Research Conducted in Zoos”. He will give us an insight into the scientific projects and species conservation in the Green Zoo Wuppertal.

Monday, 9:45-10:15

■ MA-01

Monday, 9:45-10:15 - Room: Auditorium HS33

Opening Session

Stream: Plenary Sessions
Contributed session
Chair: *Kathrin Klamroth, Michael Stiglmayr*

Monday, 10:15-11:15

■ MB-01

Monday, 10:15-11:15 - Room: Auditorium HS33

Plenary: Salvatore Corrente

Stream: Plenary Sessions
Plenary session
Chair: *Roman Slowinski*

1 - Decision rules for Explainable Decision Aiding and Interactive Evolutionary Multiobjective Optimization
Salvatore Corrente

Dominance-based Rough Set Approach (DRSA) uses preference information provided by a user—such as classifications or comparisons of alternatives—to induce decision rules. These rules link the performance of alternatives on selected criteria with the user's expressed decisions. As a result, DRSA can both explain the user's preferences in simple, understandable terms and generate recommendations for alternatives that were not previously classified or compared.

DRSA has been applied in various contexts within Multiple Criteria Decision Aiding (MCDA). In this lecture, we focus on two recent applications of DRSA decision rules: (i) explaining composite indicators, and (ii) supporting Interactive Evolutionary Multiobjective Optimization (IEMO).

Composite indicators are widely used to aggregate multiple features into a single score, but their construction is often opaque, making it difficult to understand how the score is obtained. We show how DRSA can make composite indicators more transparent by generating interpretable decision rules and assigning interval-based scores to each unit. In the context of IEMO, DRSA decision rules are used to guide the search process of evolutionary algorithms toward the most promising regions of the Pareto front. Moreover, the rules help users understand how their preferences influence the distinction between good and bad solutions in the objective space.

Monday, 11:15-12:30

■ MC-02

Monday, 11:15-12:30 - Room: Senatssaal (K.11.07)

Recent Advances in Multi-objective Programming

Stream: Multi-objective Programming
Contributed session
Chair: *Ana Belen Ruiz*

1 - A fresh look at algorithms for solving smooth multiobjective optimization problems
Sorin-Mihai Grad, *Tibor Illés*, *Petra Renáta Rigó*

We propose a new approach for constructing practical algorithms for solving smooth multiobjective optimization problems based on determining decreasing directions via suitable linear programming problems. The presented iterative method is specialized for unconstrained, sign constrained and linearly constrained multiobjective optimization problems. In all cases, the objective function values sequence is decreasing with respect to the corresponding nonnegative orthant, and every accumulation point of the sequence generated by the algorithm is a substationary point to the considered multiobjective optimization problem, becoming, under convexity assumptions, a weakly Pareto efficient solution. Different to similar algorithms from the literature, the ones proposed in this work involve decreasing directions that are easily computable in polynomial time.

2 - Anytime Multicriteria Optimal Control with Persistent Trajectories
Andrzej M.J. Skulimowski

The goal of this paper is to extend the solution of multicriteria optimal control (MOC) problems with time constraints to situations in which the control agent can autonomously determine the termination of the control period, while preserving the control objectives even if the modeled process is still ongoing. An analogous idea has been developed in AI-related computational theory, where the anytime incremental computing is assumed to produce progressively improving results when interrupted. This idea cannot be directly extended to the optimal control of linear systems with a scalar criterion, where—by virtue of the bang-bang principle—the solution computed for a terminal time Tis generally non-optimal for earlier times t

3 - Multiple Reference Point Scalarization based on Relative and Absolute Assessments
Ana Belen Ruiz, *Francisco Ruiz*, *Mariano Luque*, *Elena Bárcena-Martín*, *Francisca García-Pardo*

When working with several variables with distinct units, they are usually scaled to a uniform range. This normalization facilitates their eventual integration into a unified metric, for example, when building composite indicators to synthesize several simple indicators. Commonly used normalizations involve distance-based frameworks, which are applicable when predefined reference levels are available and which allow defining different performance bands. In this context, the transformation is typically called an achievement scalarizing function. Current linear models for this function assess performance in absolute terms by measuring the direct distance to reference points. That is, this approach considers only the absolute distance of each unit's performance from the reference levels, overlooking how achievement is distributed across all observed entities. To address this, we introduce an innovative achievement scalarizing function based on reference levels that incorporates relative assessments. Our goal is to expand the utility of distance-based scalarizations for evaluating societal issues, where comparing an entity's performance against its peers is just as important as comparing it against the reference levels. Additionally, we present a hybrid framework that combines absolute and relative measures, accommodating variables that require both perspectives during the scaling process. Research supported by the projects PID2024-155360NB-I00 and PPRO-SEJ532-G-2023.

■ MC-04

Monday, 11:15-12:30 - Room: K6 (K.11.17)

Practical Applications: Enhancing Decision Robustness

Stream: Practical Applications of MCDM
Contributed session
Chair: *Birsen Karpak*

1 - One step further for better decisions in MCDM: A noise reduction framework proposal
Nurcan Deniz

Behavioral issues in decision making have begun to attract increasing attention in recent years. Particularly researchers in MCDM started to incorporate issues such as cognitive biases and effective debiasing strategies with MCDM techniques to get more accurate results. "Noise" is another factor revealed in 2021 causing decision errors in addition to "biases" and they are related with each other. "Noise" is about the undesirable variability about experts' decisions and can arise both individual level and across individuals. While bias can be seen and explained, noise cannot easily be seen and explained due to the unpredictable nature. System noise can be categorized as level noise and pattern noise. Furthermore, pattern noise can be divided into stable pattern noise and occasion noise. There is a scarce literature on noise-reduction/(de)noise/noise-free/decision hygiene strategies. All types of noise handled in the proposed framework to close the gap. The applicability of the proposed framework is shown through a problem and there will be a comparison between noisy and noise-reduced framework. To the best of the author's knowledge, this framework is a novel approach to handle noises in MCDM studies. Decision makers will get the opportunity to take more accurate and high-quality decisions by including this framework with MCDM techniques. In addition, the results of the study will open a new door for the researchers who wants to broaden MCDM area. This work was supported by TÜBITAK 2224-A Grant Program for Participation in Scientific Meetings Abroad

2 - Benefit-Cost Framework for Banking Efficiency Analysis: A Stakeholder Approach
Jian-Bo Yang, *Alexander Ntiri-Ampomah*, *Dong-Ling Xu*

Efficiency assessments in banking have been dominated by the DEA method with a strong emphasis on optimising weighted input-output ratios.Although effective, this approach has long faced criticism for its rigidity, sensitivity to modelling assumptions, and limited capacity to reflect the priorities of real decision-makers.This study introduces a stakeholder-oriented benefit-cost framework that repositions banking efficiency analysis within a broader decision-science perspective, explicitly drawing on principles from MCDM. Guided by the COREQ framework, the study draws on semi-structured interviews with 50 senior decision-makers across Ghana's banking sector and 8 senior managers in the UK banking sector. Participants identified a persistent gap between existing performance assessment methods and the realities of managerial decision-making, citing subjectivity, ambiguity, and poor alignment with strategic priorities.The study proposes a cost/benefit framework and illustrates how it can integrate financial, operational, and qualitative performance dimensions in a more intuitive way for practitioners. The resulting framework categorises key banking variables into benefits and costs and aligns them with stakeholder expectations, providing a more inclusive and adaptable basis for efficiency assessment by integrating production theory with MCDM principles.

3 - Unlocking the Decision Power of Digital Product Passports: A MCDA Framework for Industrial Systems
Federica Tomelleri, *Matteo Brunelli*, *Alice Mondello*, *Franco Donati*, *Marco Cinelli*

The European Union is promoting Digital Product Passports (DPPs) under the Ecodesign for Sustainable Products Regulation to enhance traceability, sustainability, and circularity across value chains. Although many ongoing initiatives focus on data infrastructure and indicator development, the decision-support potential of DPPs remains largely unexplored. To address this gap, a flexible Decision Support System (DSS)—capable of accommodating different user needs, access rights, and decision contexts—could substantially increase the practical value of DPP data. Accordingly, this research aims to (i) identify and map DPP data elements that can serve as criteria in Multiple Criteria Decision Analysis (MCDA); and (ii) propose the design of a modular, user-sensitive DSS that integrates these heterogeneous criteria. Using a specific DPP ontology as a reference structure, we contextualise the workflow in an industrial scenario by demonstrating how DPP-derived criteria can be operationalised into a MCDA decision matrix to guide the selection of optimal materials for laser welding operations. This targeted application illustrates the general utility of the framework and its adaptability to different decision logics and process parameters. The resulting conceptual DSS is intended to support manufacturers, regulators, and customers in selecting products or services that best meet their requirements.

■ MC-05

Monday, 11:15-12:30 - Room: K5 (K.11.20)

Ordinal Optimization 1

Stream: Invited Sessions
Invited session
Chair: *Thibaut Lust, Julia Sudhoff*

1 - Axiomatic Foundations and Algorithmic Approaches for Ordinal Optimization
Philipp Herrmann, *Kathrin Klamroth*, *Stefan Ruzika*, *Michael Stiglmayr*, *Julia Sudhoff*

Ordinal optimization deals with problems where the objective takes values based on an ordinal ranking of categories rather than numerical values. The value of a solution is then described by a counting vector recording how many elements belong to each category. Comparing such vectors requires a dominance relation, but this choice is not unique: several alternatives have been proposed in the literature. We take an axiomatic approach and identify six properties any reasonable ordering should satisfy, among them compatibility with addition and multiplication, transitivity, and consistency with the category ranking.

It is well known that partial orders and convex cones are closely related. Building on this, we show that each axiom corresponds to a geometric property of the induced ordering cone. When the cone is polyhedral, the axioms are equivalent to the halfspace matrix having full rank, non-negative entries, and non-decreasing rows. The so-called tail-cone turns out to be the smallest ordering cone satisfying all six axioms.

To solve ordinal problems in practice, we compare two exact algorithms on two combinatorial problems. One transforms into a multiobjective problem with the Pareto cone via the halfspace matrix; the other solves a reduced problem over a largest inscribed simplicial sub-cone and filters the result. Both are evaluated in a computational study with several thousand instances, varying the number of categories and cone geometry.

2 - Representations for Multi-Objective Optimization Problems with General Dominance Cones on the Example of Ordinal Optimization Problems
Chiara Weuste, *Michael Stiglmayr*

In this talk, we discuss different representations for ordinal optimization problems (OOPs). When solving OOPs, typically even a small number of categories already generates a large number of non-dominated solutions. To provide the decision maker with a manageable set of alternatives, we are interested in identifying a representative subset. We consider cardinality, coverage, and uniformity as the main quality indicators for representations. Several approaches have been proposed to measure the latter two indicators in the context of multi-objective optimization. We discuss to what extent these approaches can be transferred to OOPs and whether they can be computed using the existing methods developed for representation problems in multi-objective optimization.

Our focus lies on dominance-based and distance-based representation measures. Dominance-based measures rely on the idea of attenuating dominance, or equivalently, enlarging the dominance cone. For distance-based measures, the choice of distance metric can influence both the resulting representation and its interpretation in the given context. Our goal is to provide an overview of the different representation approaches and to discuss their respective advantages and limitations.

The ideas presented in this talk can also be applied to multi-objective optimization problems with general dominance cones, thereby providing approaches with a wide range of potential applications.

3 - Ordinal Optimization with Additional Preference Information
Julia Sudhoff, *Kathrin Klamroth*, *Michael Stiglmayr*

Ordinal costs, i.e. ordered categories, are used whenever values are sortable but non-additive. A typical application is the evaluation of the safety of a path, where each street segment can be assigned to one of the categories, safe, medium safe or unsafe. Problems with ordinal costs can be reformulated into multi-objective problems. The resulting set of ordinally optimal solutions is in general very large and may contain not desirable solutions, like overly long or overly unsafe solutions.

To reduce the set of efficient solutions to the practically important ones, we add preference information to model marginal trade-offs. These preferences describe the relation of two consecutive categories. We show that this preference information leads to a new polyhedral ordering cone. Thus, the non-dominated set can still be computed by a transformation into a higher dimensional multi-objective optimization problem. We verify the usefulness of this approach by a small case study on safe bicycle paths in Wuppertal.

■ MC-06

Monday, 11:15-12:30 - Room: Lecture Hall HS 32

AHP/ANP: Risk Assessment and Disaster Management

Stream: Decision Analysis/Making
Contributed session
Chair: *Marcel Minutolo*

1 - Dynamic Multi-Criteria Prioritization of Post-Earthquake Sites Using AHP and TOPSIS
Yasemin Baş Cengiz, *Y. Ilker Topcu*

Post-earthquake environments are characterized by high uncertainty and chaotic information flow, challenging the effective and timely allocation of emergency response teams. Decision-makers must evaluate incoming damage reports based on multiple criteria to determine which sites require immediate intervention, forming a Multi-Criteria Decision-Making (MCDM) problem. This study proposes a dynamic prioritization framework that integrates literature review and expert input from search and rescue volunteers to define critical criteria. Criteria weights are systematically determined using the Analytic Hierarchy Process (AHP), emphasizing its central role in structured, evidence-based decision-making. To account for temporal variations, the model is applied across different times of day and weekdays, generating separate priority rankings for each scenario. Subsequently, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is employed to produce actionable rankings reflecting both spatial and temporal variations in potential casualties. The proposed framework enables data-driven, context-sensitive prioritization, supporting rapid decision-making and efficient allocation of resources in post-earthquake search and rescue operations.

2 - Prioritization Of Flood Risk Mitigation Strategies: The Case Of The Veneto Region
Chiara D'Alpaos, *Tommaso Lazzarin*

We present an application of the Analytic Hierarchy Process (AHP) for the priority ranking of flood risk mitigation strategies in the Veneto Region, Italy. The proposed AHP model is developed in collaboration with the local regional authority, and it provides an application-driven methodological framework to support policy-makers and professionals working for the local regional authority, who are subject to stringent budget constraints, in the prioritization of interventions at their feasibility study stage. The evaluation and ranking of alternative risk mitigation strategies is based on three groups of criteria: economic impact of the flooding in the area under investigation, environmental characteristics of the area, and effectiveness in risk reduction. In detail, by combining group decision-making and Value Focused Thinking approaches, we provide an AHP model to identify which interventions are top-priority policy targets according to a cost-effective perspective. To structure the decision problem, we conducted an extensive literature review and interviewed policy-makers and professionals from the local regional authority by implementing, at the beginning, a Delphi survey process, and subsequently organizing brainstorming sessions. The methodology can be applied across a wide range of interventions and allows the public authority to prioritize systematically and transparently flood risk mitigation projects.

3 - How safe is your school?
Marcel Minutolo, *Luis Vargas*, *Amos Guiora*, *Madhury Ray*

School violence - any violence that occurs in and around a school setting - affects a whole community, including not only schoolchildren, but also parents and caregivers, teachers, and school staff. Consequences of school violence extend beyond physical trauma to include absenteeism and disrupted learning, mental health trauma, teacher turnover, and parental distress, among other effects. School safety is more than just statistics. For a school to be safe, it must be perceived as safe not just by students, but by a whole school community, including parents and caregivers, teachers, and the school administration, each of whom may have different understandings of what safety means. A successful measure of school safety incorporates these often-conflicting voices in a way that is generalizable to schools in different settings and resource environments. Emergency preparedness has tackled similar problems. It is hard to reflect disaster risk accurately with statistics of past events, and the community impacted by disasters is diverse. School safety can be framed similarly using the construct of hazard risk, as a set of different hazards (e.g. cyber-bullying, school shootings, sexual assault), each associated with its own perceived risk of violence which a school aims to minimize. Instead of describing school safety as an objective fact, it can then be approached as a consensus decision. We illustrate our approach with a realistic example.

Monday, 13:30-15:15

■ MD-02

Monday, 13:30-15:15 - Room: Senatssaal (K.11.07)

Dealing with high dimensional Multiobjective Optimization Models

Stream: Multi-objective Programming
Contributed session
Chair: *Serpil Sayin*

1 - The Pareto Tracer for the Numerical Treatment of High-dimensional Multi-objective Optimization Problems
Pablo Uriel Benítez Ramírez, *Oliver Fernando Cuate González*, *Oliver Schütze*, *Carlos Ignacio Hernández Castellanos*

In many applications, the problem arises that several objectives have to be optimized concurrently. An important characteristic of such multi-objective optimization problems (MOPs) is that their solution sets typically form objects of a k-1 dimensions. Multi-objective continuation methods make use of this observation to move along the Pareto front, given an initial point. However, they are usually restricted to up to thousands of decision variables.

In this work, we will present an adaptation of the Pareto Tracer to efficiently treat high-dimensional MOPs. Mainly, we discuss how to use a truncated SVD decomposition of the Jacobian to compute a direction in decision space along the Pareto set. The resulting predictor-corrector method is Hessian-free and is applicable to problems in high-dimensional decision space. We will present numerical results on bi-objective MOPs with up to two million decision variables with different Pareto front geometries, providing a comparison with the state-of-the-art algorithms.

2 - Dimensionality Reduction Techniques as a Preprocessing Tool: Application to a Portfolio Optimization Problem with Sustainability Objectives
Serpil Sayin, *Gökhan Kof*

The number of objective functions is one of the key determinants of the computational effort required for solving a multiobjective optimization (MOO) problem. In a recent study, alternative ways of building linear transformations of a MOO problem that include a smaller number of objective functions than the original one have been proposed. The empirical assessment of the efficient sets of the transformed problem as a representation of the original one on stylized test library instances have indicated the viability of such approaches in the domain of discrete optimization problems. In this study, we investigate the dimensionality reduction techniques in an application domain in which the results can be interpreted from a decision making perspective. Based on recent studies in the literature, we formulate a portfolio optimization problem that involves sustainability objectives in addition to the financial objectives of return and risk. We propose applying the dimensionality reduction techniques to the model as a preprocessing tool, avoiding an a priori selection of the indicators. We envision that such an approach can contribute to building insights towards the interplay among the objective functions that are included in the model. We put the proposed idea to test on a data set associated with a previous study in the literature and report our observations.

3 - A Data-Driven Framework based on Dimensionality Reduction for Multiobjective Optimization
Tamey Eksi, *Serpil Sayin*

Mathematical programming models are widely used as decision making tools in many domains. Many real-world problems involve multiple objectives, known as multiobjective optimization (MOO) problems. In MOO, multiple objective functions are optimized simultaneously, leading to trade-offs due to conflicts. As the number of objectives increases, the nondominated set grows, creating computational challenges for traditional methods. We propose a data-driven framework in which lower-dimensional versions of the original problem are solved repeatedly, resembling a learning task. The framework is based on Principal Component Analysis. To preserve Pareto dominance, non-negativity of the transformation is enforced using Nonnegative Singular Value Decomposition (NNSVD). The iterative scheme begins by generating an initial set of nondominated points to form a data matrix. Initialization relies on reduction methods that remove objectives through a generalized redundancy framework based on algebraic dependencies. NNSVD is applied to the data matrix to identify dominant directions and obtain loadings that define a reduced problem. This problem is solved partially, and the data matrix is updated in subsequent iterations. This allows the reduction to adapt dynamically to the evolving geometry of the nondominated set. Results show that the proposed framework improves exploration and representation of the objective space compared to static strategies, particularly with diversified initialization.

■ MD-03

Monday, 13:30-15:15 - Room: K8 (K.11.10)

PROMETHEE

Stream: Decision Analysis/Making
Contributed session
Chair: *Boris Coquelet*

1 - A Fuzzy PROMETHEE-Based Framework for Ranking Intelligent Logistics Systems in Uncertain Environments
Vikesh Bhardwaj

Rapid advances in digital technologies are transforming logistics and supply chain systems, creating new opportunities for efficiency, coordination, and sustainability. However, selecting an appropriate logistics configuration remains challenging, as decision makers must evaluate multiple and often conflicting criteria under uncertainty.

This study aims to compare and rank alternative logistics systems to identify the most effective approach for modern supply chain environments. Four alternatives—traditional logistics, smart warehousing, semi-automated supply chains, and systems enabled by artificial intelligence and the Physical Internet—are assessed based on system interoperability, real-time information availability, cost efficiency, and environmental sustainability.

A multi-criteria decision-making framework is applied, incorporating expert judgments expressed through linguistic evaluations to address uncertainty in the assessment process. The analysis provides a structured ranking of the alternatives and highlights clear performance differences among them.

The results indicate that AI-enabled and highly integrated logistics systems outperform conventional approaches, particularly in terms of responsiveness, coordination, and sustainability. The study offers practical insights for decision makers and contributes to ongoing discussions on the adoption of intelligent logistics solutions in complex supply chain contexts.

2 - Rank reversal in the PROMETHEE methods: what do we know?
Yves De Smet

Being based on pairwise comparisons, the PROMETHEE methods are subject to the phenomenon of dependence to third alternatives. Beyond the philosophical debate on the legitimacy of such an effect, researchers have begun to study the theoretical conditions that could limit or prevent it. This led to the identification of various theoretical bounds based on differences of net flows (above which rank reversal is impossible). A corollary of this observation is that potential reversals can only occur when net flows are close, which raises questions about the nature of the indifference relation as defined in PROMETHEE. The objective of this presentation is to summarize the different contributions in order to provide a global perspective on the topic.

3 - A novel approach for ranking analysis in PROMETHEE methods
Alexandre Flachs, *Yves De Smet*

PROMETHEE is a prominent family of outranking methods for multicriteria decision making. It is based on the aggregation of pairwise preferences into positive, negative and net flow scores to produce respectively a partial and a complete ranking. These rankings depend on several (inter and intra criterion) parameters defined by the decision maker (DM) which, in practice, can be sometimes difficult to evaluate with precision. Therefore, several sensitivity analysis methods have been developed to evaluate how small perturbations of those might affect the outcome. In this presentation, we first review these contributions.

From another perspective, one could study which rankings can or must be obtained given the right instance of parameters, as developed by Kadziński, Greco and Słowiński (to extend the principle of robust ordinal regression for example). In this context, we introduce a novel formulation of PROMETHEE II based on mixed-integer linear programming which allows the study of such questions, with an emphasis on the following attainability question: given only performances of alternatives and no preference information, can a specified alternative be ranked first ? The formulation is modular by design, allowing the DM to specify some partial preference information if desired by adding constraints to the linear program. The proposed approach is illustrated on a pedagogical example.

4 - A Linear Algebra View of PROMETHEE II
Boris Coquelet

PROMETHEE is a well-known multicriteria outranking method. It has been applied across many fields, including (but not limited to) computer science, environmental management, finance and health care. These approaches typically involve two steps: first, computing pairwise preferences from an evaluation table. Then, flow scores computed from these pairwise preferences are used to generate partial or complete rankings of the alternatives.

Researchers have recently investigated the properties of net flow scores (the specific flow scores used in PROMETHEE II) to characterise or justify the obtained rankings. Particular attention was also paid to the phenomenon of rank reversal, with, again, mostly studies focusing on its relation to net flow scores.

