

MCDM **xxv**
2019 Istanbul
June 16-21

**THE 25TH INTERNATIONAL
CONFERENCE ON
MULTIPLE CRITERIA DECISION MAKING**



BEYOND THE INFORMATION AGE

BOOK OF ABSTRACTS



SCIENTIFIC PROGRAM AT A GLANCE

	16 JUNE 2019	17 JUNE 2019	18 JUNE 2019	19 JUNE 2019	20 JUNE 2019	21 JUNE 2019
	SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
08:00		Registration	Registration	Registration	Registration	
08:30						
09:00		Opening 9:00-9:40	TUE-1 Parallel Sessions 9:00-10:40	WED-1 Parallel Sessions 9:00-10:40	THU-1 Parallel Sessions 9:00-10:40	Registration
09:30		MON-1 Plenary Talk (Prof. Keskinocak) 9:40-10:40				FRI-1 Society Award Talks 9:30-12:00
10:00						
10:30		Coffee break	Coffee break	Coffee break	Coffee break	
11:00		MON-2 Parallel Sessions 11:10-12:50	TUE-2 Plenary Talk (Prof. Klamroth) 11:10-12:10	WED-2 Plenary Talk (Prof. Sandholm) 11:10-12:10	THU-2 Plenary Talk (Prof. Vargas) 11:10-12:10	
11:30				Lunch	Lunch	
12:00			Break		Lunch	
12:30						
13:00		Lunch	Lunch	WED-3 Doctoral Dissertation Award Session 13:10-14:25	THU-3 Business Meeting 13:10-14:10	FRI-2 Parallel Sessions 13:00-14:40
13:30					Break	
14:00		MON-3 Parallel Sessions 13:50-15:30	TUE-3 Parallel Sessions 13:50-15:30			THU-4 Parallel Sessions 14:20-16:00
14:30						
15:00	Registration		Outing 14:40-23:00			
15:30		Coffee break		Coffee break		
16:00						
16:30		MON-4 Parallel Sessions 16:00-17:40		TUE-4 Parallel Sessions 16:00-17:40		
17:00						
17:30						
18:00	Welcome Reception 18:00-20:00			Conference Banquet 17:45-00:00		
19:00						
20:00 - late evening						

Table of Contents

<i>Welcome Messages.....</i>	<i>1</i>
Message from Dr. Murat Köksalan President, International Society on MCDM.....	1
Message from Dr. İlker Topcu Conference General Chair, MCDM 2019.....	3
<i>General Information</i>	<i>6</i>
Venue	6
How to reach campus	6
Getting around in Istanbul.....	7
Registration Desk	7
Registration Fee	8
Internet Access.....	8
Lunch and Coffee Breaks	8
Important Phone Numbers	8
Disclaimer.....	9
<i>MCDM 2019.....</i>	<i>10</i>
Committees.....	10
Awards.....	11
Plenary Sessions	13
Tutorial Sessions	14
Parallel Sessions	14
Session Identifiers	16
Instructions for Session Chairs	16
Instructions for Presenters	16
Publications	17
Social Program	19

MCDM 2019 in Numbers	21
International Society on MCDM	23
Past Conferences	23
Sponsors.....	25
Supporting Companies.....	28
<i>Scientific Program</i>	29
<i>Author Index</i>	173
<i>List of Chairs</i>	181
<i>List of Participants</i>	183
<i>Session Information</i>	196

Welcome Messages

Message from Dr. Murat Köksalan

President, International Society on MCDM

Dear participants of the 25th International Conference on MCDM,

Together with the organizers, I am delighted to welcome you to MCDM 2019. The first conference in this series was organized in 1975 in Jouy-en-Josas, France, by Herve Thiriez and Stanley Zionts. Since then, we have met roughly once



every two years all over the world. The first MCDM conference I attended was in Cleveland, Ohio, USA in 1984. I have only missed a single conference since then. I have been fortunate to observe how our society and conferences grew and how our wonderful traditions developed. We have maintained an international composition of both our membership and the attendees to our conferences. Our society is among the most internationalized scientific communities with over 2700 members from about 100 different countries. We make an effort to maintain diversity in our committees as well. Participants of the Istanbul conference represent some 40 different countries.

Those who are attending the MCDM conference for the first time will join many of us who have been enjoying the traditions of our society over many years. We have high-quality scientific programs and we keep the number of parallel sessions small to allow participants to follow important recent developments of interest to them. We make the conferences affordable to all and provide further support to those who are short of funding. Both the organizers and the society have been sensitive to the needs of students. Our society is among the very few scientific communities that have no dues and we are determined to keep it that way. The conference venues have alternated between continents. Organizers have included tastes of

local culture in conference activities. We have an outing to a location reflecting local heritage at every conference.