In this contribution, we present a novel interpretation of the PROMETHEE II method. Indeed, the step from pairwise preferences to net flow scores can be viewed as a linear application. Then, using this interpretation and linear algebra, a series of new properties can be defined for PROMETHEE II. Furthermore, in contrast to previous studies on rank reversal, using the kernel, the linear application, and the pairwise preferences, we aim to better characterise the phenomenon of rank reversal in PROMETHEE II (beyond the interpretation exclusively based on net flow scores).

■ MD-04

Monday, 13:30-15:15 - Room: K6 (K.11.17)

Practical Applications: Energy Systems and Strategic Planning

Stream: Practical Applications of MCDM
Contributed session
Chair: *Enea Zeolla*

1 - Exclusive-Or Multiple-Criteria Data Envelopment Analysis: Application to Renewable Energy
Noureddine Kouaissah, *Tareq Ait Hsain*

This paper develops Exclusive-Or Multiple Criteria Data Envelopment Analysis (XOR-MCDEA), a novel approach for investigating the impact of XOR uncertainty on MCDEA models. We particularly focus on how XOR logic affects two major issues in DEA: discriminatory power and weight dispersion. We extend existing MCDEA models to accommodate XOR-type data, which represent mutually exclusive input/output scenarios, and propose methods for determining optimal model parameters. The usefulness of the proposed methods relative to the standard MCDEA is demonstrated through an illustrative example from the MCDEA literature. Moreover, a case study on renewable energy projects is presented as an illustrative application that demonstrates the effectiveness of the proposed approach in addressing technological uncertainties while preserving the advantages of multi criteria evaluation. The results indicate that the proposed XOR-MCDEA significantly enhances the robustness of efficiency scores and meaningfully discriminates among decision-making units, thereby contributing to the broader field of uncertainty modeling in DEA.

2 - Evaluation of decentralized energy systems using a multi-criteria evidential reasoning approach
Ting Wu

Decentralized energy, as a vital and complementary pathway toward achieving a sustainable future, enables the effective use of renewable energy resources such as small-scale hydro, solar, wind, biomass, biogas and geothermal power. Despite its importance,

the performance and broader impacts of decentralized energy systems have not yet been examined systematically in literature. Evaluating these systems requires a structured and consistent way to handle a wide range of technical, economic, social and environmental factors. This inherently constitutes a multiple criteria decision analysis (MCDA) problem, requiring the evaluation of various quantitative and qualitative factors under uncertainty, drawing on both numerical data and expert judgement. Building on a review of the concepts, current developments, emerging trends, benefits and challenges of decentralized energy, this research develops a multi criteria performance modelling and decision analysis framework for multi vector decentralized energy systems. The evidential reasoning (ER) approach is employed to represent and aggregate various performance factors in either quantitative or qualitative nature under uncertainty. The resulting framework can be used to support a range of stakeholders, including policy makers, energy suppliers, consumers and investors in making informed and insightful performance assessments and decisions related to decentralized energy system development.

3 - The Use of the SRF Method in Energy-Related MCDA: A Review of Applications, Criteria, and Methodological Trends
Enea Zeolla, *River Huang*, *Milosz Kadzinski*, *José Rui Figueira*, *Salvatore Corrente*, *Eleftherios Siskos*, *Peter Burgherr*

The SRF method is an intuitive and interactive technique in Multi-Criteria Decision Analysis (MCDA) used to determine the weights of evaluation criteria based on the decision maker's preferences. It has been widely applied in energy planning and transition problems, where decisions must balance technical feasibility, economic performance, environmental impacts, and social acceptance when selecting among renewable and low-carbon technologies.

This review examines how SRF has been used in energy-related applications, including renewable energy technologies, building and urban retrofits, solar photovoltaic integration, energy policy, and fossil-fuel-related planning. The analysis shows that energy applications are methodologically more consistent than the broader SRF literature, with most studies combining SRF with an outranking MCDA method, especially PROMETHEE II and ELECTRE III. At the same time, the original SRF method remains dominant, while more robust variants are rarely adopted.

The review also highlights the main dimensions driving energy decisions, with frequent emphasis on Total Costs, Visual Impact, Employment, and CO2 emissions. Overall, the findings suggest that SRF remains attractive in the energy sector because of its simplicity and intuitive elicitation process, while the limited uptake of improved variants points to a gap between methodological development and practical application.

4 - Energy Efficiency Signals and Housing Markets: Evidence for Policy-Oriented Decision Analytics
Rubina Canesi, *Marina Bertolini*, *Luca Doretti*, *Duccio Gamannossi*, *Giovanni Luzzatto*, *Giuliano Marella*

Improving the energy performance of residential buildings is a central objective of European climate policy. However, the effectiveness of these policies partly depends on whether housing markets recognize and internalize energy efficiency in property values. When energy performance is capitalized into prices, market signals may reinforce policy goals by encouraging private investment in building retrofits. Yet empirical evidence shows considerable variation in the magnitude of these "green premiums" across local markets, raising questions for policy design and decision-making. This study examines how energy efficiency is reflected in residential property prices across seven urban housing markets in the Veneto region (Italy), operating under a common regulatory framework for Energy Performance Certificates (EPCs). The analysis relies on a dataset of residential listings collected in 2026 and applies spatially informed hedonic pricing models to estimate city-specific premiums associated with higher energy classes. A second analytical stage explores whether differences across cities relate to municipal socio-economic, demographic, climatic, and housing-market characteristics. Results indicate that highly efficient dwellings command higher prices, while intermediate energy classes show weaker and less consistent effects. These findings provide insights for the design of renovation incentives and urban energy policies.

■ MD-05

Monday, 13:30-15:15 - Room: K5 (K.11.20)

Ordinal Optimization 2

Stream: Invited Sessions
Invited session
Chair: *Thibaut Lust, Julia Sudhoff*

1 - Solution methods for the biobjective unconstrained combinatorial optimization problem with an ordinal objective function
Baris Kaftancioglu, *Thibaut Lust*, *Olivier Spanjaard*

This communication deals with the Biobjective Unconstrained Combinatorial Optimization (BUCO) problem (see e.g., Schulze et al., Journal of Global Optimization 74(3), pp. 495–522, 2019). The BUCO problem can be viewed as a variant of the knapsack problem where the capacity constraint is converted into an objective function: a solution is non-dominated if there does not exist another feasible solution for which the profit is greater and the weight is smaller, with one of the inequalities being strict.

We consider here a variant of the BUCO problem where the profit function is of ordinal type, i.e., there is a set of ordered categories for the profits, and each item belongs to a category. Subsets of items are compared by using the ordinal dominance relation, which states that a subset A of items is preferred to a subset B if the profit of A is greater than or equal to the profit of B for all possible assignments of values to the categories that are compatible with the order on the categories. The aim of the problem is to determine all ordinally non-dominated solutions.

If there are K categories, the problem can be reformulated as a multi-objective optimization problem with K+1 objectives. We will present three exact solution methods based on this reformulation, for which we will compare the results of numerical tests.

2 - From Finding Safe Routes for Children to School to Solving High Dimensional Ordinal Optimization Problems
Rabea Freese, *Kathrin Klamroth*, *Michael Stiglmayr*, *Julia Sudhoff*, *Chiara Weuste*

A parent's decision on which route they send their child to school can significantly differ from what an "optimal" shortest path looks like. In this application in addition to minimizing the distance one might want to consider the child's safety as an additional factor.

Thus, we study an optimization approach using an ordinal cost function measuring the safety of paths on street networks in order to provide consumers with more suitable solutions. These problems are transformed into multi-objective shortest path problems which can be solved using the multiobjective Dijkstra algorithm. However, since pedestrians only accept very minor detours and prefer e.g. routes with fewer turns, in practice we need a very specific subset of the resulting Pareto-front. To compensate for that we develop a solution strategy using Yen's k-shortest path algorithm and pair it with different filtering steps to obtain a set of solutions optimal in the original instance. These are specifically tailored to footpath routing without having to solve a very high-dimensional optimization problem and without having too many solutions to choose from.

3 - Preference Quantification based on Ordinal Pairwise Comparisons
Alexander Engau

We consider the problem to measure the strength or relative preference of each element in a finite set of decision alternatives based on a typically inconsistent and incomplete multiset of possibly repeated pairwise comparisons among them. For illustration, we will begin to discuss the following examples:

1) A > B, B > A 2) A > B, A = B 3) A > B, B > A, A = B 4) A > B, A = B, A = B 5) A > B, A > B, B > A 6) A > B, A > B, A = B

It is not difficult to expect that in each of these cases, A should always be valued, or ordinally equivalently, ranked higher or at least equal to B. The interested reader of this abstract who also plans to attend its presentation may already think whether they should also be equivalent quantitatively (especially 1/3, 4/5). The methods and results that we will then present are based on a simple but original multicriteria goal program with a linear or quadratic achievement function. In particular, the solution for any scenario with only two alternatives can be derived analytically for a few interesting initial observations.

The rest of the talk will further contrast related prior work on priority ranking, consensus formation or ordinal preference aggregation that also combine individual rankings or personal preferences into a single consensus ranking or compromise choice. The similarities and differences to these other methods (including AHP, OPA, BKM) will be highlighted and discussed in the context of realistic applications in practice.

■ MD-06

Monday, 13:30-15:15 - Room: Lecture Hall HS 32

AHP/ANP: Theory

Stream: Decision Analysis/Making
Contributed session
Chair: *Petra Grošelj*

1 - Incomplete pairwise comparisons method with the reference values
Konrad Kułakowski, Anna Kędzior, Jacek Szybowski, Jiri Mazurek

This study presents two quantitative approaches for determining weight vectors from incomplete pairwise comparison matrices using reference alternatives. The proposed procedures extend the arithmetic and geometric variants of the heuristic rating evaluation (HRE) method. They allow for flexible selection of both the number of reference alternatives and the range of pairwise comparisons, from the minimum required set to the complete set. In this paper, we show that the proposed geometric HRE method for incomplete data is optimal and demonstrate the existence of a feasible solution. In addition, we provide sufficient conditions guaranteeing the existence of a solution for the arithmetic variant of the HRE method. We illustrate the effectiveness of the proposed methods with numerical examples.

2 - Linear-fractional programming model for reducing inconsistency of pairwise comparison matrices
Anett Rácz

I proposed a mixed-integer linear-fractional programming model for reducing the inconsistency of pairwise comparison matrices (PCMs). The model explicitly captures the trade-off between minimal perturbation and consistency requirements and aims to determine the smallest possible modification of an original PCM that ensures an acceptable level of consistency while preserving the decision maker's preferences as much as possible. Furthermore, I derived a linear analogue of the fractional model, which provides a computationally more tractable alternative while maintaining its essential properties. In this presentation, I present the theoretical properties of the proposed models and discuss the results obtained during the study. I demonstrate their applicability through illustrative examples and show how the models can systematically improve consistency in a controlled and transparent manner. I also present the results of computational experiments and simulation tests that support the practical applicability of the proposed approach.

3 - Beyond Triangular Fuzzy Numbers: U-Numbers for Multiplicative Preference Modelling in AHP
Petra Grošelj

Triangular fuzzy numbers (TFNs) are widely used to represent uncertainty in AHP, but their structure is not fully compatible with multiplicative preference relations. TFNs used in AHP are additively symmetric around the middle value, while pairwise comparisons are defined on a multiplicative scale. As a result, TFN and its reciprocal do not exhibit the same uncertainty. Furthermore, fuzzy AHP relies on a predefined TFN scale that assigns fixed uncertainty levels to all experts, regardless of their actual reliability. Z-numbers, which incorporate reliability, translate the preference values instead of widening the uncertainty interval, which may not reflect the intended reliability in expert judgments.

To address these limitations, we introduce U-numbers, a new representation for uncertain multiplicative comparisons. A U-number is defined as U(a,r)=(a/r,a,ar) where a>0 is crisp value from the 1-9 scale, representing the most probable preference, and the reliability factor r>=1 represents the expert's self-confidence. This formulation ensures multiplicative symmetry and compatibility with multiplicative preference relations used in AHP. The reliability factor controls the relative width of the uncertainty interval, allowing experts

to express different confidence levels while preserving reciprocity and proportional uncertainty across the scale.

A numerical example illustrates U-AHP and demonstrates transparent modeling of uncertainty in multiplicative decision frameworks

Monday, 15:45-17:30

■ ME-02

Monday, 15:45-17:30 - Room: Senatssaal (K.11.07)

Expensive Multiobjective Optimization problems

Stream: Multi-objective Programming
Contributed session
Chair: *Jonas Hürter*

1 - A two-stage hybrid combining exact and metaheuristic methods for large-scale bi-objective MIP problems
Janusz Miroforidis

Many decision problems are modeled as bi-objective mixed-integer programming (MIP) problems. In practical decision-making, instances of these problems are often large-scale in the sense that obtaining, within a reasonable time limit, a useful representation of the entire Pareto front using scalarization techniques is problematic even for contemporary optimization packages that implement exact methods. Naturally, it is possible to approximate the Pareto front using metaheuristics, for example, evolutionary multi-objective optimization algorithms. However, these methods have the drawback that the quality of the approximation can be assessed only for test instances for which the Pareto fronts are known. I propose a two-stage hybrid approach that combines exact methods with metaheuristics and, within a given computational budget, computes an approximation of the Pareto front, using the optimality gap from the exact solver to evaluate the quality of that approximation. I illustrate the performance of this hybrid on large-scale instances of selected MIP problems and show how its output can be employed in decision-making in the so-called offline process.

2 - Dichotomic Search for Expensive Multiobjective Optimization Problems
Fabian Heldmann, *Kathrin Klamroth*, *Anthony Przybylski*

We study dichotomic search (DS) as an efficient framework for multiobjective optimization based on adaptive weighted-sum scalarizations. Starting from extreme supported solutions, DS generates new weights from normals of adjacent faces of the upper image, thereby enumerating supported nondominated extreme points. While well understood in the bi-objective case, extending DS to higher dimensions and continuous settings introduces challenges such as the loss of natural ordering, numerical instability, and inexact function evaluations.

We propose a unified framework covering combinatorial and continuous problems. For continuous settings, we introduce Continuous Boundary Dichotomic Search (CBDS), combining boundary-first exploration with adaptive refinement. A bisection-enhanced variant improves robustness in flat or ill-conditioned regions. In addition, we restrict the weight set to focus on relevant trade-off regions, such as Pareto knees.

We evaluate our approach on multiobjective integer programs and nonlinear problems from physics-informed neural networks (PINNs), where each scalarization requires costly training. Results show that DS-based methods can yield accurate approximations of

the supported Pareto front with few function evaluations, making them suitable for expensive multiobjective optimization problems.

3 - One-Exact Approximate Pareto Sets for APX-hard Multiobjective Problems
Henning Jasper, *Fritz Bökler*, *Markus Chimani*

There are several frameworks to compute approximate Pareto sets for multiobjective optimization (MOO) problems. In such frameworks, some auxiliary single-objective problem is considered, for which a problem-specific oracle is required. However, often these oracles are required to be a PTAS or even FPTAS. As such, these frameworks are only applicable to MOO problems that allow for such strong oracles to exist. They are inapplicable whenever the auxiliary problem is APX-hard. We propose a general framework that, for a (possibly even non-constant) accuracy vector b=(b_2,...,b_d) and any eps>0, computes polynomially sized, one-exact (1,(1+eps)b_2,...,(1+eps)b_d)-Pareto sets for d-objective optimization problems. The running time is polynomial in the time required to solve our auxiliary problem b-RelaxedDualRestrict. We further show that if b-RelaxedDualRestrict cannot be solved in polynomial time, then no (1,b_2,...,b_d)-Pareto set can be computed in polynomial time. For biobjective problems, our framework even yields a (1,(1+eps)b_2)-Pareto set of at most O(log b_2) times the size of the smallest such set. This relative size guarantee is asymptotically tight. Further, we present techniques to obtain suitable oracles for b-RelaxedDualRestrict. Using these, we obtain new best approximation guarantees for several established MOO problems. Some of our approximation guarantees are best-possible up to a factor 1+gamma, for any constant gamma>0, under standard complexity assumptions.

4 - Lexicographic Optimality in Multiobjective Sequential Processes
Jonas Hürter, *Philine Schiewe*, *Anita Schöbel*

A sequential process (SP) is a specific sequence of finitely many multiobjective optimization problems, called stages. Here, a solution of the first stage is given to the second one as a parameter defining the feasible space and objectives of the second stage. Any later stage then takes the solutions to all previous stages as parameters in this manner as well. This process results in a sequential solution, that is, a vector combining the efficient solutions of the respective stages. Sequential solutions are heuristic solutions to the integrated problem which combines all constraints and objectives from the stages into one joint multiobjective optimization problem. SPs are often used in applications such as public transport planning or chip design. There, finding a sequential solution is often the only alternative to describing and solving the significantly more complicated integrated problem. In this talk we show how to use a given sequential process to construct lexicographic optima of the corresponding integrated problem. To this end, we introduce assumptions that yield lexicographic optimality of sequential solutions without ever considering the feasible set of the integrated problem explicitly. Furthermore, we consider SPs with a linear integrated problem and demonstrate that lexicographic optima can be computed even when relaxing the previously introduced assumptions.

■ ME-03

Monday, 15:45-17:30 - Room: K8 (K.11.10)

MCDM Theory

Stream: Decision Analysis/Making
Contributed session
Chair: *Vilmar Boff*

1 - Multicriteria analysis driven by probabilistic reasoning with imperfect data
Jian-Bo Yang

Multicriteria analysis (MA) is widespread. Robust MA is the first step for making better decisions. In professional services, for example, risk analysis relies on multiple criteria and is the most important part in insurance and financial underwriting; in human wellbeing analysis, assessment of people's satisfaction with life is associated with multiple criteria such as health, education and income. In the era of AI and big data, MA is increasingly driven by not only human judgments but also imperfect data, both inherently uncertain. Relationships among criteria characterised by such data are also more complicated than such assumptions as mutual exclusiveness or independence. Meanwhile, MA must remain transparent and auditable for making better decisions. This creates new challenges and requires original thinking.

We will discuss the new development of probabilistic reasoning with imperfect data, coined as the maximum likelihood evidential reasoning (MAKER) framework. The novel MAKER framework sets the foundation for the evidential reasoning theory that has been applied to support MCDM in various fields. We will focus our discussions on how the new MAKER framework can be applied to support robust MA where conjunctive or disjunctive probabilistic reasoning needs to be applied and various types of uncertainty must be handled, including randomness, ambiguity and unreliability. We will use real life data to demonstrate how the MAKER framework is applied to power robust MA.

2 - Recent Development of the Evidential Reasoning Approach for MCDM: Explainable, Probabilistic and Trustworthy
Dong-Ling Xu, *Jian-Bo Yang*, *Ying-Ming Wang*

This presentation summarizes recent developments in the Evidential Reasoning (ER) approach for MCDM. ER was originally designed to model diverse forms of uncertainty and to analyse how such uncertainty affects decision outcomes. Instead of single values, performance on each criterion is represented by a belief distribution, enabling the modelling of randomness, vagueness, and incomplete data. Multiple belief distributions are then aggregated through an evidence-combination process based on Dempster's rule, now proven to rigorously extend Bayesian inference when data are incomplete or unreliable. This allows imperfect data to be fully utilized without guessing missing values or discarding samples. More recently, the ER attribute-combination process has evolved into a general ER rule for probabilistic inference with imperfect information. It extends Bayes' rule across cases where priors are known, partially known, or unknown; where likelihoods contain missing information; and where all information sources vary in reliability. The ER rule has been applied to complex decision problems and explainable machine-learning methods. Examples in insurance fraud detection will be used to illustrate how ER can be applied, how it connect

Bayesian inference and MCDM for next-generation decision analysis, and how ER enables explicit modelling of randomness, ambiguity, and source reliability, supporting more robust evidence-based learning and inference from imperfect data.

3 - Anti-Fragile Decision-Making: tHink beYonD Robustness And resilience (HYDRA)
Babooshka Shavazipour

The primary aim of this study is to support decision-makers in being well-prepared for a continuously changing future and making sustainable, anti-fragile decisions to create a better world. We renewed the perspective on decision-making under uncertainty to move beyond robustness and resilience and become anti-fragile. by seeking opportunities to benefit from variability. Indeed, we conceptualize antifragility and design a generic, modular architecture for decision-support tools and antifragile decision-making. Hence, we (1) propose a proper antifragility measurement that matches the requirement and possible meaningful ways of its usage in anti-fragile decision-making, such as relevant strategy generation and analysis; and (2) design and propose a generic anti-fragile decision-making framework to determine, analyze, and compare anti-fragile strategies, based on multiple criteria. This novel perspective sheds light on the birth of a new era in decision-making under uncertainty. The possibility of installing a new agrivoltaic technology has been used to illustrate the proposals.

4 - Evaluating Ranking Inconsistencies and the Dominance Property in the Reference Ideal Method
Vilmar Boff, *Luciano Ferreira*

The Reference Ideal Method (RIM) is a recently proposed multicriteria decision-making method. It enhances the well-established Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method by allowing the decision-maker to select a preferred range for each criterion to maximize the outcome. While RIM has been acknowledged for its contributions across various domains, a detailed examination of its algorithm exposes some ranking inconsistencies. In some situations, these inconsistencies can become so serious that they can lead the method not to respect the dominance property, a fundamental principle in rational decision-making. A numerical example illustrates when and why these inconsistencies occur using the RIM and its fuzzy extension (FRIM). To solve these issues, we propose an extension of the RIM method, called Balanced RIM (B-RIM), which suggests a new normalization function for the criteria scores of the considered alternatives of a multicriteria problem. Several case studies have been used to show the effectiveness of B-RIM/B-FRIM in avoiding the observed ranking inconsistencies.

■ ME-04

Monday, 15:45-17:30 - Room: K6 (K.11.17)

Practical Applications: Maritime Operations and Marine Conservation

Stream: Practical Applications of MCDM
Contributed session
Chair: *Sadaf Farboodi*

1 - Participatory MCDA for Marine Conservation: A Design Science Research Approach Using ELECTRE III to Address Recreational Boating and Beluga Coexistence
Irene Abi-Zeid, *Maud Thermes*, *Franck Taillandier*, *Nathalie Niquil*, *Arnaud Sentis*

The St. Lawrence beluga whale was classified in 2014 as an endangered species, highlighting the urgent need for effective conservation measures. Recreational boating represents a significant disturbance to this vulnerable population, threatening its long-term survival. To address this challenge, we conducted a participatory project to co-construct and evaluate management scenarios aimed at improving the coexistence of recreational boating and beluga conservation.

Engaging key local stakeholders through a sociotechnical process, we applied a Design Science Research methodology to develop a Multi-Criteria Decision-Aiding (MCDA) evaluation process based on the ELECTRE III method implemented in the freeware MCDA-ULaval. Eight management scenarios, categorized as "Awareness-raising" or "Regulatory," were constructed and assessed.

The "Ambassadors" network, a peer-based outreach and education scenario, achieved the highest ranking, demonstrating strong stakeholder support for community-centered solutions. Our results illustrate the potential of participatory MCDA to integrate diverse values and promote socially acceptable conservation strategies in complex marine governance contexts. In this talk, we will present our participatory process and highlight how the group collaboratively addressed the challenges of coexistence, how the scenarios and the criteria were co-constructed, and how the multi-criteria analysis was performed to reach these results.

2 - Assessing Alternative Fuel Scenarios for Green Shipping Corridors: A Multi-Stakeholder Decision Framework Combining MCDA and Cost Assessment
Sadaf Farboodi, *Michael Bruhn Barfod*

Green Shipping Corridors (GSCs), defined as zero-emission maritime routes between ports, have emerged as key initiatives to accelerate maritime decarbonization. A central component of GSC development is selecting suitable alternative fuel pathways. However, identifying appropriate fuel options for a specific corridor remains challenging due to differences in technological maturity, infrastructure requirements, safety considerations, costs, and stakeholder priorities. These complexities require structured decision-support approaches that integrate diverse evaluation criteria and stakeholder perspectives. This study develops a multi-stakeholder decision framework integrating Cost Assessment (CA) with Multi-Criteria Decision Analysis (MCDA) to evaluate alternative fuel scenarios in GSCs. The CA component evaluates monetary criteria using a Total Cost of Ownership (TCO) framework. The MCDA component applies an adapted Simple Multi-Attribute Rating Technique (SMART) to assess non-monetary criteria, including environmental, technical, social, and regulatory dimensions, while incorporating stakeholder preferences. The framework is demonstrated through a case study of the Esbjerg-Immingham RoRo corridor between Denmark and the United Kingdom using operational data and collaboration with key stakeholders. The study develops a multi-stakeholder MCDA-based framework, supported by cost modelling, to enable transparent evaluation of maritime decarbonization pathways.

■ ME-05

Monday, 15:45-17:30 - Room: K5 (K.11.20)

Interactive and Preference-Based Multiobjective Optimization: Improving the Decision-Making Process

Stream: Interactive Methods
Contributed session
Chair: *Sandra Gonzàlez Gallardo, Mariano Luque, Ana Belen Ruiz, Rubén Saborido*

1 - Multiobjective Optimization: A Thematic Analysis on the Analysts' Perspectives on Decision-Support
Giovanni Misitano, *Zuzanna Osika*, *Jazmin Zatarain-Salazar*, *Pradeep K. Murukannaiah*

Multiobjective optimization is widely applied to real-world decision problems, yet research remains focused mainly on algorithmic development. Less attention has been paid to how it is practiced, particularly from the perspective of analysts, practitioners who bridge computational methods and decision-makers.

We present the first study combining semi-structured interviews with reflexive thematic analysis, a qualitative method for identifying patterns in interview data, to examine analyst perspectives on multiobjective optimization-based decision-support. Through 15 interviews across domains including water management, healthcare, and logistics, we identify four themes shaping real-world practice: collaboration and communication, complexity and real-world constraints in problem modeling, the decision-making process, and practical applicability.

These themes surface nine critical research gaps: strengthening academy-industry collaboration, developing unified visualization tools, ensuring context-specific problem representations, establishing comprehensive application guidelines, addressing real-world complexity overlooked by current assumptions, supporting elicitation of diverse and unquantifiable preferences, moving beyond single decision-maker frameworks, providing information beyond objective function values, and overcoming limited trust and resource constraints. These gaps call for more human-centered and interdisciplinary research in multiobjective optimization.

2 - Interactive Multiobjective Optimization Guided by Decision-Rules
Jingyi Wang, *Salvatore Greco*, *Roman Slowinski*

An interactive multiobjective optimization procedure based on preference learning is proposed to guide the search for a best-compromise solution in the decision maker's (DM's) preferred region of the Pareto front. The procedure follows the paradigm of Artificial Intelligence for Decision Aiding (AIDA), which aims to design intelligent systems that support, rather than replace, the DM. As in typical interactive procedures, the calculation phase alternates with the decision phase. In the calculation phase, the Achievement Scalarizing Function generates a representative sample of Pareto-optimal solutions by projecting the current ideal point onto a hyperplane grid spanned by the individual objective optima. A small set of representative solutions is then presented to the DM in the decision phase and classified as "Good" or "Not good". Based on this preference information, interpretable "if. . . , then. . . " decision rules are induced using the Dominance-based Rough Set Approach. These rules represent the DM's current preferences and are transformed into constraints guiding the next optimization phase. Two interaction settings are considered: classification of all solutions in the sample or an active learning approach selecting a single solution for classification. Computational experiments compare these settings in terms of cognitive effort, preference learning efficiency, and convergence toward a small region containing candidate best-compromise solutions.

3 - Interactive Multiobjective Optimization Under Uncertainty: A Flexible Preference-Driven Approach
Juho Roponen

Uncertainty in objective functions has not been widely explored in interactive multiobjective optimization (IMOO). However, IMOO methods have some unique advantages for handling uncertainty. Because decision makers often have difficulty expressing their preferences about uncertainty, eliciting preference information a-priori is not always feasible, when uncertainty is involved. Computing a Pareto-frontier is similarly difficult. With an IMOO method, the decision maker can spend time iteratively learning about the tradeoffs between the objective functions and the associated uncertainties and correlations. They are then able to make an informed decision that optimally corresponds to their preferred priorities.

We propose a new IMOO method where exploring uncertainty is not limited to fixed uncertainty measures. Instead, the decision maker will be free to choose how the uncertainty for each objective function should be represented, and this choice is not final, but can be changed during the interactive process. They can choose among multiple optimization criteria traditionally used for decision making under uncertainty, e.g., expected value, min-max, min-max regret, or value-at-risk. While these measures could be used as an objective function in any IMOO method, incorporating multiple at once is rarely done, because it drastically increases the number of objective functions, which can cause problems with user interfaces and increase cognitive load of the decision maker.

4 - On the Region of Interest in Preference-based and Interactive Evolutionary Multiobjective Optimization
Mariano Luque, *Antonio Borrego Ortega*, *Sandra Gonzàlez Gallardo*, *Ana Belen Ruiz*, *Rubén Saborido*

In multiobjective optimization problems (MOPs), decision-makers (DMs) are usually interested in solutions located within specific regions of interest (ROIs) rather than in approximating the entire Pareto front. Preference-based and interactive evolutionary multiobjective optimization algorithms (P-EMO and I-EMO) address this need by incorporating DM preferences to guide the search toward relevant regions of the objective space. The definition and modelling of the ROI play a critical role in these methods, as it influences search direction, convergence behaviour, and the interpretability of the obtained solutions. Preferences can be integrated through several mechanisms, including scalarizing function reformulation, dominance relation modification, and distance-based information. Each mechanism induces different geometric properties and search dynamics, shaping the resulting ROI. This paper presents a state-of-the-art review of ROI definitions

and modelling strategies in the P-EMO and I-EMO algorithms available in the literature. We propose a classification framework based on ROI approximation mechanisms and analyse their geometric implications, algorithmic behaviour, and decision-support capabilities, highlighting key challenges and future research directions.

■ ME-06

Monday, 15:45-17:30 - Room: Lecture Hall HS 32

AHP/ANP: Business Strategy, Marketing, and Healthcare Services

Stream: Decision Analysis/Making
Contributed session
Chair: *Khalidah Maruan*

1 - Practical MCDM and Game-Theoretic Decision Support for Competitive Real Estate Offer Selection
Pushpa Raj Bhatta, *Manoj Shakya*

Residential real estate transactions in the U.S. involve sellers receiving multiple competing offers that differ across price, financing, contingencies, and closing timelines. In practice, offer selection often relies on price-only comparisons or informal judgment, overlooking important non-price factors that affect transaction outcomes. This paper presents a practical decision support framework deployed on a live real estate platform combining multi-criteria decision-making methods with game-theoretic modeling. Six evaluation criteria covering financial returns, transaction certainty, timeline alignment, contingency risk, seller expenses, and possession flexibility are defined and weighted using AHP. Offers are ranked using both AHP based weighting and TOPSIS. A BNE model using Monte Carlo simulation supports buyers by estimating win probabilities and recommending rational bid adjustments under competitive uncertainty. Experimental results on real offer data show that AHP rankings remain stable under sensitivity and ablation analysis, while TOPSIS proves more sensitive to changes in ideal solutions. The BNE component provides bidding guidance balancing competitiveness with economic rationality. The framework has been integrated into an operational platform and validated through expert feedback, demonstrating that structured MCDM and game-theoretic tools can practically improve decision quality in competitive real estate markets.

2 - Better Measurement for Better Decisions: Healthcare Quality Assessment in Malaysia Using Analytic Network Process
Khalidah Maruan, *Samsiah Awang*, *Izzatur Rahmi Mohd Ujang*, *Divya Nair Narayanan*, *Nur Ezdiani Mohamed*

Measuring healthcare quality is inherently complex due to the interdependence of multiple factors. Hence, reliable and standardised measurement is essential for evaluating performance and guiding quality improvement. This study adopts the Analytic Network Process (ANP) with the aim of measuring healthcare quality performance in Malaysia based on indicators across seven local quality domains: Safe, Timely, Effective, Efficient, Equitable, People-centred, and Accessible (STEEEPA). Pairwise comparisons of 54 quality indicators mapped to STEEEPA domains were conducted based on ratings by an expert panel to derive priority weights for each domain and indicator. A weighted super matrix was computed and normalised to derive the indicator's final weights. Two-year weighted performance data were computed for a national-level composite index for each domain, enabling national performance assessment. Timely, Effective, People-centred, and Accessible domains were close to meeting the standards in both years. Safe, Effective, and People-centred domains showed improvement in 2024 compared to 2023. Equitable domain was not measured due to the limited availability of standardised national data to support robust assessment, reflecting a data gap rather than a lack of relevant indicators. The ANP-based composite index provides policymakers with a systematic tool to compare performance and identify areas for improvement, informing better decisions and higher-quality service delivery.

3 - WEB-MAUT-DSS: A web-based decision support system based on an additive multiattribute utility function
Alberto Gómez, *Antonio Jiménez-Martín*

WEB-MAUT-DSS is an improved web-based version of GMAA decision support system based on the Decision Analysis (DA) methodology. It is designed to operate in decision-making contexts characterized by partial or incomplete information, accommodating uncertainty in alternative performances through probability distributions or ordinal information, as well as imprecision in the assessment of decision-makers" (DMs") preferences for both component utilities and attribute weights. The system supports hierarchical weight elicitation, enabling the use of different weighting methods at various levels and branches of the objective hierarchy. An additive multi-attribute utility model can be directly applied to obtain overall utilities for the different alternatives, which serve as the basis for the final ranking. Alternatively, Monte Carlo simulation techniques are incorporated when non-uniform probability distributions or ordinal information are used to describe alternative performances. Additionally, WEB-MAUT-DSS incorporates a range of sensitivity analysis tools that exploit the available imprecision to provide deeper insights into the robustness of the resulting evaluations.

WEB-MAUT-DSS was developed using Shiny, a package that enables the creation of interactive web applications directly from R. The system is freely accessible at https://vps155.cesvima.upm.es/web-maut-dss/. A user"s guide and three illustrative real decision-making problems are available in the system.

Tuesday, 9:00-10:45

■ TA-02

Tuesday, 9:00-10:45 - Room: Senatssaal (K.11.07)

Parametric Optimization

Stream: Invited Sessions
Invited session
Chair: *Stefan Ruzika, Levin Nemesch, Alina Wittmann, Clemens Thielen*

1 - Exact Objective Space Contraction for the Preprocessing of Multi-objective Integer Programs
Stephanie Riedmüller, *Thorsten Koch*

Large or widely ranged objective coefficients in integer optimization can cause numerical instability and long runtimes. Those effects are amplified in multi-objective settings. We address this issue by transforming the coefficients of linear objective functions into smaller integer coefficients while preserving dominance relations in the objective space. We formalize this transformation problem and propose both a simple scaling heuristic and a novel exact method for multi-objective binary problems. The exact approach computes minimal integer objective coefficients via an integer programming formulation with exponentially many constraints. We present a cutting-plane algorithm that can efficiently handle the problem size. Computational results show how often the transformation actually leads to smaller coefficients and how the proposed preprocessing affects the runtime and numerical stability of the Defining Point Algorithm.

2 - Weight Space Decomposition for Multiobjective Linear Programming in the Context of Equitable Optimization
Ozlem Karsu, *Firdevs Ulus*

We consider equitable linear optimization problems (ELOP), which are multiobjective optimization problems, with each objective representing the benefit that one entity receives. In such problems, the concept of dominance is replaced by equitable dominance. The aim is to find the set of equitably nondominated points, which can be done by solving ordered weighted averaging (OWA) scalarization. Each solution corresponds to a different set of weights that make the solution optimal, hence a different degree of inequity aversion. We discuss a novel use of the parametric simplex algorithm to address ELOP. The algorithm not only provides the set of equitably nondominated solutions but also yields the corresponding weight space decomposition. We also propose an alternative method based on geometric duality to compute the weight space decomposition given the set of nondominated solutions.

3 - From the Positive Orthant to Polyhedral Cones: Generalizing Approximation
Levin Nemesch, *Stefan Ruzika*, *Clemens Thielen*, *Alina Wittmann*

Approximation is a key tool for dealing with the computational challenges of multi-objective optimization problems (MOPs). In an α-approximation set, every point in the Pareto front is represented with a relative error of at most α (with α being greater than one). A seminal result was shown by Papadimitriou and Yannakakis in 2000: As long as the Pareto front is nonnegative, every MOP has an α-approximation set of polynomial cardinality. However, this result only applies if the positive orthant is used as ordering cone.

In this talk, we study approximation for MOPs with general polyhedral ordering cones. We formulate an appropriate notion of approximation for this setting and discuss the obstacles that arise. For the slightly relaxed notion of convex approximation, we show that — under some mild problem assumption — α-approximation sets of polynomial cardinality exist in our setting. In addition, we sketch an algorithmic approach for computing such sets. To obtain these results, we adopt a parametric perspective and use tools from parametric approximation.

4 - Beyond the Epsilon-Constraint Method: Linear Programs with Parameter-Dependent Feasible Set
Alina Wittmann, *Levin Nemesch*, *Stefan Ruzika*, *Clemens Thielen*

A well-known scalarization technique for computing nondominated points in multiobjective optimization is the epsilon-constraint method (sometimes also known as the budget-constraint method). In this method, one objective is selected as the primary objective to be optimized, while the remaining objectives are transformed into constraints with upper bounds. Many state-of-the-art algorithms find the nondominated points by varying the bound systematically. Such algorithms can be viewed as a search through the parameter space. In this talk, we study linear parametric optimization problems in which the right-hand sides of the feasibility constraints depend linearly on an unknown parameter. The goal is to determine optimal solutions for all possible parameter values. The epsilon-constraint method is closely related to this setting. However, solving these parametric problems exactly is computationally challenging. In the worst case, the optimal solution set has infinite cardinality. Consequently, computing the complete optimal solution set efficiently is not possible in general, which motivates the study of approximation algorithms. We propose an approximation algorithm that iteratively selects solutions with maximal feasibility ranges in the parameter space. We present the algorithm and discuss further structural results, including bounds on the cardinality of approximation sets for problems where the feasible set depends (inclusion-wise) monotonically on each parameter.

■ TA-03

Tuesday, 9:00-10:45 - Room: K8 (K.11.10)

Group Decision Making

Stream: Decision Analysis/Making
Contributed session
Chair: *Salvatore Greco*

1 - Characterizing Decision-Making in Networked Digital Environments
Yu-wang Chen, *Tao Wen*, *Ting Wu*

In today's deeply interconnected society, digital platforms, from social medias to online news platforms, have become central to how people communicate, collaborate, and exchange information. By eliminating the spatial and temporal constraints of traditional communication, these platforms enable instantaneous, global interaction. At the same time, they introduce

complex challenges for understanding how human decision makers make decisions within networked environments. This research proposes a comprehensive framework for modelling and analysing decision-making and behavioural dynamics in such networked settings. The framework examines how individual decision makers implicitly form their initial beliefs within a multi-criteria decision-making context, how they interact with others, and how these interactions drive ongoing belief updating. Through these processes, collective opinion dynamics emerge and ultimately shape decision processes and outcomes across the network. The framework aims to generate deeper insight into how decisions and behaviours evolve within networked digital environments. Building on this foundation, the research can also be extended to heterogeneous human-AI networks, in which human and AI agents can jointly shape belief formation and decision-making in collaborative, co-evolving ways.

2 - Deriving voting scoring systems from individual preference intensities via the deck of cards method
José Luis García-Lapresta

Scoring rules require voters to rank alternatives from best to worst using linear orders. Each alternative is assigned a fixed score based on its position in the corresponding individual ranking. The alternatives are then socially ranked according to the sum of their individual scores. In this context, voters cannot express the intensity of their preferences because the scores are fixed.

In this contribution, the scoring rules have been extended to the case of reciprocal preferences using the deck of cards method. Initially, each voter ranks the alternatives in a weak order and can then insert several cards between consecutive equivalence classes representing the corresponding preference intensities. A consistency condition generates the number of cards between non-consecutive equivalence classes.

Taking this information into account, each voter is associated with a reciprocal preference relation on the set of alternatives, satisfying a strong transitivity condition. A score is then assigned to each alternative for each voter, computed as the sum of the preference intensities between that alternative and all others. Finally, the alternatives are ranked according to the sum of these individual scores.

3 - An explainable decision-rule-guided group decision-making method for multiple-criteria sorting problems
Jie Guo, *Salvatore Greco*, *Roman Slowinski*

We are presenting a new method for supporting group decision making concerning multiple-criteria sorting of a finite set of alternatives. The multiple decision-makers (DMs) differ in values and knowledge backgrounds. To reduce the preference elicitation effort and cognitive burden of DMs, they are asked to provide holistic preference information in the form of sorting examples of selected reference alternatives, together with graded confidence levels. The sets of reference alternatives need not be the same for all DMs; they are aligned with their expertise. The preference model representing the preferences of individual and group DMs is a set of "if-then" decision rules induced from sorting examples using the Dominance-based Rough Set Approach (DRSA). Then, for each DM, two mixed-integer linear programming models are solved to obtain sets of decision rules that satisfy DMs' assignment preferences while ensuring non-contradictory classifications of all alternatives. To ensure non-contradictory group classifications and minimal inconsistency with DMs' preferences, a bi-objective mixed-integer linear programming is solved to obtain a maximal subset of group rules. As a result, we obtain the group classification result together with a minimal subset of rules that explain this result in well interpretable and transparent terms. A case study on firm credit risk assessment is conducted to demonstrate the feasibility of the proposed method.

4 - Methodology to achieve consensus in Group Multi-Criteria Decision-Making
Manuela Otalvaro, *Jose Alfredo Vasquez*, *Jorge Andres Polanco*

Solving problems that require a group decision process demands that consensus be reached among the participants regarding a solution alternative, as this is a determining factor for the acceptance and legitimacy of the decision. Traditionally, the achievement of consensus in group decision-making has been addressed from a quantitative perspective, without considering that it could arise as a result of the contradiction between the different thinking paradigms of decision-makers. This article proposes a new methodology to promote consensus in Group Multi-Criteria Decision-Making, which integrates, from a qualitative perspective, the thinking paradigm of the decision-making group as a determining factor in its behavior during the decision-making process. Based on the identification of this paradigm, the methodology provides a way to guide the development of the group decision-making process. Finally, an application of the methodology to a case study in a hydropower company is presented.

■ TA-04

Tuesday, 9:00-10:45 - Room: K6 (K.11.17)

Practical Applications: Healthcare and Medical Decision Systems

Stream: Practical Applications of MCDM
Contributed session
Chair: *Alexander Urtheil*

1 - MAUT-KBP model for the evaluation of IMRT treatment plans in cancer: Integration of multi-criteria theory and knowledge-based planning.
Sandra Gonzàlez Gallardo, *Liany Tobón-Castro*, *Guillermo Cabrera-Guerrero*, *Ana Belen Ruiz*, *Mauricio Moyano*

Intensity-Modulated Radiation Therapy (IMRT) is essential in the treatment of cancer due to its precision in dose shaping. However, evaluating plan quality remains a challenge, since standard protocols rely on binary compliance and do not capture the nuances of trade-offs between conflicting clinical objectives. This work proposes a methodological integration between Knowledge-Based Planning (KBP) and Multicriteria Decision Making (MCDM), using Multi-Attribute Utility Theory (MAUT) to evaluate clinically approved IMRT plans. Based on a retrospective analysis of 91 treatment plans, a set of sensitive indicators was defined, utility functions were modeled, and a Global Utility Score was calculated to rank plan quality. Preliminary results demonstrate that MAUT enables robust

plan discrimination and reveals clinically relevant differences that traditional approaches do not detect. The findings support the integration of KBP and MCDM as tools to strengthen clinical decision-making in prostate cancer radiotherapy.

2 - EPAMed: A Digital Decision Aid for Preference-Sensitive Treatment Decisions
Jakub Fusiak, *Andreas Wolkenstein*, *Verena S. Hoffmann*

Introduction: Shared decision making requires patients to weigh benefits, risks, burdens, and practical implications across multiple criteria, yet many patient decision aids lack a rigorous, usable preference elicitation method. We present EPAMed, a web-based decision aid that embeds Potentially All Pairwise RanKings of all possible Alternatives (PAPRIKA) in a structured shared decision-making workflow.

Methods: EPAMed was developed using Design Science Research with iterative input from patients, clinicians, epidemiologists, and medical ethics researchers. Implemented in R Shiny, it combines pairwise trade-off questions, answer revision, preference-profile visualization, ranked option presentation, and consultation preparation. All processing occurs locally within the user session.

Results: EPAMed supports reflective preference construction through revisable answer histories, optional manual weight adjustment, comparison tables, and exportable summaries for clinical encounters. It also incorporates risk communication using natural frequencies, icon arrays, glossary support, and certainty labels. Multiple sclerosis treatment decisions served as an illustrative instantiation, showing how the tool can be adapted by replacing the decision model and evidence tables.

Conclusions: EPAMed shows how multicriteria preference elicitation can be embedded in a transparent, user-centered decision aid across clinical contexts.

3 - DECODE: A Multi-objective Analysis Toolbox
Alexander Urtheil, *Sanaz Mostaghim*

Due to the interconnected nature of systems within the human body, medical data is difficult to order with respect to a single criterion, which leads to unique representations of each person. This inherent individuality requires methods of analysis that reveal underlying patterns while minimizing generalization. For this we propose Multi-objective Data Analysis (MODA), which employs scoring functions to partially order static data with non-dominated sorting and is coupled with correlation analysis. In this way we cluster data into groups defined by various fronts that can assign similarities to the groups while maintaining their individuality. Our goal is to identify new similarity patterns between and within the groups. A specific focus is on the delta-domination methodology, which relaxes the domination criteria to account for noise in medical data. The outcome of non-dominated sorting is a set of fronts in the objective space; our grouping and clustering methodology relies on the separation of fronts and since the fronts of medical data often have unclear boundaries (due to noise), delta-domination widens the inclusion criteria for individual fronts, providing a clearer separation between them. Our preliminary work on medical and behavioral data has shown that MODA can help to unleash latent variability. In this presentation, we present the DECODE toolbox as a decision analysis software that incorporates MODA and the underlying correlation analysis.