Those of you who have been to our conferences know that there is a lot more than the great scientific programs at these events. I encourage you to enjoy all opportunities the organizers have prepared for you and more. In addition to the scientific program and material, the conference provides all lunches, coffee breaks, a couple of dinners, and the legendary banquet. These are great opportunities to spend time with fellow participants, to get together with old friends, and to make new friends. Many of us attest to the fact that long-lasting friendships and collaborations start at these conferences.

As is the tradition, we will have the regular business meeting of our society on Thursday June 20, 2019 at 13:10. We will provide brief information about the society, discuss business, and have an open forum about the future. I would like to encourage all participants to attend and contribute to discussions. If you are not a member yet, I encourage you to apply at <http://www.mcdmsociety.org> as soon as possible.

This is the second time we are meeting in Turkey. I had the privilege of chairing the organizing committee in year 2000 in Ankara. I know how much effort goes into organizing one of these conferences. There are many hard-working volunteers. I have been in close contact with the organizers of the Istanbul conference and I have observed their efforts to put together high-quality scientific and social programs. This is a great service to our community and I would like to thank the General Chair İlker Topcu and his colleagues for all their efforts.

I look forward to meeting you and experiencing our traditions together in the fascinating city of Istanbul during June 17-21!

Murat Köksalan

President, International Society on MCDM

president@mcdmsociety.org

Message from Dr. İlker Topcu

Conference General Chair, MCDM 2019

İstanbul'a hoşgeldiniz!

I am very honored to host the 25th International Conference on Multiple Criteria Decision Making (MCDM 2019) at Istanbul Technical University, Istanbul, Turkey from June 16th to June 21st, 2019.



This honor does not just belong to me; I have been encouraged and assisted by the greatest group of colleagues and friends anyone ever had to organize such a distinguished meeting consisting of a high-quality scientific program and an attractive social program. We, the organizing team from five different universities, are all very pleased and proud to welcome you to MCDM 2019.

Istanbul Technical University is one of the leading universities of Turkey with a history stretching back to 1773. Istanbul Technical University Macka Campus, the conference venue, is in the heart of Istanbul and located very near the Bosphorus strait through which the city's heart runs.

Istanbul, the meeting point of cultures and civilizations and the capital of empires, is the only city in the world straddling both Europe and Asia. With historic streets, architectural masterpieces of old empires, exciting art scenes, panoramic vistas, and mystical beauties; Istanbul, the Capital of Culture, is truly a city that never sleeps. On the other hand, Turkey offers some of the world's most important archaeological sites and historical monuments, vast and varied activities, welcoming Turkish hospitality and a delicious and assorted national cuisine.

The official web site of the conference is www.MCDM2019.org. To check for news, updates, and recent developments, you may also follow MCDM 2019 on Twitter (twitter.com/mcdm2019) and on Instagram (www.instagram.com/mcdm2019).

"MCDM beyond the Information Age" is the main theme of the conference. The submissions, covering several different topics and application areas support the theme strongly. We believe the scientific program is very rich and will be inspiring academicians and students as well as professionals in years to come.

Based on the traditions of the International Society on Multiple Criteria Decision Making, at MCDM 2019, a number of conference participants are financially supported by subsidized registration fees. For this conference, the International Society on MCDM and Creative Decisions Foundation deserve special recognition since they have offered grants for students and young researchers from developing and emerging countries.

We have 261 participants coming from 5 continents and 39 countries. Among all participants, 84 of them are students who are the future of our Society.

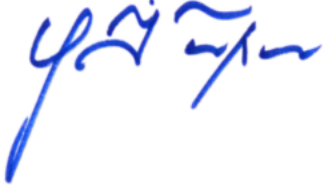
In the scientific program, 211 presentations are scheduled in mostly 5 parallel sessions. We have 38 contributed, 12 invited, and 3 special sessions along with 2 tutorials. We also have 4 plenary talks; a doctoral dissertation award finalists' session as well as International Society on MCDM awardees' talks. We all look forward to finding out about award recipients during our traditional banquet dinner.