■ TA-06

Tuesday, 9:00-10:45 - Room: Lecture Hall HS 32

AHP/ANP: Logistics and Distribution

Stream: Decision Analysis/Making
Contributed session
Chair: *Puren Veziroglu*

1 - A Decision Support Framework for Infrastructure Prioritization in Urban Water Distribution Systems: A Case Study of Istanbul
Berrak Güneş Sevinç, *Zeynep Başak Tepe*, *Duygu Çamsarılıoğlu*, *Y. Ilker Topcu*

Urban water distribution systems face increasing pressures from climate variability, rapid urbanization, and aging infrastructure. In metropolitan contexts like Istanbul, these challenges are compounded by high non-revenue water levels and spatial imbalances between supply and demand. This study proposes a multi-criteria decision support system (DSS) for prioritizing District Metered Areas (DMAs) based on economic and operational criticality. The framework integrates three district-level cost indicators: leakage-related cost, demand-driven cost, and transfer-related energy cost. These indicators are derived from heterogeneous data sources and structured for consistent comparison under data uncertainty. An integrated MCDM approach combines the AHP method for criteria prioritization with PROMETHEE for ranking alternatives. The DSS follows a flexible, scalable architecture enabling district-level infrastructure evaluation rather than single-metric assessments. It supports strategic planning in large-scale water utilities by revealing hidden economic burdens from leakage, demand growth, and energy-intensive transfers. This study contributes to MCDM application in urban infrastructure management through an integrated, data-driven framework aligned with improving decision-making for sustainable and resilient urban systems.

2 - Last-Mile Carrier Selection for an Early-Stage Startup using the Integration of AHP, TOPSIS, and Goal Programming
Sema Nur Gur, *Elif Sezer*, *Y. Ilker Topcu*

In the contemporary e-commerce logistics ecosystem, particularly for early-stage startups, the ability to make strategic decisions under resource constraints is a critical prerequisite for sustainable growth. This study aims to optimize the last-mile carrier selection process for a startup focusing on international B2C e-commerce shipments. Within the scope of this research, a comprehensive evaluation framework comprising six main and 21 sub-criteria was developed by integrating an extensive literature review with expert judgments. To mitigate the uncertainties inherent in the decision-making process, an analytical, objective, and data-driven DSS was designed. Methodologically, a three-stage integrated approach was employed. First, the criteria weights were determined using the AHP method. Then, these weights and the performance values for four alternative carriers with respect to the sub-criteria were incorporated into the TOPSIS method to evaluate the carriers. Finally, a 0-1 goal programming optimization model was developed, utilizing binary decision variables for carrier selection, weights as objective function coefficients for deviations, and TOPSIS scores, service cost per unit package, and delivery time targets as constraints. The optimization model identifies the most efficient portfolio to achieve

an effective balance between cost efficiency and delivery speed for the startup firm.

3 - Identification and Priorization of the Barriers to Adoption of Bioplastic Food Packaging
Puren Veziroglu, Y. Ilker Topcu

Despite their environmental promise, bioplastics continue to face a significant gap between expected sustainability benefits and real-life performance. This gap results from several interconnected barriers, including high production costs, the limited realization of economies of scale, inadequate waste-management infrastructure, the absence of appropriate disposal conditions, and consumer knowledge deficits regarding material characteristics, certification logos, and disposal routes. In conventional waste streams, the appropriate disposal pathway for bioplastic materials often remains unclear, and when they are disposed of together with their fossil counterparts, this results in contamination and operational challenges for municipalities. This study identifies the recurring barriers limiting the adoption of bioplastic food packaging based on the relevant literature and organizes them into a hierarchical decision structure. The study then prioritizes these barriers through an AHP based framework on judgements from real experts and generative LLMs personas. The proposed framework aims to rank the identified barriers according to their relative importance and to provide a systematic decision-support tool for prioritizing the key constraints on the wider adoption of bioplastic food packaging.

Tuesday, 11:30-12:30

■ TB-01

Tuesday, 11:30-12:30 - Room: Auditorium HS33

Plenary: Andreia Guerreiro

Stream: Plenary Sessions
Plenary session
Chair: *Luis Paquete*

1 - Set-Quality Indicators in Multiobjective Optimisation
Andreia Guerreiro

Set-quality indicators, which map a point set into a scalar value, are a convenient way to assess (the image of) solution sets in multiobjective optimisation. Such indicators may comprise in this scalar value the proximity of the set of points to the Pareto front, as well as information regarding the distribution of points in the set. Quality indicators are widely used for performance assessment, but have also been used within different algorithmic approaches (e.g., evolutionary algorithms, scalarisation methods) to guide the search process for (a well-distributed set of) Pareto-optimal solutions. This relates to transforming the multiobjective optimisation problem into a single-objective one, where the goal is to find a point set, frequently bounded in size, that maximises the quality indicator. Since each indicator is biased towards some point sets, understanding the theoretical properties of quality indicators allows to characterise the indicator-optimal subsets and, therefore, to understand such biases and their implications in performance assessment and in indicator-based algorithms. The theoretical and practical aspects of quality indicators will be discussed in this talk.

Tuesday, 14:00-15:15

■ TC-02

Tuesday, 14:00-15:15 - Room: Senatssaal (K.11.07)

Handling Uncertainties in Multiobjective Optimization

Stream: Multi-objective Programming
Contributed session
Chair: *Pelayo S. Dosantos*

1 - Optimization with generalized invex fuzzy functions
Yury Nikulin, *Ville Rinne*, *Marko M. Mäkelä*

This paper investigates optimality conditions for optimization problems involving generalized invex fuzzy functions. We extend the classical Karush-Kuhn-Tucker (KKT) framework to nonsmooth, vector-valued, and fuzzy-valued objective and constraint functions satisfying generalized invexity assumptions, including vecotr types of invexity, pseudoinvexity, and quasiinvexity. Building on tools from nonsmooth analysis and multiobjective optimization, we derive new KKT-type necessary and sufficient conditions that guarantee (weak) Pareto optimality in fuzzy environments under assumptions significantly weaker than classical convexity. The proposed results unify and generalize several existing optimality conditions, notably those introduced by Antczak and Mishra, and highlight the effectiveness of generalized invexity in establishing optimality without requiring differentiability or convexity. Illustrative examples are provided to demonstrate the applicability of the developed theoretical framework.

2 - The Multi-Objective Shortest Path Problem under Interval Uncertainty
Pelayo S. Dosantos, *Kathrin Klamroth*

The multi-objective shortest path problem with imprecise data constitutes a relevant topic in network optimization due to its broad range of applications. This work addresses uncertainty by representing arc costs through intervals that capture the set of feasible values each cost may assume, without requiring distributional assumptions. Classical concepts from multi-objective optimization, such as efficiency, dominance, and Pareto optimality, are extended to the interval framework using admissible orders to properly assess solution quality. The relationships between efficient solutions in the imprecise setting and those obtained in the corresponding deterministic associated multi-objective problem are analyzed. Furthermore, an algorithm is proposed to efficiently solve the multi-objective interval shortest path problem by avoiding unnecessary comparisons among candidate solutions. The behaviour of the proposed approach is illustrated through a simulated case study.

■ TC-04

Tuesday, 14:00-15:15 - Room: K6 (K.11.17)

Practical Applications: Urban Governance and Public Policy

Stream: Practical Applications of MCDM
Contributed session
Chair: *Ivana Marjanović*

1 - Adriana Method For Integrating State Capacity, Smart Services, Sustainability, And Quality Of Life
Nelson Hein, *Danielly Rodrigues da Cruz*, *Adriana Kroenke*, *Marcos Roberto da Cruz*

This study proposes a multicriteria decision analysis framework to evaluate municipal performance, integrating four complex and interdependent dimensions: quality of life, smart services, state capacity, and sustainability. The ADRIANA method (Análise Decisória Relativa Interativa de Aquisição e Não-Aquisição - Interactive Relative Decision Analysis of Acquisition and Non-Acquisition) was applied, a structured multicriteria approach capable of simultaneously capturing the effects of acquisition and non-acquisition. Using data from 176 Brazilian municipalities, the indicators were normalized and synthesized to construct the LISS index (Life, Intelligence, State, and Sustainability). Unlike conventional aggregation procedures, ADRIANA allows interactive classification based on the Thaler Value, incorporating gain and loss perspectives in the decision evaluation. The results indicate that the classification based on ADRIANA produces a differentiated municipal ranking, highlighting structural asymmetries in performance. The approach increases transparency in multi-criteria evaluation and offers a robust alternative for evaluating complex public policies. This study contributes to literature by demonstrating the applicability of ADRIANA in large-scale empirical contexts and by promoting structured support for decision-making in urban governance. The framework offers replicability for international comparative studies and for strategic public management.

2 - Policy Analytics for Urban Wellbeing: Integrating Stakeholder Preferences into an Outranking-Based Decision Dashboard for Cities
Ivana Marjanović, *Jelena J. Stanković*, *Marina Stanojević*

Policy decisions in urban development increasingly require transparent trade-offs across competing objectives such as mobility, housing, environmental quality, and governance. Yet many city assessments remain either purely indicator-driven or purely opinion-driven. This paper proposes a policy-analytics workflow that combines structured indicator systems with elicited stakeholder priorities to produce interpretable decision support for local authorities. A multidimensional framework is specified to represent core urban policy domains, and preferences are obtained from multiple stakeholder groups using harmonised survey instruments. The elicited priorities are translated into model parameters, enabling the construction of domain profiles and city comparisons within an outranking logic. The approach is designed to support non-compensatory reasoning, so that poor performance in essential domains is not automatically "offset" by strengths elsewhere. The resulting outputs are positioned as a policy dashboard: overall assessments are

accompanied by domain-level diagnostics, sensitivity checks, and stakeholder-gap indicators that reveal where policy priorities diverge across groups. The contribution is twofold: (i) a replicable integration of stakeholder preference data into an MCDM model suited for public decision contexts; and (ii) a governance-oriented interpretation that translates multicriteria results into actionable policy levers and communication-ready evidence.

■ TC-06

Tuesday, 14:00-15:15 - Room: Lecture Hall HS 32

Preference Modeling

Stream: Decision Analysis/Making
Contributed session
Chair: *Jafar Rezaei*

1 - How Much Harder Are Indifference Adjustments? An Experiment on the Cognitive Effort in Multi-Criteria Decisions
Florian Burnat, *Juergen Branke*, *Walter Gutjahr*

Preference elicitation is central to multi-criteria decision analysis. The dominant paradigm relies on preference statements (PSs - binary comparisons yielding roughly one bit of information). Indifference adjustments (IAs), where a decision-maker adjusts a continuous attribute until two alternatives feel equally desirable, provide far richer information. Yet the field has assumed for decades that IAs impose prohibitive cognitive costs; an assumption never empirically tested with professional decision-makers.

We ran a field experiment with 83 Austrian roofing professionals evaluating pairs of roofing tiles across 2-4 attributes. Each participant answered both PS and IA questions for matched pairs (within-subject). Response time and subjective difficulty (1-5) served as effort measures.

IAs required only 15% more time (13.4 vs 11.6 s) and consistently higher difficulty than PSs. For two attributes, IAs were actually faster. The differential grew modestly with attribute count but remained small. Most effort stems from comprehending alternatives, not the judgment itself.

These findings challenge the assumption driving three decades of PS-only elicitation. Given IAs' far greater information content at marginal extra cost, adaptive strategies mixing query types based on empirical cost-benefit data deserve serious consideration.

2 - Profile-based multicriteria ranking and scoring: ELECTRE TRI CC and ELECTRE-Score CC
Luis C. Dias, *José Rui Figueira*, *Salvatore Greco*

ELECTRE methods are well established in the MCDA community due to their theoretical foundations and desirable characteristics, such as dealing with imperfect knowledge of data and avoiding unwarranted systematic compensation among criteria. Several variants of ELECTRE have been proposed for choice, ranking, and sorting problems. The established ELECTRE ranking methods are based on pairwise outranking relations among the alternatives under evaluation, and therefore are not immune to rank-reversal effects. These methods, with the exception of ELECTRE Score, also do not provide a numerical score, as some of the more popular MCDA methods do. This work presents two new ELECTRE methods, ELECTRE TRI CC and ELECTRE-Score CC, which build upon ELECTRE TRI and ELECTRE Score. ELECTRE TRI CC produces a ranking of alternatives compatible with ELECTRE TRI, which is based on a set of profiles and ensures that changes in the set of alternatives under evaluation do not cause rank-reversal effects. ELECTRE-Score CC yields a numerical score for each alternative compatible with this ranking, which offers a finer-grained result when compared to ELECTRE Score. Analogously to ELECTRE TRI, these new methods can follow a Pseudo-Conjunctive and/or a Pseudo-Disjunctive perspective. An analysis of a composite indicator is presented to illustrate the application of these methods in that context.

3 - Coalition-Indexed Voting Assessment: An Adaptive Weight Elicitation Method for Multi-Criteria Decision Analysis
Jafar Rezaei

This article introduces the Coalition-Indexed Voting Assessment (CIVA), an adaptive weight-elicitation method for multi-criteria decision-making grounded in outranking reasoning. CIVA is designed for decision problems that rely on intrinsic criterion weights (voting power) and preclude full compensation across criteria. After structuring the problem and identifying the criteria and relevant thresholds, the decision-maker answers a set of pairwise comparisons (queries) between stylized alternatives that differ on selected criteria. In CIVA, each response is interpreted as a coalition-based voting comparison, yielding a linear relation among the criterion weights; together with monotonicity and normalization, these relations define a feasible weight region and feed an optimization model that estimates weights that best fit the answers. We show that the number of required queries can be large even for a moderate number of criteria. To address this, we develop two adaptive algorithms that learn from prior answers and exploit logical relationships among comparisons to shrink the query set: a maximin query-and-propagate procedure and an LP-certified variant that infers additional comparisons without asking them. These mechanisms substantially reduce elicitation effort while preserving the non-compensatory character of the model and the interpretation of weights. We also outline an extension for problems with many criteria and provide a numerical application.

Tuesday, 15:45-17:30

■ TD-02

Tuesday, 15:45-17:30 - Room: Senatssaal (K.11.07)

GOR Working Group

Stream: Plenary Sessions
Contributed session
Chair: *Michael Stiglmayr*

■ TD-03

Tuesday, 15:45-17:30 - Room: K8 (K.11.10)

AHP/ANP: Web-based SuperDecisions software

Stream: Decision Analysis/Making
Contributed session
Chair: *Y. Ilker Topcu*

1 - Stakeholders, personas, and priorities: AI-assisted MCDM in action with the web-based SuperDecisions
Elena Rokou

SuperDecisions Web Showcase (online)

■ TD-04

Tuesday, 15:45-17:30 - Room: K6 (K.11.17)

Practical Applications: Multi-Objective Optimization

Stream: Practical Applications of MCDM
Contributed session
Chair: *Diclehan Tezcaner Ozturk*

1 - Scenario Optimization in Fuzzy Cognitive Maps by Means of Multi-objective Evolutionary Algorithms
Carlos Ignacio Hernández Castellanos, *Aaron Ulises Poot Hoil*, *Fernanda Pérez Lombardini*, *Marco A. Rosas*, *Jesús Mario Siqueiros García*

Urban mobility and sustainability planning involve complex interactions among social, environmental, and infrastructure factors, which often generate competing impacts across stakeholder objectives. In this context, decision-makers need tools that help identify actionable interventions under conflicting criteria. Fuzzy Cognitive Maps provide a framework for representing these systems and modeling how interventions affect key concepts over time.

In this work, we propose a decision-support workflow for scenario analysis and intervention design based on multi-objective optimization of Fuzzy Cognitive Maps. The approach is illustrated through a case study in the city of Mérida, Mexico, focused on mobility and sustainability, and validated with decision-makers. The results show that the proposed workflow can identify interventions across key concepts such as well-being and transportation access while explicitly representing trade-offs among objectives.

From an algorithmic perspective, we formulate the search for interventions as a multi-objective optimization problem and solve it using NSGA-II combined with an external archive, ArchiveUpdateTight2, to approximate the Pareto front. We then apply a reference-point approach in which a utopian point is specified, and the scenarios closest to it are selected from the computed approximation set. In our opinion, this provides a practical approach to support participatory decision-making in urban systems.

2 - A Multiobjective Optimization Perspective On Resilience
Stephan Helfrich, *Gabriela Ciolacu*, *Jan Boeckmann*, *Emilia Grass*

Resilience is commonly understood as a system's capability to prepare, resist, absorb, and recover from expected and unexpected adverse events without irreversible declines in essential performance. This broad interpretation implies that resilience must jointly capture multiple capabilities under adverse events. For instance, a system should be able to maintain routine performance as long as possible immediately after an adverse event, or to ensure both the extent and speed of recovery. Despite the growing importance of operations research in strengthening system resilience, existing optimization models often focus on single capabilities. Furthermore, systematic identification and balancing of trade-offs among these capabilities remain underexplored.

In this talk, we address this research gap by proposing a set of criteria that reflect resilience capabilities and allows the integration of those into an optimization framework. By doing so, our approach clarifies conceptual ambiguities in the resilience literature and translates resilience into explicit decision objectives. As a consequence, this enables both the identification and structured analysis of potential trade-offs among these criteria as well as the assessment of their implications for decision-making. We illustrate these trade-offs and their practical consequences through a use case based on the German healthcare system.

3 - Impacts of Plausible Scenarios on the Operational Optimization of a District Heating System Under Deep Uncertainty: A Finnish Case Study
Ghazaleh Saboori, *Giovanni Misitano*, *Soumen Atta*, *Juho Roponen*, *Timo Laukkanen*, *Babooshka Shavazipour*

Energy systems face increasing disruptions, including extreme weather, price spikes, resource depletion, and geopolitical shocks. This leads to increased uncertainty, and may cause decision-makers to disagree on model structure, plausible futures, and outcomes. This is classified as deep uncertainty, and the way of addressing it is evaluating the consequences of decisions across multiple plausible future scenarios while balancing conflicting objectives and avoiding major losses.

We examine a resource allocation case study of a district heating system in Finland. This is a multi-energy system that utilizes data center waste-heat supported by electrical and biomass boilers that ensure a reliable

heat supply and help meet district heating demand. Our contribution is to support robust decision-making under deep uncertainty.

We consider a multiobjective optimization model, minimizing total costs and CO2 emissions, while identifying system vulnerabilities and exploring robust solutions across plausible scenarios. To assess the effects of uncertainty on decisions and different objectives, we generate disruptive scenarios, including volatility in outside temperature and electricity and biomass prices, an unexpected loss of a data center, component outages, and biomass exclusion due to policy. We analyze system robustness and resilience across different scenarios, with the aim of finding a system that can reconfigure itself with minimal loss of heating efficiency.

4 - Bi-Objective In-Plant Logistics Problem in a Manufacturing Company
Diclehan Tezcaner Öztürk, *Murat Seçmen*, *Erdi Dasdemir*

This study addresses the Bi-objective Pickup and Delivery Problem (BO-PDP) in the in-plant logistics of a multi-product manufacturing company. During each shift, several heterogeneous vehicles collect products from their origin stations and deliver them to their destination stations. Since products are released at different times, timely delivery is critical to minimize their idle waiting times. Our first objective minimizes the total delivery lead times, which in turn increases operational efficiency. As a second objective, we minimize the route durations to maximize fleet utilization. We propose a bi-objective mixed-integer linear programming model to find efficient routes of the BO-PDP. We generate the efficient frontiers of instances with 8 to 15 parts with the augmented epsilon-constraint method. Due to high computationa times required for the largest instances of 15-parts we are developing a multi-objective genetic algorithm with tailored mechanisms such as solution representation, crossover, mutation, and repair operations. The results of the two methods will be evaluated and compared using real-world company data.

■ TD-05

Tuesday, 15:45-17:30 - Room: K5 (K.11.20)

Multi-objective Optimization Approaches

Stream: Interactive Methods
Contributed session
Chair: *Murat Koksalan, Gulsah Karakaya*

1 - A Bi-Criteria Optimization Approach for Outpatient Chemotherapy Planning
Gunsu Dagistanli Calli, *Meral Azizoglu*

The increasing demand for chemotherapy treatments often exceeds oncology clinic capacities, making efficient planning essential. This study addresses deterministic Outpatient Chemotherapy Planning under limited nurse and chair capacities, based on observations from Hacettepe Oncology Hospital. We propose a mixed-integer linear programming framework that assigns multiple treatments of each patient within a finite planning horizon while explicitly optimizing the total weighted worload and controlling daily overtime. Unlike online or template-based approaches, the model adopts an offline, horizon-wide perspective that captures patient-specific treatment windows and resource constraints. The planning problem is also formulated as a bi-criteria optimization model that maximizes the total weighted workload while minimizing total overtime. To support multi-criteria decision making, we generate the Pareto set using a classical nondominated objective vector algorithm, enabling decision makers to evaluate workload and overtime trade-offs instead of relying on a single solution. Computational experiments based on realistic problem instances with upto 75 patients demonstrate that the proposed model significantly outperforms current practice. The generated Pareto sets reveal clear trade-offs between total weighted workload and overtime levels, providing objective and practically relevant decision support for chemotherapy capacity planning.

2 - A novel reinforcement learning-assisted genetic algorithm for the multi-objective capacitated vehicle routing problem with time windows
Ali KoÇ, *Diclehan Tezcaner Öztürk*, *Ceren Tuncer Sakar*

This study proposes a Reinforcement Learning (RL)-assisted Genetic Algorithm (GA) framework for the Multi-Objective Capacitated Vehicle Routing Problem with Time Windows (MOCVRPTW). In this problem, homogeneous vehicles depart from a depot, visit each customer exactly once, and return to the depot. Routes are constructed by considering three objectives: minimizing total travel time, minimizing the number of vehicles used, and maximizing the satisfaction obtained from customers served within their time windows. This structure represents a multi-objective decision-making problem in which decision makers must evaluate trade-offs between operational cost, efficiency, and service quality. The proposed approach performs operator selection within an NSGA-II-based evolutionary algorithm through a Q-learning-based adaptive mechanism. Unlike traditional GAs that employ fixed operators, the proposed method selects crossover and mutation operators in a learning-based manner depending on the current state of solutions, dynamically managing the exploration-exploitation balance of the search process. In this study, five different Q-learning-based operator selection strategies are tested and compared with fixed-operator and randomly selected operator approaches. Experimental results demonstrate that learning-based operator selection significantly improves the quality of Pareto solutions and produces more balanced alternative solution sets for decision makers.

3 - Using LLM-Based Agents for Interactive Multi-Objective Optimization
Gökhan Ceyhan

At Just Eat Takeaway (JET), many logistics decisions require balancing multiple conflicting objectives. Two examples are real-time capacity management, which adapts partner delivery areas during demand surges, and courier–order assignment, which assigns incoming orders to couriers and determines delivery sequences. In both cases, outcomes depend on trade-offs among service quality, travel time, delivery delay, and operating cost.

In practice, multi-objective problems are often converted into a single objective through weighted sums, penalty terms, or lexicographic rules. Although this approach is operationally convenient, it has limitations. A fixed scalarization may not represent the full set of nondominated points. In addition, business users

may struggle to interpret and tune scalarization parameters, especially when changing preferences require repeated experimentation.

To address these issues, we explore LLM-based agents as an interaction layer between decision makers and optimization systems. Our agent accepts natural-language user queries, maps them to scalarization parameters, and calls optimization functions to support iterative solution refinement. Our goal is to help users better understand the solution space of their problems and reduce the time and effort required to obtain satisfactory solutions. To evaluate our approach, we compare its performance with well-known methods in interactive multi-objective optimization.

4 - An exact interactive algorithm for identifying and ranking the most preferred k solutions
Gulsah Karakaya, *Murat Koksalan*

Selecting the most preferred solution(s) with multiple conflicting objectives requires a decision maker (DM) to provide preference information reflecting their trade-offs between objectives. Interactive multi-objective approaches actively involve a DM to provide preference information throughout the search for preferred solutions. These approaches typically assume and exploit the properties of an underlying preference function to guide the search toward preferred solutions. Weighted distance functions are a flexible family of preference functions that represent a wide range of preference structures. In this study, we focus on the choice problem, in which the set of solutions (alternatives) is explicitly available. We develop an exact interactive algorithm that identifies and ranks the k most preferred solutions of a DM whose preferences are consistent with an underlying weighted distance function. We do not assume any prior knowledge of the parameters of the distance function. Our algorithm requires pairwise comparison information from the DM between selected alternatives and efficiently exploits the search region. We compare our algorithm with benchmark algorithms from the literature through extensive computational experiments on three- and four-objective problems under different true preference structures of the DM. The results show that our algorithm converges to the desired ranking after a relatively small amount of preference information, even for very large problems.

■ TD-06

Tuesday, 15:45-17:30 - Room: Lecture Hall HS 32

Policy Analytics

Stream: Decision Analysis/Making
Contributed session
Chair: *Marta Bottero, Alexis Tsoukias, Alessandra Oppio, Irene Pluchinotta*

1 - Policy analytics: further steps towards a common understanding
Marta Bottero, *Alessandra Oppio*, *Irene Pluchinotta*, *Alexis Tsoukias*

The concept of "policy analytics", introduced more than 10 years ago, aims at developing frameworks, tools, and methods to address public decisions (Tsoukias et al., 2013; De Marchi et al., 2016). Indeed, in public policies specific approaches able to consider not only data driven processes but also individual and social values, culture and public engagement are needed. Since then, different studies have discussed the evolution of the concept (Meinard et al. 2021) and many applications have explored the characteristics of policy analytics considering stakeholder participation and co-design. For example, in water management, interaction spaces and system dynamics models have been used to address conflicts over shared resources in multi-actor decision processes (Pluchinotta et al., 2018) and the design of decision and policy alternatives has been developed by combining Problem Structuring Methods and the participatory tool based on Concept-Knowledge theory (Pluchinotta et al 2020, Tosunlu et al 2025). Similar methods are relevant in urban planning, where scenario-based exploration helps navigate trade-offs between environmental, social and economic aspects (Oppio et al., 2024) and design-oriented frameworks support the creation of unforeseen policy alternatives, enabling innovative and inclusive decision processes (Bottero et al, 2025). Grounding on these studies, the contribution aims to highlight research frontiers to further expand the concept of policy analytics.

2 - Multicriteria Decision Analysis of Blue-Green Infrastructure based on Multifunctional Performance and Stakeholder Preferences
Sebastian Schär, *Judit Lienert*

Blue-green infrastructure (BGI) have been lauded as a multifunctional solution for cities. BGI can simultaneously contribute to stormwater management, heat mitigation, and biodiversity conservation. However, deciding on BGI, such as green roofs or ponds, which perform differently, is complex. Their performance is interdependent and societal valuation of trade-offs also varies. This study assesses 61 BGI configurations in a municipality near Zurich, Switzerland with respect to 13 technical, social, environmental and economic objectives via participatory multicriteria decision analysis (MCDA). Using expected expected utility (EEU), we integrated probabilistic performance predictions from mechanistic and statistical models with expert judgement and elicited preferences of six stakeholders from different political and technical domains. Overall, bioretention cells combined with detention ponds performed well in face of heterogeneous stakeholder preferences, indicating potential compromise. Smaller implementation rates performed better than larger spatial coverage because the higher associated drawbacks, e.g., costs and potential for invasive species outweighed marginal performance gains of larger coverage. This work advances the systematic sustainability assessment of BGI by proposing a participatory, model-informed approach, providing insights for policy design.

3 - A Robust Multi-Criteria Decision-Making Framework for Policy-Sensitive Decisions under Near-Deflation Uncertainty
Yi-hsien Huang

Decision-making in near-deflation environments is highly policy-sensitive and structurally uncertain, so forecast-driven optimization can yield fragile recommendations. This paper proposes a robust multi-criteria decision-making (MCDM) framework that supports policy-sensitive choices without relying on macroeconomic forecasting. We combine scenario design with explicit weight-uncertainty modeling to evaluate alternatives across risk exposure, resilience, stability, and adaptability under multiple plausible policy and economic regimes. Robustness is assessed through ranking-stability diagnostics, including rank-frequency profiles, pairwise dominance rates, and sensitivity

thresholds with respect to criteria weights and scenario assumptions. An illustrative case study demonstrates that the proposed approach reduces rank reversals and improves decision confidence compared with conventional single-scenario MCDM. The framework provides a structured and transparent basis for policy-aware decisions in near-deflation settings where small policy shifts can materially change outcomes.

Wednesday, 9:00-10:45

■ WA-02

Wednesday, 9:00-10:45 - Room: Senatssaal (K.11.07)

Global Aspects in Multiobjective Optimization

Stream: Multi-objective Programming
Contributed session
Chair: *Margaret Wiecek, Lavinia Amorosi*

1 - Solving Two-Stage Robust Biobjective Linear Programs with Parametric Benders Decomposition
Margaret Wiecek, *Herve Kerivin*, *Rakhi Goswami*

Multistage multiobjective optimization addresses decision problems under conflict and uncertainty allowing for decision making in stages to suit changing environments. A two-stage robust biobjective linear program (TSRBOLP) models two-stage decision processes with strategic decisions being made first, and operational decisions being made at a later time after more information about the decision problem is known. The goal is to compute the first-stage feasible solutions that are Pareto-efficient with respect to the first and second-stage objectives and account for the worst-case uncertainty scenario. TSRBOLP is studied under uncertainty in the right-hand-side of the constraints. The weighted-sum scalarization transforms the TSRBOLP into a single-objective optimization problem (SOP) whose optimal solutions are Pareto-efficient to TSRBOLP. The SOP assumes the form of a parametric linear program with bilinear terms in the constraints. A parametric Benders decomposition algorithm is designed to compute the exact parametric optimal solution functions to the SOP that provide a set of first-stage subrobust efficient solutions to TSRBOLP. The algorithm relies on a new adaptation of Benders decomposition into a parametric optimization environment. The implemented algorithm, making use of MATLAB Multiparametric Toolbox and the Biconvex Approximate Simplex Method (Pangia, 2024), computes approximate first-stage subrobust efficient solutions to TSRBOLP. Numerical examples are included

2 - Global Multi-Objective Simulation Optimization: Error Bounds and Convergence Rates
Susan Hunter, *Burla Ondes*

Consider the context of solving a multi-objective simulation optimization problem with one or more continuous objective functions to global optimality on a compact feasible set. For a simple algorithm that consists of selecting a finite set of feasible points using a space-filling design, expending the same number of simulation replications at each point to estimate the objective values, and returning the discretized estimated efficient and Pareto sets, we (i) introduce a mathematically tractable performance indicator for assessing the optimality gap of the discretized estimated efficient set, (ii) derive finite-time probabilistic upper bounds on the optimality gap, and (iii) determine how to trade off the number of feasible points with the number of simulation replications per point to ensure the optimality gap converges to zero in probability at a fast rate. Thus, we identify both an upper bound on the convergence rate for simple algorithms and a lower bound on the convergence rate for other algorithms that exploit structure. In addition, if the optimality gap is measured under the infinity norm, then the required total simulation budget grows slightly faster than logarithmically in the number of objectives. We demonstrate our results through numerical examples having one, two, or three objectives.

3 - Novel multi-objective dominance inequalities
Yue Zhang, *Lucas Létocart*, *Pierre Fouilhoux*

In this work, we present a new polyhedral approach for multi-objective combinatorial optimization problems. The principle is to cut locally dominated solutions and approach the convex hull of the locally non-dominated solutions. We call the inequalities separating the locally dominated solutions the dominance inequalities. Dominance inequalities were originally shown to be effective for single-objective problems, simultaneously improving relaxation bounds and reducing redundant regions of the feasible set. We extend dominance inequalities to a generic multi-objective setting, and theoretically show that they can be tight on the non-dominated frontiers of the feasible polytope in the criteria space. The multi-objective dominance inequalities, therefore, can be integrated into both the criteria space search algorithms and the decision space search algorithms. The empirical behavior are experimented on multi-objective (unconstrained nonconvex quadratic) Max-Cut instances.

4 - On the Use of Lagrangian Relaxation in Multi-Objective Integer Programming
Mariagrazia Cairo, *Lavinia Amorosi*, *Dell'Olmo Paolo*, *Serpil Sayin*

Lagrangian relaxation is one of the most effective techniques for deriving strong bounds in single-objective discrete optimization. A direct, straightforward extension of this idea to multi-objective optimization can be obtained by applying it to the scalarizations of the original problem. When the multi-objective structure of the problem is preserved, and a Lagrangian relaxation is applied to the original problem, the setting becomes considerably more challenging. In this case, the relaxation naturally yields bound sets instead of scalar bounds. Recent works have introduced a theoretical framework for Lagrangian duality in multi-objective integer programs, showing that suitable choices of Lagrangian multipliers may yield bound sets tighter than those obtained from the convex hull relaxation. Building on these theoretical results, this work develops an algorithmic framework to generate bound sets for multi-objective integer linear programs via Lagrangian relaxation while preserving the multi-objective structure of the dual problem. The proposed approach generates Lagrangian bound sets that can strengthen the ones obtained from the linear relaxation. Computational experiments on benchmark instances of different problem classes show that the resulting bound sets can be significantly tighter. Finally, as a proof of concept, we illustrate how these bound sets can be incorporated into a branch-and-bound procedure and discuss their impact on search tree pruning.

■ WA-03

Wednesday, 9:00-10:45 - Room: K8 (K.11.10)

Advances in MCDM Theory and Teaching MCDM

Stream: Advances in MCDM Theory
Contributed session
Chair: *Boris Naujoks*

1 - Comparative analysis of decision rules and value functions as preference models in multiple criteria sorting
Silvano Zappalà, *Salvatore Corrente*, *Salvatore Greco*, *Roman Slowinski*

We undertake a detailed examination of decision rules derived through the Dominance-based Rough Set Approach and value functions according to the UTADIS model, as they relate to sorting problems of varying complexity and structure. By situating these two approaches in parallel, we seek to highlight their main operational characteristics, strengths, and limitations, as well as the ways in which they represent preferences and support decision-aiding processes. Using the same data sets as a starting point, we reflect on how these frameworks can lead to different, yet complementary, interpretations of the same underlying sorting tasks, and we consider a multiplicity of factors that may influence their behavior, from data composition to decision context. Beyond theoretical reflections, we provide illustrative examples drawn from real-world applications, highlighting nuanced distinctions in outcomes and the interpretive value each approach may offer. Throughout the discussion, we refrain from asserting any universal superiority of one approach over the other, instead emphasizing the diversity of insights and perspectives that arise when well-established preference modeling techniques are applied and compared. Our objective is to provide a comprehensive view that encourages reflection and comparison, offering readers a multifaceted understanding of the practical and conceptual dimensions of decision rules and value functions in sorting contexts.

2 - A preference-based indicator normalization
Ignacy Kaliszewski

Social, economic, or technological indicators, when aggregated by composite indices, need to be normalized. We postulate that the normalization of indicators is based on preferred relationships between them. It is a novel approach that makes indicator normalization independent of the ranges of indicator values. We demonstrate that standard normalization methods can have detrimental effects on rankings.

For a composite index, we postulate the use of the Generalized Leontief Function, which provides a simple mechanism for controlling the balance of indicator values.

We illustrate our suggestions on European Union circular economy indicators and a popular ranking, the Human Development Index.

3 - Counterfactual analysis in Multicriteria Decision Analysis: Exploring decision and objective spaces
Renata Pelissari, *Sajid Siraj*, *Sarah Ben Amor*

Recent discussions on fairness in artificial intelligence have highlighted the role of counterfactual analysis as a way of understanding how alternative outcomes could be achieved. In machine learning, counterfactual explanations typically address questions such as what minimal changes in input variables would lead to a different prediction. The use of counterfactual reasoning remains largely unexplored in multicriteria decision analysis (MCDA). This work discusses the potential integration of counterfactual analysis into MCDA models through the conceptual distinction between two spaces involved in decision processes: the objective space and the decision space. The objective space corresponds to the evaluation outcomes of items or individuals based on a set of criteria, while the decision space consists of controllable or institutional variables that influence the generation of the performance outcomes observed in the objective space. We discuss that, for fairness-oriented decision processes, the preferable approach is to act on the decision space rather than on the objective space, which allows preserving the evaluation criteria and their associated requirements. These changes can be suggested based on the parameters of the decision model, such as the category profiles in multicriteria sorting methods. The purpose of this work is to introduce this conceptual perspective for MCDA, particularly in contexts of institutional decision processes.

4 - Towards a new approach to MCDM pedagogy
Boris Naujoks, *Olaf Mersmann*

Multi-criteria decision making and Pareto optimization are increasingly central to research across fields like operations research, machine learning, and engineering. Yet there are in our opinion gaps in the way these methods are taught in introductory courses and reproduced in textbooks. We perceive there to be a collection of ideas that have become part of the folklore passed down from generation to generation of researcher and practitioner that is not prominently found in the MCO literature.

This talk is aimed primarily at junior researchers who have encountered multi-objective optimization in their work and are building their intuitions about what these methods actually guarantee. We focus on a small collection of well-known but not well-documented insights about the structure of Pareto fronts and Pareto sets, and the practical challenges encountered when solving MCO problems. By giving concrete examples, we aim to replace a collection of common misconceptions with sharper models. The broader goal is to advocate for a more rigorous, example-driven approach to MCDM pedagogy.

■ WA-04

Wednesday, 9:00-10:45 - Room: K6 (K.11.17)

Practical Applications: AI and Software Ecosystems

Stream: Practical Applications of MCDM
Contributed session
Chair: *Esra Erarslan*

1 - AI-Driven Resilient Multi-Criteria Decision-Making Under Uncertainty for Multi-Agent Systems
Ali Nasir

Uncertainty, intermittent communication, and limited observability often hinder decision-making in multi-agent autonomous systems. This paper introduces an AI-driven resilient multi-criteria decision-making (MCDM) framework that combines a modified federated learning scheme with a partially observable Markov decision process (POMDP) to support decentralized decision-making under such constraints. The key idea is to enable agents to learn and update decision policies collaboratively without relying on continuous communication, while explicitly accounting for uncertainties in system states. The suggested method combines multi-criteria evaluation with the POMDP structure, which lets agents weigh competing goals like performance, safety, and energy efficiency. A modified federated learning mechanism is developed to

handle communication disruptions and asynchronous updates, ensuring robustness against partial information loss. Unlike conventional MCDM approaches, the framework captures both the dynamic evolution of system states and the distributed nature of decision-making. The resulting methodology supports adaptive and resilient coordination across agents operating in uncertain environments. We demonstrate its effectiveness by applying it to autonomous multi-agent scenarios, which demonstrate improved decision consistency and robustness under communication uncertainty.

2 - An Extensible Python MCDA Ecosystem, Illustrated with PROMETHEE
Gilles Dejaegere

We present a modular Python ecosystem for Multi-Criteria Decision Analysis (MCDA) designed to address fragmentation and maintenance issues in existing software. The framework currently consists of up to three libraries: mcda_core, defining standard data structures and APIs; mcda_methods, implementing general MCDA methods; and promethee, a specialized library for PROMETHEE methods maintained by our laboratory. This hierarchy ensures consistency, extensibility, and ease of integration. While our lab guarantees long-term support for PROMETHEE, the architecture is explicitly collaborative: we invite other research groups to contribute to any of the existing libraries or develop new method-specific libraries, while remaining fully compatible with mcda_core. This approach encourages shared development of well-documented, interoperable, and maintainable MCDA software, supporting reproducible research and method benchmarking. By separating core functionality from specific methods, the ecosystem lowers barriers for method developers, reduces duplication, and fosters a sustainable collaborative framework for the MCDA community.

3 - Bridging Scoring Methods Through Modular Decision Support: Meta Multiple Criteria Decision Aiding and Its Software Support
River Huang, *Milosz Kadzinski*, *Marco Cinelli*, *Salvatore Corrente*, *Peter Burgherr*

Scoring-based MCDA methods are traditionally applied as fixed, monolithic procedures, limiting users' ability to adapt the decision model to the characteristics of their data or preferences. This work introduces meta Multiple Criteria Decision Aiding (meta-MCDA), a modular framework that decomposes scoring methods into interchangeable components for polarity adjustment, normalization, aggregation, and optional post-aggregation steps. By exposing these modules and their admissible combinations, the framework enables both transparent reconstruction of established methods and the creation of principled hybrid designs tailored to specific decision contexts. To operationalize this approach, we present an enhanced version of the browser-based MCDA Calculator, which integrates feasibility checks and a guided questionnaire to support component selection for novice and expert users alike. The resulting system not only improves methodological clarity and robustness but also offers a practical environment for experimentation, education, and methodological innovation in MCDA.

■ WA-06

Wednesday, 9:00-10:45 - Room: Lecture Hall HS 32

Recent advances in interactive multiobjective optimization

Stream: Interactive Methods
Contributed session
Chair: *Kaisa Miettinen, Juho Roponen*

1 - Interactive SCORE Bands: A Progressive, Visual, Efficient, and Interactive Method for Solving Multiobjective Optimization Problems
Bhupinder Singh Saini, *Giomara Lárraga*, *Jonathan Fieldsend*, *Kaisa Miettinen*

Multiobjective optimization problems often have a large number of Pareto optimal solutions (or their approximations), making their exploration challenging for a decision maker (DM). Interactive methods address this challenge by iteratively incorporating preference information from the DM to guide the search toward preferred solutions.

SCORE band visualizations are designed to help DMs explore sets of solutions even in case of many objectives. The visualization extends parallel coordinates plot by grouping solutions into bands that represent clusters. Correlations among objectives are highlighted by ordering the axes and adjusting the distances between them to form clusters of correlated objectives. SCORE bands support in digesting key decision making elements in solution sets.

We propose a new interactive method utilizing SCORE Bands. The method first generates a sparse representation of Pareto optimal solutions and presents it to the DM as SCORE Bands. The DM can then select some bands to conduct a focused search. We developed a new evolutionary algorithm designed for this task. The new set of solutions is then visualized again as narrower bands, essentially "zooming in" to those regions of particular interest to the DM. The process continues iteratively until the DM identifies a satisfactory solution. The method allows efficient exploration of the Pareto solutions and rapid convergence to the DM's region of interest on a real-world problem using our open-source tool.

2 - Extending SCORE Band Visualizations for Group Decision Making in Multiobjective Optimization
Juuso Pajasmaa, *Bekir Afsar*, *Bhupinder Singh Saini*, *Giomara Lárraga*, *Kaisa Miettinen*

We present a novel interactive method to support group decision making in multiobjective optimization. It makes use of recently introduced SCORE band visualization technique and enables multiple decision makers to collaboratively explore a set of even high-dimensional Pareto optimal solutions. The decision makers can iteratively express individual preferences and, with the help of SCORE bands visualizations, reach a consensus through structured visual interactions over a small number of iterations. The solution process is structured in three phases: learning, consensus-reaching and decision phases, each of them serving different needs to reach a final solution that all decision makers can accept. The method employs group-oriented features such as a consensus indicator, objective axes highlighting the level of

agreement of decision makers and consensus rules for aggregating their preferences. We validate the effectiveness of the method with an experimental case study. In this study, the decision makers collaboratively solve a real-world forest management problem. The results demonstrate the applicability of the method in collaborative group decision making, facilitating efficient consensus-building and improving decision makers' understanding of trade-offs in complex decision problems.

3 - Role of Explanations in Improving Understanding of Trade-Offs in Interactive Multiobjective Optimization Methods
Giomara Lárraga, *Bekir Afsar*, *Kaisa Miettinen*

Interactive multiobjective optimization methods support decision makers in identifying preferred trade-offs among conflicting objective functions through an iterative solution process. However, it may be difficult for a decision maker to understand how their preference information influences the generated solutions. This may reduce transparency and confidence in the final solution. Recently, LIME-inspired explanations based on local linear approximations have been proposed to help explain trade-offs among objective functions.

In this work, this idea is extended and applied to the NIMBUS method. NIMBUS allows the decision maker to classify objective functions into different categories reflecting desired changes. We integrate LIME-based explanations into the interactive process to provide local trade-off information, helping the decision maker understand how improving one objective function value may affect the others. To support these explanations, we also provide visualizations. The approach is implemented in the open source DESDEO framework.

We conduct an experimental user study in which participants solve a multiobjective optimization problem using both the original NIMBUS method and an explainable version of it. The order of the methods is randomized across participants to mitigate order effects. The study investigates whether the explanations help users better understand trade-offs and support preference articulation during the interactive solution process.

4 - How can agents and explainability support a decision maker in interactive multiobjective optimization?
Matias Nieminen, *Giovanni Misitano*, *Michael Emmerich*, *Kaisa Miettinen*, *Bekir Afsar*

In interactive multiobjective optimization, a decision maker (DM) iteratively provides preference information to guide the solution process toward preferred Pareto optimal solutions while learning about trade-offs among objectives. Although interactive methods allow the DM to gradually refine preferences, it may still be challenging to understand how preference changes influence the resulting solutions and the values of different objectives.

To increase transparency and confidence, we propose MAS-XIMO, a multi-agent system for explainable interactive multiobjective optimization that provides additional decision support during the interactive solution process. The system consists of several autonomous software components, called agents, that perform specialized tasks and collaborate to assist the DM. In particular, MAS-XIMO generates tailored explanations that help the DM understand how modifying preferences may improve the value of a desired objective, and example-based explanations especially show how such improvements affect the remaining objectives through trade-offs.

The usability and potential of MAS-XIMO are illustrated through a case study. The results suggest that the proposed system can enhance the DM's understanding of refining preferences, provide additional support in identifying more desirable solutions during an interactive multiobjective optimization process, and increase the DM's confidence in the final solution.

Wednesday, 11:30-12:30

■ WB-01

Wednesday, 11:30-12:30 - Room: Auditorium HS33

Plenary: Manuel Bickel

Stream: Plenary Sessions
Plenary session
Chair: *Michael Stiglmayr*

1 - Decision contexts in applied sustainability science - navigating data challenges, trade offs and the promises of digitalization
Manuel Bickel

Sustainability science addresses the complex interactions within socio-ecological systems. Especially in times of accelerated resource consumption and the overstepping of planetary boundaries, the pressure to make sound, transformative decisions is immense. From a sustainability perspective, such decisions must balance intergenerational and intragenerational equity while incorporating systemic sustainability principles. Inevitably, this high complexity results in decision-making contexts characterized by poor data quality and trade-offs between competing targets. To safeguard our planet and ensure human well-being, we must urgently improve the tools and processes that guide these choices.

This contribution introduces key lenses of sustainability science and provide insights into concrete, real-world projects situated within this complex context. It seeks to initiate a dialogue between the MCDA community and applied sustainability science by showing potential interfaces. The presented projects span product-service systems, urban real-world laboratories, and the development of the German Sustainability Strategy. The contribution highlights where data availability is a critical bottleneck, where tools and methodologies from the field of multiple criteria decision analysis (MCDA) are needed, and where digitalization offers new pathways to improve decision-making, e.g. through digital product passports.

Wednesday, 13:30-15:15

■ WC-01

Wednesday, 13:30-15:15 - Room: Auditorium HS33

PhD Award Session

Stream: Plenary Sessions
Award Competition session
Chair: *Jafar Rezaei*

1 - Decision support methods resistant to imperfections of learning data
Grzegorz Miebs

This presentation addresses gaps between existing MCDA methods and real-world needs. Many established approaches handle idealized data but struggle with imperfections common in practice, such as measurement errors, imprecise values, and inconsistent decision-maker preferences. Different types of imperfections require tailored solutions, and in some cases, their sources can be identified and reduced or eliminated.

2 - Enhancing the decision-support capabilities of interactive multiobjective optimization with explainability
Giovanni Misitano

Real-life decisions often involve balancing conflicting criteria, modeled as objective functions in multiobjective optimization problems. These problems have multiple Pareto optimal solutions requiring input from a decision maker to identify the most preferred one. Interactive multiobjective optimization methods are particularly suited for this, as they allow decision makers to iteratively express preferences, and learn about the problem and its solutions. However, decision makers often receive insufficient support for understanding how their preferences influence computed solutions, and for justifying the decisions made.

This thesis introduces explainability, a concept from artificial intelligence, as a design principle for interactive multiobjective optimization. We present three novel methods: R-XIMO, which uses SHAP-based explanations to help decision makers understand the impact of their preferences on solution candidates; INFRINGER, which employs interpretable rule-based models to capture and model preferences; and XLEMOO, which extracts explainable rules characterizing solution regions aligned with expressed preferences. All methods are openly available in the open-source DESDEO framework.

This thesis establishes the foundations of explainable interactive multiobjective optimization, a new direction within MCDM that has already inspired numerous ongoing and planned follow-up studies, demonstrating the vitality and growing impact of this line of research.

3 - Parallelization in Multi-Objective Optimization based on the Epsilon-Constraint Scalarization
Kathrin Prinz

Until now, little attention has been paid to the possibility of parallelization in multi-objective optimization, even though it offers immense potential as modern processors are designed with multiple cores. We present an image-based algorithm, PEA, that takes advantage

of this. PEA computes all Pareto-optimal images (together with one solution each) with as few calls of some scalarization problem as possible, is easy to implement, is easy to parallelize, and scales as well as possible in terms of the number of used threads.

To achieve this, we use a lexicographic variant of the well-known epsilon-constraint scalarization. For the tri-objective case, we introduce a novel order on the non-dominated set that induces a rooted directed acyclic graph with edges corresponding to scalarization problems. We then generalize this framework to arbitrary numbers of objectives by defining an order on a finite parameter set, yielding a directed tree structure that enables independent subtree exploration and intuitive parallelization. We further relate these parameters to local upper bounds and use the connection to derive a polynomial bound on the number of scalarization problems required. Numerical experiments on benchmark instances from Kirlik and Sayin, including knapsack, assignment, and general integer problems, demonstrate that PEA achieves near-linear speedup with the number of threads and significantly outperforms existing state-of-the-art sequential and parallel algorithms on multi-core processors.

4 - A Decision Support Tool for Multi-Objective Production Scheduling and Lot-sizing - Exact, Approximate, and Hybrid Algorithms
Yannik Nikolas Zeiträg

In the modern manufacturing landscape, achieving operational efficiency has become increasingly important for companies to remain competitive in a globalized market. Production planning and scheduling are recognized as one of the most significant levers in operations management, offering substantial potential to enhance a company's operational performance. Therefore, the pressure on decision-making processes regarding lot-sizing and scheduling, is immense. These processes are crucial for optimizing manufacturing operations, yet they are fraught with complexity due to the need to balance conflicting objectives, such as minimizing production costs while simultaneously maximizing resource utilization and meeting tight delivery schedules. The rising globalization and the increasing demand for customized products have further complicated these tasks with a high level of variability and uncertainty that traditional optimization methods often struggle to accommodate effectively. This dynamic and complex environment underscores the urgent need for advanced decision support tools that are not only capable of addressing these multifaceted challenges but also adaptable enough to function efficiently in real-world manufacturing settings.

This PhD thesis seeks to bridge the gap between theoretical models and practical application, targeting the development of a sophisticated decision support tool for multi-objective lot-sizing and scheduling problems. Through addressing identified gaps in the literature, such as the integration of multiple objectives, the efficiency of solution methods, and the adaptability to dynamic events, this research aims to contribute innovative solutions that can significantly enhance decision-making in optimization processes in manufacturing, leading to improved operational efficiency and competitive advantage in the global market.

The research journey unfolds through a series of studies, each building on the insights and challenges uncovered in the preceding ones. It begins with the challenge of incorporating multiple objectives into the mathematical formulation of lot-sizing and scheduling problems, leading to the creation of an interactive decision support tool. This tool guides decision-makers towards optimal compromise solutions by balancing various objectives. However, the initial reliance on exact solving methods highlighted the necessity for a more efficient approach in order to allow quick decision-making which is required in dynamic real-world applications. Therefore, the exploration of artificial intelligence techniques, specifically machine learning, to enhance the efficiency of solution procedures, was elaborated.

Subsequent studies focus on optimizing the training of new heuristics through genetic programming and exploring the potential of reinforcement learning for dynamic job shop scheduling problems. Despite the advantages of genetic programming, the exploration into reinforcement learning techniques underscored the value of continued investigation into multi-objective optimization methods.

The research culminates in the development of a genetic programming-based approach that not only addresses the efficiency of automatically evolving heuristics but also tackles the integration of interconnected lot-sizing and scheduling decisions. This approach proved promising, achieving solutions close to the exact optimum and demonstrating suitability as a reactive optimization method in the face of uncertain events. The development of a rolling horizon planning scheme further illustrates the potential of the proposed methods to efficiently respond to short-term changes in customer demands.

Through systematic exploration and innovative methodology development, this thesis contributes significantly to the fields of operations research and management science, particularly in enhancing the decision-making processes and the efficiency of solution methods in manufacturing. By addressing the identified gaps with practical and integrated solutions, this research marks a substantial advancement in the optimization of production planning and scheduling and paves the way for more adaptable, efficient, and sustainable manufacturing operations.

Wednesday, 15:45-16:30

■ WD-01

Wednesday, 15:45-16:30 - Room: Auditorium HS33

Outing Introduction Talk

Stream: Plenary Sessions
Contributed session
Chair: *Kathrin Klamroth, Michael Stiglmayr*

1 - Research for evidence-based decision-making in conservation - Examples of research conducted in zoos
Dr. Arne Lawrenz

Scientifically managed zoos in Germany and around Europe are undergoing a transformation. The shift from historical menageries, where in the past animals were simply displayed for entertainment, to modern conservation centers, which is what many Zoos are today, is shaped by research and scientific work. In this lecture, the director of the Green Zoo Wuppertal, Dr. Arne Lawrenz, will provide an overview of evidence-based decision-making in species conservation using state of the art research examples. He will showcase the work of modern zoological gardens, explain what this transformation is all about and why it is necessary for our future.

Thursday, 9:00-10:45

■ HA-02

Thursday, 9:00-10:45 - Room: Senatssaal (K.11.07)

Representations in Multiobjective Optimization

Stream: Multi-objective Programming
Contributed session
Chair: *David Könen*

1 - Representations of Multiobjective Optimization Problems based on Low Discrepancy Point Sets
Renée Lamsfuß, *Kathrin Klamroth*, *Michael Stiglmayr*, *Carola Doerr*

In this talk, we present an approach for constructing representations of multiobjective optimization problems using low discrepancy point sets. Such point sets are well distributed within a given space, as characterized by a discrepancy measure defined on the respective space. We construct optimal point sets on the parameter spaces of different scalarization methods to derive representations of the nondominated set. We evaluate the quality of these representations with respect to various metrics and test the approach across a range of test problems.

2 - Decision and Objective Space Representations (DO-REP) in Continuous Multi-objective Optimization
Lara Löhken, *Kathrin Klamroth*, *Serpil Sayin*

While recent research on representation algorithms and representation measures focuses mainly on the objective space of a given multi-objective optimization problem (MOP), we aim at finding high-quality representations both in the decision and objective space for continuous MOP.

By stating optimality conditions for weighted sum scalarizations, we derive parametric equations for Pareto critical points, parameterized by the weights. Sensitivity analysis of such points wrt. variations of the weights yields a system of differential equations. Under appropriate assumptions, its solution is a function whose image is the set of Pareto optimal solutions. In our proposed continuation method, we approximate this function using numerical solvers for differential equations, thereby speeding up the computation and outperforming existing methods.

The determination of Pareto optimal solutions at selected grid points can be interpreted as a representation of the Pareto front. The resulting approximation method contrasts with other common representation approaches as it operates in the decision rather than the objective space. By using different discretization strategies for the computation of grid points in the decision space, we derive different representations that are evaluated wrt. their approximation and representation quality. We analyze how different discretizations in the decision space affect representation quality in the objective space, using suitable quality indicators.

3 - A general framework for representations of the non-dominated set
Marie Humbert–Ropers, *Lucie Galand*, *Daniel Vanderpooten*

The aim of this work is to determine concise and meaningful representations of the non-dominated set. Concision is ensured by imposing a fixed cardinality of the resulting representation set. Meaningfulness is defined using a binary representation relation that specifies the conditions under which a point can represent another. Required properties for such relations, which may integrate preference information, are investigated. The problem of generating a representation set is then formally defined imposing coverage and non-redundancy requirements, as detailed in [HGV25]. We show how to solve this problem in two different contexts. When the non-dominated set is explicitly available as a finite list of points, we propose a polychotomic method, adapted from location theory [CT13]. When the non-dominated set is implicitly defined through a mathematical programming formulation, we propose a method based on kernels [BJV17].

[BJV17] C. Bazgan, F. Jamain, D. Vanderpooten. Discrete representation of the non-dominated set for multi-objective optimization problems using kernels. Eur. J. Oper. Res., 260(3):814-827, 2017. [CT13] H. Calik, B. Tansel. Double bound method for solving the p-center location problem. Comput. Oper. Res., 40(12):2991-2999, 2013. [HGV25] M. Humbert-Ropers, L. Galand, D. Vanderpooten. On the representation of the non-dominated set of multiobjective optimization problems. Eur. J. Oper. Res., online, 2025.

4 - Supported Nondominated Points as a Representation for Multi-Objective Network Optimization Problems
David Könen, *Lara Löhken*, *Michael Stiglmayr*, *Kathrin Klamroth*

In multi-objective combinatorial optimization, nonsupported nondominated points typically outnumber their supported counterparts and are significantly more challenging to determine. While recent studies suggest that extreme supported non-dominated points provide sufficient representations for certain binary problems, this paper demonstrates that this does not generally hold for network optimization. Specifically, this paper evaluates the quality of supported nondominated points (YS) and extreme supported nondominated points (YES) as representations of the complete nondominated point set across various network optimization problems. While YES provides high-quality representations for binary problems such as the Multi-Objective Shortest Path and Minimum Spanning Tree problems, relying solely on YES yields insufficient representation quality for problems with increasing arc capacities. Conversely, YS consistently maintains high representation quality with a near-optimal hypervolume indicator, regardless of problem size or capacity scaling. Furthermore, a cardinality-constrained approach is introduced, demonstrating that small subsets directly selected from YS or YES bypass the computationally expensive generation of YN, while already serving as effective representations for decision makers requiring a limited number of solutions.

■ HA-03

Thursday, 9:00-10:45 - Room: K8 (K.11.10)

MRDM (Multiple Rule-Based Decision Making) and Fuzzy MADM 1

Stream: Invited Sessions
Invited session
Chair: *James Liou, Sun-Weng Huang, Shan-Lin Huang, Jian-Hua Xia, Gwo-Hshiung Tzeng*

1 - Barriers to Exit for Multinational Firms during Geoeconomics Fragmentation
Hsin-Tsz Kuo

Exit barriers faced by multinational firms amid the current fragmentation of global geopolitics directly impact the feasibility and timing of exit decisions. This study aims to examine how the following four categories of exit barriers influence exit decisions and their prioritization: (1) Structural barriers, (2) Strategic barriers, (3) Managerial barriers, and (4) Geopolitical barriers. Experts' opinion obtained through interviews, we employed fuzzy DMENTAL analysis to provide constructive reference for both practitioner and academic.

2 - Applying the Dynamic Z-number Fuzzy Delphi Method to Explore Core Competencies for Daily Care of Patients with Dementia
Fu-mei Pang, *Jian-Hua Xia*, *Sun-Weng Huang*

As the global population ages, dementia has become one of the fastest-growing and most costly conditions in healthcare systems. Daily dementia care involves multidimensional demands, long-term engagement, and high uncertainty, making the identification of key care competencies essential. This study develops core competencies for dementia daily care through an expert-supported decision framework. A literature review first identified relevant competencies. The Dynamic Z-number approach was applied to quantify expert inconsistency and uncertainty, followed by the Fuzzy Delphi Method to achieve consensus. The Interquartile Range (IQR) was then used to determine core competencies. Experts included nursing supervisors, clinical specialists, and academic scholars. Results show strong expert consensus on seven core competencies, providing a structured reference for improving dementia care practice and decision-making.

3 - A BWM-mV Model for Evaluating Five-Axis CNC Metal Machining Suppliers: A Comparative Study of China and Vietnam
Chincheng Yeh

High-quality 5-axis CNC metal processing suppliers are instrumental in ensuring precision, accelerating lead times, and optimizing manufacturing costs, all while enhancing supply chain resilience. Conversely, inadequate supplier capabilities often result in quality discrepancies and logistical bottlenecks, undermining a product's market competitiveness and its time-to-market. Within the realm of supply chain management, existing literature predominantly focuses on general manufacturing selection or the technical nuances of CNC hardware. There is a notable gap in the systematic exploration of evaluation frameworks specifically tailored to 5-axis CNC metal processing. In real-world decision-making, evaluation criteria are often deeply interrelated. Under constraints of limited resources and compressed timelines, identifying and prioritizing critical criteria is a pivotal challenge.To address these multi-criteria decision-making (MCDM)complexities, this study utilizes the BWM-mV model. This model systematically determines the weight of evaluation criteria and ranks solution performance, enabling decision-makers to pinpoint priority areas for improvement. Specifically, this research constructs an evaluation index framework and a comprehensive selection for 5-axis CNC metal OEM suppliers, analyzes the characteristic differences between Chinese and Vietnamese suppliers, and identifies the core competencies of high-tier providers to propose actionable enhancement strategies.

■ HA-04

Thursday, 9:00-10:45 - Room: K6 (K.11.17)

Evolutionary Multi-Objective Algorithms and Other Heuristics

Stream: Heuristic Algorithms
Contributed session
Chair: *Jyrki Wallenius*

1 - Multi-Objective Multi-Agent Pathfinding in Path-Influenced Environments
Carlo Nübel, *Sanaz Mostaghim*

In multi-agent pathfinding, the goal is to find collision-free paths for all agents in a shared environment. These paths are often optimized for objectives such as travel time, safety, or smoothness. Most related work assumes the environment to be predictable: either only static obstacles are considered, or some include dynamic obstacles that can move in predictable ways. But there is very limited research on pathfinding problems in which the agents can move the obstacles out of their way, actively changing the environment globally for all agents. In our work we study pathfinding in path-influenced environments. While an agent traverses on its path, it can push obstacles out of its way instead of going around. This changes the environment for all agents, adding new complexity to multi-agent pathfinding. This opens a door to a range of real-world applications. Imagine, for example, a fleet of warehouse robots moving around shelves and boxes in a warehouse. Here, agents could block each other's paths if the paths and actions are not planned carefully. We currently study versions of this problem in which multiple agents must solve the same TSP while optimizing paths and actions under multiple conflicting criteria in a path-influenced environment. In particular, we study how cooperative objective formulations-such as minimizing the time agents block each other with obstacles-affect emergent behavior compared with formulations where each agent optimizes only its own goal.

2 - Towards a Robust Sampling Method in Multi-Objective Genetic Programming
Pravin Pandey, *Sanaz Mostaghim*

Genetic programming is an approach to discover symbolic expressions from scientific data. Current GP methods rely on randomly initialized populations and focus on the performance of the algorithm in terms of accuracy/error and rarely emphasize developing robust expressions. However, in many applications, symbolic expressions should be generalizable, reliable, and accurate.

To address this, we propose to develop a robust sampling method based on the perturbation and uncertainty quantification for each expression. The definition

of expression perturbation is challenging, since even a small change in a value can result in an entirely different expression. We define the perturbation based on neighborhood distances. The robust sampling method initially concentrates on exploring the search space and later exploits the best-performing solutions. We develop a ranking system based on the robustness of the expressions. For quantifying expression uncertainty, we introduce data variability and noise in the dataset and evaluate the solutions using two objective functions: error and sensitivity of error to data variability. In our experiments, we study the effect of robust sampling over several scientific benchmarks.

3 - Meta-Learning and LLMs Integration for Evolutionary Multiobjective Optimization
Wouter Koppen, *Sebastian Rojas Gonzalez*, *Bhupinder Singh Saini*, *Ivo Couckuyt*

When solving multiobjective optimization problems via evolutionary multiobjective (EMO) methods, Decision-Makers (DM) often struggle to articulate the objective trade-offs they value most, while analysts lack tools to translate these abstract preferences into algorithmic choices that account for the inherent biases of different optimization methods.

Moreover, the plethora of EMO algorithms implicitly favor distinct quality indicators (e.g. hypervolume), but no single quality metric can be said to be the best one for any given real-world application. This makes performance assessment difficult for inference and decision-making. To address this, we analyze an extensive dataset of EMO algorithm executions from a novel perspective. Rather than relying on standard indicators purely for benchmarking, we map algorithmic performance profiles by integrating problem types, performance metrics, Pareto front topologies, and search trajectory dynamics.

Building on this empirical foundation, we learn a meta-model capturing relationships between problem characteristics and algorithm behavior. We then integrate this model with Large Language Models (LLM) to enable DMs and analysts to articulate their abstract algorithm and/or problem performance goals in natural language, which the framework translates into informed, data-driven algorithm recommendations tailored to the problem at hand.

4 - Use of Heuristics in Pairwise Multicriteria Choice Tasks: An Experimental Study
Jyrki Wallenius, *Eeva Vilkkumaa*, *Patience Anipa*, *Matias Kivikangas*, *Pekka Malo*, *Kalyanmoy Deb*, *Konstantinos Katsikopoulos*

People use heuristics in decision-making when problem complexity and uncertainty is increased. Heuristics as a scholarly field of decision making was pioneered by Tversky and Kahneman, although Simon talked about heuristics already in the 1950's. Our focus is on multi-attribute choice in a deterministic setting.

Examples of common heuristics used by humans are non-compensatory heuristics take the best and compensatory heuristics tallying. There is also evidence that people use heuristics that are somewhere between non-compensatory and compensatory. Examples of such heuristics include Take-Two heuristic and threshold heuristic.

Against this background, we study the following research questions:

1. What is the "fit" of different heuristics and their variations to available data? 2. How do these heuristics depend on the number of criteria? 3. How do these heuristics depend on the time spent on the task?

To address these questions, we use data from a previous experiment in which 48 subjects made altogether 5,670 pairwise choices between product bundles. The number of attributes ranged between 2-10. In addition to the subjects' choices, we have gathered process data through questionnaires and eye-tracking measures. We use these data to study whether the outcomes as well as the process data align with four different heuristics. We are not studying, which heuristic is "prescriptively best", but rather, which heuristic is "descriptively best".

■ HA-05

Thursday, 9:00-10:45 - Room: K5 (K.11.20)

Practical Applications: Transportation Systems

Stream: Practical Applications of MCDM
Contributed session
Chair: *Birsen Karpak*

1 - A Multi-Criteria Decision Framework for Freight Forwarders' Air Carrier Selection
Konrad Gastpari

Freight forwarders play a central role in the air cargo supply chain, as their choice of airline partners directly influences carriers' commercial performance. However, the decision logic behind carrier selection remains insufficiently explored in both academic research and industry practice. This study investigates the key parameters influencing freight forwarders' carrier choices and develops a structured decision-support framework.

The research is conducted in collaboration with Swiss International Air Lines (SWISS) and combines literature review, industry interviews, workshops, and a global survey of more than 200 freight forwarders. The exploratory phase identified over twenty decision parameters, including price, capacity availability, service quality, network coverage, brand perception, and shipper preferences.

Based on these insights, a Multi-Criteria Decision Making framework is developed to model carrier selection. The framework is currently being validated using real contract and pricing data from SWISS to test decision scenarios and refine the weighting of decision criteria.

2 - Prioritizing Integrated SDG-Transport Scenarios: A Hybrid MEREC-AROMAN Approach for Strategic Roadmap Development
Fusun Ulengin, *Y. Ilker Topcu*, *Sule Onsel Ekici*, *Özgür Kabak*, *Ozay Ozaydin*

Transport systems are crucial to the UN SDGs. Prioritizing integrated SDG-Transport scenarios for strategic planning requires handling of conflicting criteria. We propose a hybrid MCDM framework to prioritize 17 scenarios with respect to 22 sustainability factors including transparency, equality, and decarbonization. This research utilizes the MEREC (MEthod based on the Removal Effects of Criteria) to determine objective importance based on data variance, mitigating subjective bias. The analysis reveals that specific social factors, such as "Access to Care" and "Equality," are more important than governance factors due to their greater

variance across scenarios. Then, the AROMAN (Alternative Ranking Order Method Accounting for two-step Normalization) technique is applied to evaluate the scenarios. AROMAN employs a dual-normalization strategy that combines linear and vector techniques. This hybrid mechanism minimizes information loss during data transformation and provides greater stability against outliers. Therefore, AROMAN delivers a more reliable ranking in high-dimensional decision environments. The results reveal "Accessibility Metrics & Mobility Justice Mainstreaming" and "Rail-Centric Transition" as the top-performing scenarios, shifting focus from broad policy integration to targeted social and infrastructural interventions. This study provides a validated, data-driven roadmap for policymakers to align national transport strategies.

3 - Measuring Employee Satisfaction of Public Transport Personnel: A Participatory Multi-Method Approach
Nils Katzke, *Irene Abi-Zeid*, *Natalia Kliewer*

Ongoing urbanization and labor shortages challenge public transport operators to improve working conditions. While crew scheduling, rostering, and rerostering models in operations research traditionally focus on cost minimization or robustness, employee satisfaction lacks conceptualization as a structured, multidimensional construct. This study presents a transdisciplinary research design that quantifies employee satisfaction through a participatory framework to bridge the gap between qualitative stakeholder perspectives and formal decision-making. The methodology follows a multi-stage process combining qualitative elicitation, quantitative analysis, and participatory stakeholder engagement within the real-world organizational context of a German municipal public bus company. The results reveal statistically significant dimensions of employee satisfaction within the personnel planning process, with work-life balance and duty structure emerging as principal determinants. Clustering reveals four heterogeneous workforce profiles with distinct preferences influenced by demographic factors such as life phase, contract type, and caregiving responsibilities. Ultimately, this study provides an empirically grounded conceptual basis for integrating heterogeneous stakeholder values into multicriteria personnel planning in shift-based environments, enabling transparent trade-offs between operational efficiency and the diverse needs of a modern workforce.

■ HA-06

Thursday, 9:00-10:45 - Room: Lecture Hall HS 32

AHP/ANP: Urban Infrastructure, Energy, and Construction

Stream: Decision Analysis/Making
Contributed session
Chair: *Cigdem Kadaifci*

1 - An MCDM-based DSS for Sustainable Solar Power Plant Site Selection: A Multi-Regional Application in Türkiye
Taha Kulekaya, *Goktug Berke Yalcin*, *Y. Ilker Topcu*

Identifying optimal sites for solar power plants is a complex multi-criteria problem involving conflicting technical, economic, environmental, and social criteria. This study presents the design and application of a hybrid MCDM-based DSS for sustainable solar energy site selection in Türkiye. The system follows an Input-Process-Output architecture integrating a GIS-based filtration module, an AHP-based criteria prioritization approach, and dual TOPSIS-VIKOR ranking algorithms. Evaluation criteria were selected based on the systematic meta-analysis by Jong & Ahmed (2024), yielding six empirically grounded criteria: Solar Radiation, Distance to Grid, Slope, Average Air Temperature, Land Cost, and Social Acceptance. Six Turkish cities representing distinct geographic archetypes — Konya, Şanlıurfa, Antalya, Istanbul, Erzurum, and Rize — are evaluated as candidate alternatives. The DSS design phase is complete; the empirical application, including decision matrix construction, AHP prioritization, TOPSIS-VIKOR rankings, and sensitivity analysis, is currently being finalized. The dual-method validation approach ensures robustness of recommendations for high-stakes energy investment decisions, directly supporting Türkiye's Net Zero 2053 targets, the UN Sustainable Development Goal 7 (SDG7), and the European Green Deal's renewable energy objectives.

2 - A Fuzzy Analytic Hierarchy Process Framework for Group-Based Prioritization of Climate Hazards in Infrastructure Adaptation
Shereen Altamimi, *Liping Fang*, *Lamya Amleh*

Climate adaptation for infrastructure requires prioritizing multiple hazards under uncertainty. This paper develops a group decision-support framework based on the fuzzy analytic hierarchy process (FAHP) to quantify the relative importance of climate hazards using expert judgment. Expert preferences are represented as triangular fuzzy numbers, aggregated into a decision model using a fuzzy aggregation procedure. The decision problem is structured hierarchically, linking climate hazards to bridge systems and propagating their relative importance through to asset-level adaptation prioritization. The resulting hazard-importance weights are combined with bridge-specific information to enable comparative ranking of assets by climate sensitivity and adaptation urgency across an infrastructure portfolio. A municipal bridge inventory is used to demonstrate the framework, showing that alternative hazard-weighting structures materially influence network-level prioritization outcomes, thereby highlighting the importance of group aggregation in adaptation planning. The framework supports planning tasks such as identifying high-priority assets, comparing interventions, and communicating results to non-technical stakeholders. The paper contributes to MCDM literature by operationalizing fuzzy group-based prioritization at network scale in data-limited, uncertainty environments, extending FAHP beyond traditional hazard ranking toward actionable infrastructure decision support.

3 - Transforming regional energy systems - An integrative approach to optimised site planning for hydrogen production
Caroline Andersen, *Sina Narimani Abar*, *Martin Schulwitz*, *Lars-Peter Lauven*

Hydrogen plays a central role in the energy transition by decarbonising energy-intensive industries and enabling the storage of fluctuating renewable energies through hydrogen production via electrolysis. As demand for hydrogen is expected to increase in the near future, there is a need to establish an increasing number of suitable sites for electrolysis. Electrolysers are highly dependent on local conditions, including environmental resources, public supply infrastructure, and local demand potential. In this study, we conducted a GIS-based multi-criteria decision analysis

(MCDA) to identify the most suitable locations for electrolysers, ensuring environmental compatibility, cost-effectiveness, and supply security. The criteria were weighted using the analytic hierarchy process (AHP), based on an expert survey, and applied in a case study to identify sites with high suitability. A total of 3,000 locations were identified as potentially suitable for electrolysis within the designated study area, meeting all relevant planning regulations and technical requirements. The results indicate that 19% of the study area, corresponding to 82.12 km', is suitable for electrolysis. The most influencing factors are connectivity to the planned core network infrastructure and the local hydrogen demand.

4 - A Two-Stage MCDM Framework for Organizational Capability Assessment in Construction Industry
Cigdem Kadaifci, *Gorkem Kayacioglu*

This study aims to prioritize organizational capabilities in the construction industry by examining how capability priorities vary across different project types within a structured multi-criteria decision-making framework. First, a comprehensive capability model was developed through a literature review and refined for the construction industry. The importance of these capabilities was determined using the Analytic Network Process (ANP), enabling consideration of interdependencies among capabilities. In the second stage, construction project types were identified, and the required capabilities for each type were assessed using the Weighted Aggregated Sum Product Assessment (WASPAS) method. This approach incorporates expert judgments to capture project-specific capability requirements. Findings indicate that while certain capabilities remain critical across all project types, their relative importance changes significantly depending on project characteristics. These results highlight the need to align organizational capability development strategies with project types. The main contribution of this study is the integration of ANP and WASPAS within a single framework to evaluate capabilities at both industry and project-type levels. Acknowledgement: This work was supported by the Scientific Research Projects Coordination Unit (BAP) of the Istanbul Technical University (Project ID: 48040).

Thursday, 11:15-12:30

■ HB-02

Thursday, 11:15-12:30 - Room: Senatssaal (K.11.07)

Applications in Multiobjective Optimization

Stream: Multi-objective Programming
Contributed session
Chair: *Maren Manzke*

1 - Multi-Criteria Optimization in Material Modeling
Joris Wenzel, *Michael Bortz*, *Fabian Jirasek*, *Stefan Ruzika*, *Hans Hasse*

Mathematical modeling of material properties is essential in many areas of engineering. Important model classes in this field are equations of state (EOS) and force-field models for molecular simulations. These models contain parameters that are fitted to experimental data to describe properties of interest accurately. However, improving the description of one property typically deteriorates the description of others. These conflicting objectives naturally motivate the use of MCO. In previous work, we observed characteristic topologies of Pareto sets in MCO problems for fluid material modeling using EOS and force-field models. These Pareto sets have a pronounced "Pareto knee" region with long, nearly linear extensions connecting it to the individual minima [Stöbener et al. 2014, Kulkarni et al. 2022]. This can be explained by the approximately quadratic nature of the objective functions in many practical problems we studied. Such approximations are necessary because evaluating the objective functions, often not available in explicit form, can be computationally expensive. Based on the quadratic approximation the Pareto knee can be identified efficiently. This region is of high interest, as it represents well-balanced compromises. The approximation can then be refined iteratively based on these results. We will discuss the observed Pareto-set topologies, the effectiveness of quadratic approximations of the objective functions, and the advantages of MCO in these problems.

2 - Optimizing Students' Academic Performance and Well-Being: An Interval Multiobjective Approach
Andrea Orozco Villodres, *Mariano Luque*, *Ana Belen Ruiz*, *Sandra GonzÁlez Gallardo*

To properly evaluate educational success, policymakers must take into account not only students' academic achievement but also their overall well-being, as both dimensions are essential for healthy development and long-term learning. This study examines how these two areas can be simultaneously strengthened among students in Spain. Drawing on data from the PISA 2022 report for Spain, the analysis incorporates five key indicators: performance in mathematics, reading, and science as measures of academic achievement, along with bullying prevalence and health indexes as core components of student well-being. Using econometric techniques, the study develops an interval multiobjective linear programming model designed to identify balanced solutions across different scenarios. The results show that the profile of the "compromise student"

— the one who would maximize both academic outcomes and well-being — varies notably depending on the scenario considered. The research also evaluates the potential improvements achievable in each indicator relative to the current situation of Spanish students, revealing substantial disparities in the margin for progress across dimensions. Finally, the study discusses several socio-educational strategies and policy measures aimed at creating more supportive environments that enhance both learning and well-being.

3 - Target Date Scheduling within a General Framework for Multi-Objective Online Optimization
Maren Manzke, *Sven Krumke*

In parallel machine scheduling, not only processing times but also memory requirements can affect solution quality. Bilò et al. studied this setting in the online model, where jobs have to be assigned upon arrival. They extended Graham's classical list-scheduling algorithm to the bi-objective problem of minimizing makespan and maximum memory load. Their results yield a family of online algorithms whose parameter induces a trade-off in the objective-wise competitive ratios: it increases competitiveness in the first objective and decreases it in the second.

We extend these results to the more general target date assignment problem of Heinz et al. with bi-objective parallel machine scheduling as downstream problem. In this two-stage problem, each job arrives online and has to be assigned to one of finitely many feasible target dates. For every target date, an instance of the downstream problem has to be solved and the goal is to minimize the maximum downstream cost in each objective. Using the algorithm of Bilò et al. as a subroutine, we obtain a parameterized family of online algorithms (with two parameters) which provide similar trade-offs with respect to the competitiveness in each objective.

We place the results of both problems into a general framework for multi-objective online optimization. Besides evaluating objective-wise competitiveness, the framework allows to measure how far the solution of an online algorithm must be shifted to become non-dominated.

■ HB-03

Thursday, 11:15-12:30 - Room: K8 (K.11.10)

Session MRDM (Multiple Rule-Based Decision Making) and Fuzzy MADM 2

Stream: Invited Sessions
Invited session
Chair: *James Liou, Sun-Weng Huang, Shan-Lin Huang, Jian-Hua Xia, Gwo-Hshiung Tzeng*

1 - Team Functioning in Self-Directed Group Learning Activities and Its Influence on Holistic Care and Well-being among Older Adults: An Integrated PLS-SEM and Rough Set Appr
Pi Ching Weng

With the rapid ageing of the global population, the health and quality of life of older adults have become important public policy concerns. Holistic care has emerged as an important approach to elderly services, emphasizing integrated support across physical, psychological, social, and spiritual dimensions to improve well-being and life satisfaction.

Self-directed group learning activities provide opportunities for older adults to engage in collaborative learning and social participation. However, the effectiveness of these activities depends on team functioning capability, including communication, collaboration, motivation, and group cohesion. Previous research mainly focuses on single factors and rarely examines the integrated relationships among team functioning capability, holistic care, and well-being.

This study proposes an integrated research model and combines Partial Least Squares Structural Equation Modeling and the Rough Set Approach to analyze these relationships. The findings provide insights for designing community programs that promote active ageing and enhance the well-being of older adults.

2 - Developing Novel Fuzzy Measure Survey Methods to Enhance the Reliability of Fuzzy Integrals in Multi-Criteria Decision-Making
Shan-Lin Huang, *Chin-Yi Fang*, *Gwo-Hshiung Tzeng*

This study develops a new survey method for eliciting fuzzy measures to improve the reliability of fuzzy integrals in Multi-Criteria Decision-Making (MCDM) filed. Traditional fuzzy measure value often relies on expert judgments or questionnaires, which may suffer from data collection errors and reduced consistency, particularly when the number of criteria increases. To address this problem, we propose: (i) a fixed-total binary assessment method, (ii) a discrete linguistic scale method, and (iii) a parameterized fuzzy number method using triangular and trapezoidal fuzzy numbers. A validation procedure across three-, four-, and five-criterion structures was designed, including Likert-based correlation analysis, direct synergy and redundancy checks, and fuzzy integral aggregation with ANOVA tests. The experimental results demonstrate that the new methods reduce survey bias, enhance the credibility of the collected data, and better capture criterion interactions compared with the traditional approach. These findings suggest that the proposed framework provides a more reliable foundation for applying fuzzy integrals in complex decision environments.

3 - Prioritizing Governance Strategies for Sustainable City Transformation: A Modified DANP-mV-VIKOR Model with Evidence from Japanese Urban Cases
Chiehyu Cheng

Sustainable city research has shifted from conceptual and indicator-based approaches toward governance-oriented and action-driven perspectives. However, a gap remains in translating these insights into operational decision-support tools for prioritizing urban transformation strategies. This study develops a decision-oriented framework for sustainable city governance prioritization by integrating the Modified DANP-mV model with the VIKOR method within a multi-criteria decision-making approach. DANP identifies causal relationships and interdependencies among governance dimensions, while VIKOR determines priority improvement strategies under complex conditions. Empirical evidence is drawn from Japanese urban cases, including industrial heritage regeneration, civic cultural infrastructure, public libraries, and community-oriented public spaces, to refine evaluation criteria and validate the framework. The results reveal key governance structures and priority pathways for sustainable city

transformation, highlighting the importance of civic engagement, cultural regeneration, and integrated public services. This study contributes a practical decision-support framework and bridges theory and practice, offering implications for policymakers and urban planners.

■ HB-05

Thursday, 11:15-12:30 - Room: K5 (K.11.20)

AHP/ANP: Supply Chain Management

Stream: Decision Analysis/Making
Contributed session
Chair: *Birsen Karpak*

1 - Exploring the Interaction of Pressure Sources and Types on SSCM Practices: An ANP Framework
Birsen Karpak, *Alina Marculetiu*, *Cigdem Ataseven*, *Y. Ilker Topcu*

The growing emphasis on sustainability has intensified internal and external pressures on firms to adopt Sustainable Supply Chain Management (SSCM) practices. These pressures, exerted by stakeholders such as governments, customers, suppliers, and employees, take the form of coercive (regulatory), normative (social), and mimetic (competitive) influences. While these drivers are well documented, their relative importance and interdependencies remain underexplored. This study addresses this gap by proposing an Analytic Network Process (ANP) model to evaluate and prioritize interactions between pressure sources and types, offering a comprehensive view of how they jointly shape SSCM practices across internal, upstream, and downstream operations. Drawing on a synthesis of 93 articles, the study identifies key factors and develops a network-based framework capturing complex, multidirectional relationships. Expert input is incorporated through pairwise comparisons. The ANP model quantifies the influence of each source-type combination, identifying those most effective in driving SSCM adoption. Results highlight how interactions among pressures can amplify or weaken their overall impact, providing actionable insights for firms and policymakers. By moving beyond linear cause-effect assumptions, this study offers a nuanced, systems-based perspective to support more effective and context-sensitive sustainability strategies.

2 - Distance-Correlation-Based Criterion Weighting Integrated with MULTI-MOORA for Circular Agri-Food Supply Chain Evaluation
Chinmoy Kalita

Evaluating sustainability-oriented supply chain architectures requires balancing multiple criteria often which exhibit complex nonlinear interdependencies. Conventional multi-criteria decision-making approaches frequently rely on Pearson-correlation-based weighting techniques that are structurally incapable of detecting nonlinear relationships among evaluation criteria. This limitation is critical in case of sustainability-driven supply chain systems where there are nonlinear interdependencies between various factors. The study proposes a multi-criteria decision-making tool based on the integration of the D-CRITIC weighting method with the MULTI-MOORA ranking algorithm to assess circular agri-food supply chains. In the D-CRITIC method, distance correlation measures nonlinear dependencies and calculates the objective criterion weight. It is then used in the MULTI-MOORA Ratio System, Reference Point, and Full Multiplicative Form with the help of a decision matrix based on expert opinions. The results indicate a convergence of rankings for all three components of the proposed MULTI-MOORA model. The circular supply chain outperforms on criteria focused on sustainability, while the traditional model is better ranked on criteria focused on short-term costs. The study proves the effectiveness of distance-correlation-based D-CRITIC weighting with a dominance-aggregated approach to a proposed nonlinear decision model based on a MULTI-MOORA framework.

■ HB-06

Thursday, 11:15-12:30 - Room: Lecture Hall HS 32

AHP/ANP: AI & LLMs in Decision Making

Stream: Decision Analysis/Making
Contributed session
Chair: *Y. Ilker Topcu*

1 - Multi-Criteria Evaluation of Large Language Models using the Analytic Hierarchy Process
Omer Bekmezci, *Nazim Yola*, *Y. Ilker Topcu*

Large Language Models (LLMs) have revolutionized the field of natural language processing by enabling machines to understand and generate human-like text with unprecedented accuracy. These models have become integral across various sectors, ranging from automated customer support and content creation to complex data analysis and software development. This study aims to develop a decision-making model to identify the most efficient LLM for specific requirements according to the expert comments. For this purpose, a multi-criteria decision-making analysis is conducted on leading LLMs in the field of AI. We establish a structured, analytical framework for evaluating LLMs. Existing literature highlights key criteria categorized by linguistic performance, systemic robustness, cost efficiency, and operational efficiency. The list is further refined through consultation with industry professionals and academics in the field. To evaluate the LLMs, expert judgments are used to assess how well they perform with respect to each criterion. The AHP method is used to prioritize the criteria and the LLMs. Finally, a sensitivity analysis is conducted to examine how changes in the criteria's priorities affect the LLMs' priorities. This study provides the importance of criteria that can be used to navigate rapidly evolving LLM environment and the decision support system to be used. Future research may extend this framework by incorporating ethical and environmental sustainability criteria.

2 - GenDI: A Generative AI Framework for Scalable Multi-Criteria Decision Intelligence
Mohammad Dehghani, *Nihan Kabadayi*

This paper introduces GenDI (Generative Decision Intelligence), an AI-enabled decision making model where the end-to-end process of Multi-Criteria Decision Making (MCDM) is automated. Traditional MCDM methods are powerful for structuring complex decisions, yet their reliance on human expert panels for

criteria identification, importance evaluation, and alternative assessment creates bottlenecks in cost, consistency, and scalability. GenDI leverages Large Language Models as autonomous agents capable of data collection through web search, literature review, and domain-specific research, followed by structured analysis within established MCDM frameworks. The system operates through a generalized pipeline: (1) generating diverse virtual domain experts with distinct backgrounds; (2) enabling these agents to identify decision criteria based on their expertise and real-time information gathering; (3) facilitating structured voting on the relative importance of each criterion; (4) aggregating criteria into a coherent decision hierarchy; and (5) evaluating alternatives through the selected MCDM methodology. GenDI is method-agnostic, supporting AHP, ANP, TOPSIS, DEMATEL, and other techniques within a single platform. We demonstrate the framework through a case study using AHP while discussing its extensibility to other methods. GenDI combines the research capabilities of generative AI with the rigor of classical MCDM, offering a scalable approach to complex decision-making.

3 - Persona-Based Generative AI vs. Human Decision Makers: An ANP Analysis of the Turkish Mobile Market
Y. Ilker Topcu, *Cigdem Kadaifci*, *Sonya Javadi*

This study evaluates the effectiveness of GenAI tools, Gemini, ChatGPT, and CoPilot, in replicating expert and consumer decision-making within the mobile telecommunications sector. We developed a decision model that groups 11 customer preference factors into 4 clusters (Financial, Network, Service Experience, and Market Perception) to evaluate the operators in the Turkish GSM market. Following the ANP sequence, we formed an influence matrix and prepared pairwise comparison questions. Comparison data were gathered from a real human subject and 3 GenAI tools. Each AI was prompted with 2 personas: a Senior GSM Professional and a Regular Customer. Using these 7 respondents' judgments, we computed limit matrices and validated the results against real-world market shares using SCI. The SCI values indicate that the AI Senior Professional personas achieved the highest accuracy, with Gemini outperforming its AI counterparts, the human subject, and the AI Customer personas, respectively. Beyond validating GenAI's potential as an effective proxy for expert judgment in complex MCDM problems, this study reveals Price, Bundling & Campaigns, and Coverage as the dominant drivers. The prioritization of the factors in the decision model provides the mobile telecommunications sector with critical managerial insights into customer operator preferences. Acknowledgment: This work was supported by Scientific Research Projects Coordination Unit of Istanbul Technical University Project ID 48047.

Thursday, 13:30-15:15

■ HC-02

Thursday, 13:30-15:15 - Room: Senatssaal (K.11.07)

Multiobjective Combinatorial Optimization

Stream: Multi-objective Programming
Contributed session
Chair: *Andrzej Jaszkiewicz*

1 - Multi-Objectivization of block-structured Integer programs with a single (soft) coupling constraint
Mark Lyngesen, *Kathrin Klamroth*, *Britta Efkes*, *Sune Lauth Gadegaard*

We seek to solve block-structured integer programs with a single coupling constraint by interpreting the coupling constraint as a second objective. This results in an additively-separable bi-objective optimization problem with a solution set which contains the optimal solution to the original problem. The resulting bi-objective problem is in general harder to solve than the original problem. We therefore propose ways of directing the search for solutions to those solutions mapping to a predefined region of interest. This approach allows us to use decomposition methods while also providing the decision maker with a set of alternative 'interesting' solutions.

2 - Solving Hypervolume Scalarizations for MOCO Problems
Gonçalo Lopes, *Kathrin Klamroth*, *Luis Paquete*

Hypervolume scalarizations have emerged as a promising strategy to find efficient solutions to multiobjective combinatorial optimization problems. Despite their potential, the exact optimization of hypervolume scalarizations remains challenging. We introduce new formulations of hypervolume scalarizations that exploit particular transformations to compute optimal solutions efficiently. Extensive experiments on multiobjective knapsack problems show that our methods can improve upon existing approaches that are based on straightforward linearizations, achieving improvements of several orders of magnitude in terms of problem size, number of objectives, and number of reference points.

This presentation is based upon work from COST Action Randomised Optimisation Algorithms Research Network (ROAR-NET), CA22137, supported by COST (European Cooperation in Science and Technology). This presentation is partially financed through national funds by FCT, in the framework of the Project UIDB/00326/2025 and UIDP/00326/2025. The authors acknowledge the financial support of the DAAD/FCT project OCO -Ordinal Combinatorial Optimization (DAAD-ID: 57711909; FCT reference 2023.10131.CBM).

3 - NonDomLib - A library for creating and maintaining archives of nondominated points
Bruno Lang

We introduce NonDomLib, a C library for working with (Pareto) archives of nondominated points. It allows to generate an archive from a sequence of points by filtering out dominated points, to add points to the archive,

to merge archives, and to determine the nondominated points of a Minkowski sum. NonDomLib features highly competitive performance, and additional speedup can be obtained through thread-level parallelism. The use of the library is demonstrated with the multiobjective knapsack problem.

4 - Consistent and unbiased estimation of the hypervolume of an unknown true Pareto front
Andrzej Jaszkiewicz, *Xavier Gandibleux*

Hypervolume has become the standard indicator for evaluating the quality of solution sets in (evolutionary) multi-objective optimization. It allows us to evaluate and rank sets of solutions based on how well their objective-space images approximate the underlying Pareto front. However, such comparisons remain incomplete without knowing the hypervolume associated with the actual Pareto front. For most practical problems, determining this exact front is computationally infeasible. To overcome this obstacle, we introduce a method that repeatedly solves scalarized versions of the original problem using an exact optimization solver. This produces a consistent and unbiased estimate of the hypervolume corresponding to the unknown true Pareto front—without needing to explicitly enumerate its points—and retains both the linear structure and the differentiability of the initial multi-objective formulation. The procedure also provides a confidence interval for the hypervolume estimate. We implemented this technique in Julia and assessed its performance through numerical experiments on a multi-objective combinatorial optimization task. The results validate the method, demonstrate that it scales to problem sizes far beyond those amenable to explicit Pareto-front construction, and show that it effectively estimates hypervolume gaps between various approximation sets and the true Pareto front.

■ HC-03

Thursday, 13:30-15:15 - Room: K8 (K.11.10)

Best-Worst Method (BWM)

Stream: Decision Analysis/Making
Contributed session
Chair: *Jafar Rezaei*

1 - The max-min BWM method to maximise resilience capabilities and minimise supply chain disruptions
Alessio Ishizaka, *Cristina Lopez*, *Jehangir Khan*

The increasing frequency of supply chain disruptions has made resilience and digital integration essential. Indeed, firms that succeeded during the COVID-19 pandemic demonstrated advanced digital and supply chain resilience capabilities, enabling them to mitigate adverse consequences. Addressing this forefront topic in operations management, the presentation introduces an innovative max-min best-worst method to guide digital transformation in global supply chains. This approach aims to maximise resilience capabilities and minimise the impact of supply chain disruptions. The method is examined through an empirical case study of a highly digitalised furniture company. The findings emphasise the importance of redundancy, a robust risk management culture, and adaptability, with raw material delays and cyberattacks being the most significant threats. Moreover, prioritising the adoption of big data, digital platforms, blockchain, and advanced control systems is crucial for addressing ongoing geopolitical disruptions. Finally, the study discusses both theoretical and managerial implications and suggests avenues for future research.

2 - PIvot-Linked Elicitation (PILE): A unified approach to hierarchical weight elicitation
Matteo Brunelli, *River Huang*

We study the weight elicitation problem in Multiple Criteria Decision Analysis when decision criteria are organized hierarchically. We show that the conventional practice of eliciting weights separately at each level can lead to practical and conceptual limitations, including reliance on abstract upper-level judgments and the fragmentation of consistency across independent sub-models. To address these issues, we propose the PIvot-Linked Elicitation (PILE) framework, which links groups of criteria through a small set of pivot criteria and integrates intra- and inter-group preference information into a single model. We instantiate PILE for best-worst methods, deriving nonlinear and linear PILE-Best-Worst Method formulations, and illustrate the approach on a published use case. The results suggest that PILE preserves the cognitive benefits of hierarchical structuring while enabling a more holistic and consistency-aware elicitation.

3 - Group Decision Making in Multidisciplinary Settings: Applications of a Certainty-Weighted Group Best-Worst Method in Battery Cell Development.
Anastasiya Khramchenkova, *Ediz Erdönmez*, *Thomas Knoche-Sam*, *Björn-Ingo Hogg*, *Michael Hiete*

Group decision-making methods are essential for managing complex projects, especially when input from experts across multiple disciplines is required. A key challenge in this context lies in effectively combining the preferences of individual decision makers (DMs) into a single, unified group decision. While numerous aggregation methods exist to combine multiple DMs' preferences, there remains a significant gap in approaches that consider differences not only in expertise level but also across domains of specialization. In this work, we address this gap by extending the Best-Worst Method (BWM)—a multi-criteria decision-making method that has gained considerable popularity in recent years—to multidisciplinary group decision settings. Our approach aggregates preferences using a weighted average, where each DM's input is weighted based on their self-reported certainty for each criterion or alternative. Designed to be both computationally simple and time-efficient, the framework systematically incorporates and tracks uncertainty throughout the decision-making process. We demonstrate the practical value of this method in the context of battery cell development at an electric vehicle manufacturing company. Through three real-world case studies, we show how our proposed group BWM approach enhances transparency and accelerates decision-making in complex, multidisciplinary R&D programs.

■ HC-04

Thursday, 13:30-15:15 - Room: K6 (K.11.17)

Bayesian and Surrogate-Model Assisted Multiobjective Optimization

Stream: Heuristic Algorithms
Contributed session
Chair: *Michael Emmerich*

1 - Multi-Objective Optimization with Desirability and Morris-Mitchell Criterion
Thomas Bartz-Beielstein, *Eva Bartz*, *Alexander Hinterleitner*, *Christoph Leitenmeier*, *Ihab Abd El Hussein*

Industrial experimental designs frequently lack optimal space-filling properties, rendering them unrepresentative. This study presents a comprehensive methodology to refine existing designs by enhancing coverage quality while optimizing experimental outcomes. We discuss and analyse variants of the Morris-Mitchell criterion to quantify and improve spatial distributions. By integrating potential theory, we establish that minimizing these criteria equates to minimizing internal Riesz energy, a repulsive force driving points toward a uniform distribution. Based on potential theory, we analyze monotonicity properties and limitations of the Morris-Mitchell criteria. Practically, we implement a multi-objective optimization framework utilizing the Python packages 'spotdesirability' and 'spotoptim'. This framework uses desirability functions to combine surrogate-model predictions with space-filling enhancements into a unified score. Demonstrated through data from a compressor development case study, this approach optimizes performance objectives alongside design coverage. To facilitate implementation, we introduce novel infill-point diagnostics that visually guide the sequential placement of design points. This integrated methodology successfully bridges spatial theory with engineering application, balancing the crucial exploration and exploitation trade-off.

2 - BONO-Bench: A Comprehensive Test Suite for Bi-objective Numerical Optimization with Traceable Pareto Sets
Lennart Schäpermeier, *Pascal Kerschke*

The evaluation of heuristic optimizers on test problems, better known as benchmarking, is a cornerstone of research in multi-objective optimization. However, many frequently used test problems either feature a limited degree of optimization challenges or have poorly understood reference solutions. BONO-Bench is a recently proposed problem generator and benchmark set for bi-objective numerical optimization. Building on convex-quadratic problems, it features diverse challenges ranging from different levels of conditioning, shapes of Pareto set and front as well as plateaus to different structured and unstructured multimodality patterns. Reference solutions can be approximated to an arbitrary degree, resulting in precise target values for the hypervolume and exact R2 indicators and enabling best practices in performance assessment and empirical runtime analysis of optimizers. In this talk, we present the overall problem construction procedure of BONO-Bench as well as the test suite consisting of 20 different problems to evaluate diverse optimization challenges. Further, we discuss results of some common multi-objective optimization heuristics, hinting at problem properties that are easy and hard to solve for the different optimizers.

3 - An Approach for Evolutionary Multi-objective Optimization Under Heteroscedastic Noise
José Olivas Díaz, *Sebastian Rojas Gonzalez*, *Carlos Ignacio Hernández Castellanos*

In multiobjective optimization problems under heteroscedastic noise, not only is the true performance unobservable, but the level and structure of the noise also depend on the decision variables. Moreover, the detrimental effect of this noise is exacerbated with an increasing number of objectives. A common practice is to estimate performance using the sample mean after a fixed number of replications. However, this estimator often leads to an over- or under-estimation of performance, yielding misclassification errors when computing the non-dominated set. In this work we propose a method for multi-objective evolutionary algorithms (MOEAs) to handle input-dependent noise. Using heteroscedastic Gaussian Process regressors, our method exploits both sample and posterior information to accurately approximate each solution's fitness. This refined fitness approximation directly improves parent ranking and selection. Experimental results indicate that the proposed approach generally outperforms the standard baseline. Our work also highlights a major gap in the literature of MOEAs, where rudimentary noise handling techniques may yield significant issues in inference and decision-making when the level and structure of the noise are heteroscedastic. Moreover, despite the rich literature on performance indicators for deterministic problems, these metrics can yield misleading performance evaluations when relying only on sample means.

4 - Shaping R2- and Hypervolume-based Expected Improvement by Decision Maker Preferences
Michael Emmerich

Bayesian optimization offers a route to solving multiobjective problems with costly black-box problems, but its success depends on how acquisition functions define and reward progress. Two influential examples are the Expected Hypervolume Improvement (EHVI), rooted in multicriteria Bayesian global optimization (Emmerich et al., IEEE TEVC 2006), and the Expected R2-Indicator Improvement (ER2I), using dystopian/utopian reference points (Deutz et al., EMO 2019). We present recent work on shaping such a-posteriori acquisition functions through additional decision maker preference information. A challenge is to enrich EHVI and ER2I with preference models, such as reference points, aspiration levels, or value functions, while preserving exactness and computational efficiency. We study modelling principles that separate posterior inference from preference articulation and analyze how this changes the notion of improvement, the geometry of preferred search regions, and the exploration-exploitation balance. We identify structural conditions under which preference-shaped acquisition functions remain exactly and efficiently computable, avoiding crude Monte Carlo approximation. In this way, Bayesian optimization moves closer to not just finding non-dominated solutions, but finding the right ones.

■ HC-05

Thursday, 13:30-15:15 - Room: K5 (K.11.20)

Practical Applications: Climate Risks and Circular Economy

Stream: Practical Applications of MCDM
Contributed session
Chair: *Emmanuel Krieger*

1 - Strategic valorization of food waste: a multi-criteria decision analysis for sustainable policy-making
Simone Lima, *Maria João Santos*

As food waste reduction becomes a global priority, transitioning toward waste valorization provides a circular alternative to conventional disposal methods. This study integrates economic, environmental, social, and technical criteria into a comparative framework to evaluate food waste valorization options and provide applicable public policy recommendations. Despite existing research on food waste decision-making, comprehensive evaluations of specific valorization strategies remain underexplored. To address this gap, we propose an integrated approach using Multiple Attribute Value Theory (MAVT) and the Flexible Interactive Tradeoff (FITradeoff) method. This framework provides a compensatory analysis that is easily interpretable for decision-makers. Effectively evaluating these pathways directly supports Sustainable Development Goals (SDGs) by ensuring food waste is managed to maximize its positive contribution to circular value chains.

2 - Integrating Multiple Stakeholders in Multicriteria Decision Aid for Municipal Flood Adaptation: An Application
Francis Marleau Donais, *Melanie McGrory*, *Magalie Gravel*, *Simon Gervais*, *Jean-Luc Martel*

Climate change increases flood frequency and intensity, requiring municipalities to make complex adaptation decisions. These decisions demand both multidisciplinary technical expertise and engagement of impacted residents. This project presents an action-research project applying multicriteria decision aid (MCDA), problem structuring and decision conferences to flood adaptation with the city of Montreal, Canada. Working collaboratively with the city professionals, we analyzed five flood-vulnerable sectors. For each sector, four alternatives were co-constructed with the residents to represent different adaptation strategies: asset maintenance, renaturalization, hybrid and building adaptation. These alternatives were assessed and prioritized using the MACBETH method. To succeed, more than 30 group workshops were facilitated over a period of five months, engaging more than 40 professionals from hydrology, civil engineering, heritage, biology, urban planning, economic and public participation. Workshop formats varied, ranging from focussed technical sessions with few professionals to integrated workshops mobilizing nearly 20 professionals to elicit multidisciplinary trade-offs. We will discuss methodological insights and practical challenges encountered in this multi-stakeholder and multi-sectoral context. The results will inform public consultation with the impacted residents; therefore, connecting technical analysis with citizen participation in climate adaptation planning.

3 - Location, Climate Risk, and Adaptability: Toward an Integrated Valuation Framework for Circular Real Estate
Mingyang Yu, *Giuliano Poli*, *Pasquale De Toro*, *Maria Cerreta*

Real estate markets are increasingly exposed to climate-related risks. Recent evidence indicates that properties subject to flooding, heat stress, or sea-level rise face significant price discounts (Foerster et al., 2025; Ortega & Taşpınar, 2018). Despite this, mainstream valuation practices remain anchored in short-term historical comparables and overlook two interrelated limitations: the dynamic relationship between locational quality and hazard exposure, and the potential of building adaptability to buffer climate-induced depreciation. Although adaptability—understood as a building's capacity to support functional or spatial change without demolition—has gained traction in circular economy discourse (Le & Nguyen, 2023), it has yet to be operationalised as an economic variable in property valuation. This paper addresses that gap by proposing an integrated framework that treats location quality, climate risk exposure, and building adaptability/circularity as interacting determinants of long-term real estate value.

4 - How material and energy flow analysis can support complex participatory planning
Emmanuel Krieger, *Mathilde Boissier*, *Marine Valette*, *Jean-Yves Courtonne*, *Peter Sturm*, *Nils Ferrand*

Material and energy flow analysis (MEFA) methods quantify stocks and flows of energy and materials to make visible the physical structure of socio-economic systems. Despite their analytical power, their contribution to transdisciplinary decision-making remains poorly documented. We therefore used and evaluate MEFA models in the Grand Briançonnais, a region of the French Alps comprising 36 municipalities. In this case study, researchers collaborated with a local agency to develop a territorial energy dialogue aimed at co-producing a coherent regional energy policy with citizens. In total, 330 citizens participated. Two MEFA-based tools supported the process: Sankey diagrams representing regional energy production and consumption and a serious game designed to explore links between energy, biodiversity, governance, and territorial development. Both tools were developed based on interviews and workshops with citizens to take into account different social values and were explicitly designed to represent sustainability issues in all their complexity. Among other things, the evaluation shows that linking local data modelling with citizens' knowledge needs is crucial for supporting local multi-criteria decision-making. Furthermore, energy flow analyses have proven promising for developing a common systemic vision, but despite efforts to link this systemic vision to elements of foresight and operationalization, this aspect of scientific support has remained insufficient.

Thursday, 15:45-17:15

■ HD-01

Thursday, 15:45-17:15 - Room: Auditorium HS33

Business Meeting

Stream: Plenary Sessions
Plenary session
Chair: *José Rui Figueira, Salvatore Corrente*

Friday, 9:30-11:00

■ FA-01

Friday, 9:30-11:00 - Room: Auditorium HS33

Award Talks 1

Stream: Plenary Sessions
Plenary session
Chair: *Murat Koksalan*

1 - Georg Cantor Award Talk
Free the weights! (You can lock them later)
Luis C. Dias

Abstract
This talk revisits my work most related to dealing with partial information, mainly focusing on criteria weighting. Such information might consist of ordinal rankings, holistic judgments, or stochastic distributions. Methods dealing with this type of information can provide approximations, robust conclusions and stochastic results. I argue one might wish to use partial information, not only out of necessity, but as a way of facilitating dialogue and guiding the decision aiding process. I also mention links to efficiency analysis and preference learning. Some applications of these developments are briefly presented, showing their practical relevance

Bio
Luis Dias has a degree in Informatics, a Ph.D. in Management, and Habilitation in Decision Aiding Science, from the University of Coimbra. He is a Full Professor at the Faculty of Economics, University of Coimbra, where he has been teaching courses on decision analysis and operations research, and has supervised 13 PhD students. He held temporary invited positions at the University Paris-Dauphine, the University of Vienna, and the University of Porto, and was invited for PhD committees and project evaluation panels in several countries. He was the founding Director of the Centre for Business and Economics Research at U. Coimbra and a former Vice-Dean for Research. He was Vice President, and later Chair of the General Assembly of the Portuguese Operational Research Society. He is an Area Editor for the J. Multi-Criteria Decision Analysis and OMEGA, being also on the Editorial Board of the EURO J. on Decision Processes, and Group Decision and Negotiation. Luis's research interests include multicriteria decision analysis, performance assessment, group decision and negotiation support, contributing with methodology, software and applications. He has published over a hundred articles in peer-reviewed international journals and has authored an MCDA book in Portuguese language.

2 - MCDM Edgeworth-Pareto Award Talk
Multi-Objective Optimization: My journey over the past 35 years
Xavier Gandibleux

Abstract
This presentation outlines a selection of my contributions to multi-objective optimization over the past 35 years. Five periods are covered, highlighting various research topics within MCDM field: scalarization functions, interactive procedures, and multicriteria decision support systems (MCDSS) since 1989; multi-objective combinatorial optimization (MOCO), multi-objective metaheuristics (MOMH), and benchmarks with libraries of datasets since 1995; study of efficient solutions (XE) and nondominated points (YN), the study of multi-objective branch--bound, and the design of exact generic and specific algorithms since 2000; the world of multi-objective mathematical programming (MOMP) software, with open source modelers and solvers since 2014. The presentation will conclude with an overview of my current and future research topics.

Bio
Xavier Gandibleux is Full Professor at Nantes University, France. He is member of the MCDM Society since 1992, after having participated to the 10th International MCDM Conference held in Taipei, Taiwan. His research in MCDM mainly concerns the conceptual and algorithmic aspects of multi-objective mathematical programming: interactive procedures, metaheuristics, combinatorial optimization, branch-and-bound, solvers. He also enjoys tackling concrete multi-objective problems, and has provided operational solutions to problems encountered in national electricity production, communication networks, railway transport, and supply chain. He is a founding member of ROADEF, the French OR society, created in 1998, for which he served as vice president for four years. He is co-founder of the French national group PM2O (Multi-Objective Programming), created with Vincent T?Kindt in 1999 and active in France ever since. He has organized several international conferences on MCDM in France, such as MOMH (Multi-Objective MetaHeuristics, Paris) in 2002, MOP/GP (Multi-Objective Programming and Goal-Programming, Tours) in 2006, and EMO (Evolutionary Multi-Objective Optimisation, Nantes) in 2009. More recently he has organised the editions 2015 and 2018 of the RAMOO (Recent Advances in Multi-Objective Optimization, Nantes) workshop. Currently he is co-chair with Matthias Ehrgott of the MCDM area for the IFORS'2026 conference, to be held in Vienna, Austria. More information about him is available at: https://xgandibleux.github.io/

Friday, 11:30-12:15

■ FB-01

Friday, 11:30-12:15 - Room: Auditorium HS33

Award Talks 2

Stream: Plenary Sessions
Plenary session
Chair: *Murat Koksalan*

1 - MCDM Gold Medal Award Talk
Best-Worst Method: A decade of evolution and future prospects
Jafar Rezaei

Abstract Best-Worst Method (BWM) is a structured approach for eliciting criteria weights in multi-criteria decision-making. This talk revisits the original BWM formulation and procedural logic, and discusses behavioral motivations for dual anchoring and structured elicitation. It then synthesizes major methodological developments, covering linear and multiplicative formulations, interaction modeling extensions (non-additive models), Bayesian formulations, group-aggregation models, tradeoff-based elicitation, parsimonious and disaggregation-based variants, sorting extensions, and fuzzy and belief-based treatments of imprecision and epistemic uncertainty. Because the reliability of inferred weights depends on judgment quality, the talk consolidates and compares consistency checking approaches and discusses their implications for practice. Representative application domains are reviewed to illustrate how BWM is deployed in practice. Finally, future research directions are outlined, emphasizing behavioral validation, integration into complete decision pipelines, scalable elicitation support, and cautious human-AI co-production that preserves problem-specific preference meaning. These directions also include transferring BWM?s anchored elicitation principle to other preference elicitation approaches.

Bio Jafar Rezaei is Professor of Decision Science at Delft University of Technology, The Netherlands. His research focuses on multi-criteria decision-making/analysis (MCDM/MCDA), preference modelling, decision support systems, and the behavioural foundations of decision processes. He is widely known for developing the Best-Worst Method (BWM), a structured preference elicitation method that has generated an extensive body of methodological developments and applications across many domains. He is the Editor-in-Chief of the Journal of Multi-Criteria Decision Analysis (JMCDA) and the Director of the Graduate School of the Faculty of Technology, Policy and Management at TU Delft. He teaches MCDA courses, has supervised more than 20 PhD candidates, and has published extensively in scientific journals. He has also organized major academic conferences and has been awarded several national and European research projects.

Friday, 12:15-13:15

■ FC-01

Friday, 12:15-13:15 - Room: Auditorium HS33

Plenary: Stefan Ruzika

Stream: Plenary Sessions
Plenary session
Chair: *Michael Stiglmayr*

1 - Approximation in Multiobjective Optimization
Stefan Ruzika

We all know that multiobjective optimization problems are hard. Typically, the Pareto set consists of a very large number of solutions and also images. Even obtaining one of these images can be quite hard. This imposes a considerable challenge in the design of multiobjective algorithms. From a theoretical point of view, this means that we typically cannot hope for polynomial time exact algorithms.

But what else can we hope for? Well, the next best thing would probably be a polynomial time algorithm that computes an approximation - a set that is provably close to the Pareto set. More formally, this means, that for every Pareto optimal solution there exists a solution in the approximation which dominates it up to a certain multiplicative factor.

In this talk, we give a gentle introduction into multiobjective approximation. We illustrate some of the key ideas, state basic results and describe some algorithmic approaches. In particular, we review the seminal work of Papadimitriou and Yannakakis. They show that, under mild assumptions, every multiobjective optimization problem admits an approximation of polynomial size. Additionally, they propose a grid-based approximation technique that repeatedly calls some specific subroutine. We investigate how different subroutines can be employed as building blocks for grid-based approximation algorithms. Here, a focus is put on the well-known and widely used weighted sum scalarization method. Finally, we propose an adaptive approximation algorithm that shows a good practical performance on top of the theoretical guarantees.

Friday, 13:15-13:45

■ FD-01

Friday, 13:15-13:45 - Room: Auditorium HS33

Closing Session

Stream: Plenary Sessions
Contributed session
Chair: *Kathrin Klamroth, Michael Stiglmayr*

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