We worked hard to organize great social events to make the conference even more memorable. The "Welcome Reception" will be at Havuzbasi in Istanbul Technical University Macka Campus; the "Outing on Wednesday" will be at "Sakip Sabanci Museum" and "Emirgan Park", followed by a "dinner cruise on the Bosphorus"; the "Conference Banquet" will be at "Sait Halim Pasa Mansion", overlooking the seafront of Bosphorus. We hope you will enjoy the social program and find it worthy of the 25th organization of MCDM conferences!

I owe a great deal of thanks to my friends General Co-chairs Özgür Kabak and Özay Özaydın as well as Organizing Committee Chair Şule Önsel Ekici and Program Committee Chair Serpil Sayın. I wish to thank Conference Secretary Çigdem Kadaifçi and Organizing Committee Members Sezi Çevik Onar, Bilal Ervural, Sait Gül, Gül İmamoğlu, Berk Küçükaltan, Başar Öztayşi, Seda Yanık, and Özgür Yanmaz.

I would like to finish my message by expressing my gratitude to our supporting companies: Professional Conference Organizer Cormep and Event Management Company Beyaz Event as well as our sponsors: TÜBİTAK (The Scientific and Technological Research Council of Turkey), International Society on MCDM, Creative Decisions Foundation, Sabancı University Sakıp Sabancı Museum,

Çimtaş Pipe Fabrication and Trading Ltd. Co., Borçelik, Arama Participatory Management Consulting, Mavi, Anadolu Efes, Coca Cola İçecek, Dimes, Muratbey Peynir, Varta, Istanbul Metropolitan Municipality, Springer, International Association of Turkish Ukrainian Businessmen, and Turkish Airlines.



Best wishes,

Y. İlker Topcu

MCDM 2019 Conference General Chair

General Information

Please bookmark the official web site of the conference www.MCDM2019.org for detailed information.

To check for news, updates, and recent developments, you may also follow the meeting:

- on Twitter (twitter.com/mcdm2019) and
- on Instagram (www.instagram.com/mcdm2019)

Venue

Istanbul Technical University, one of the leading universities of Turkey with a history stretching back to 1773, provides education in a modern educational setting and has a strong academic staff.

The Macka campus which houses Faculty of Management, School of Foreign Languages and Conservatory is in the heart of Istanbul and located very near the Bosphorus strait.

Address:

ITU Management Faculty (Istanbul Teknik Universitesi Isletme Fakultesi),
Macka St., 34367, Istanbul/TURKEY

How to reach campus

ITU Management Faculty is located in one of the central districts of Istanbul.

Welcome Reception, Opening Ceremony and Recommended Hotels are within walking distance of the conference venue.

From Taksim Square, you may walk to Gondola lift station Taskisla and take the lift to Macka. The campus is just across the street from Macka station.

From Besiktas, you may take the bus 30M Besiktas – Mecidiyekoy and get off at “Macka” stop. The stop is right in front of the campus. If you like walking up hills, you may also walk for 15 mins (1km) from Besiktas to Macka via Akaretler Yokusu (Suleyman Seba Street).

Getting around in Istanbul

The easiest way to get around in Istanbul is by taxi unless there is too much traffic. The fares are relatively cheap if we consider with distances. You should pay a minimum 10 TL to the driver due to minimum fare rule. In case of your journey fare above 10 TL, you will pay the fare that wrote on the taximeter. Make sure you have some Turkish liras with you. Most of the taxi drivers won't accept credit cards. We advise you to only take official taxis those have a sign on the roof with the word “taksi” on it. Furthermore, their taxi registration number (and sometimes company logo) should be clearly visible on the front doors and the roof. Most importantly, all official taxis have digital meters. You may hail a taxi on the street by waving your hand in the air. You can take a yellow taxi (cheapest one), a turquoise taxi (it is a bit expensive), or a black taxi (most expensive and very luxury). You may use the mobile applications BiTaksi or Itaksi to call a taxi online. Via these apps, you can pay with your credit card or cash.

Public transport in Istanbul comprises a bus network, various rail systems including underground ones, funiculars, and maritime services. Participants will be given a public transport map with details.

Registration Desk

The registration desk is located on the first floor of ITU Management Faculty. We recommend picking up your conference material as soon as you arrive on Sunday before the Welcome Reception. You will require your badge and ticket for the Reception.

The registration desk will be open at:

- 15:00 – 19:00 on June 16, Sunday
- 08:00 – 17:00 on June 17, Monday
- 08:00 – 17:00 on June 18, Tuesday
- 08:00 – 14:00 on June 19, Wednesday
- 08:00 – 15:30 on June 20, Thursday
- 09:00 – 14:00 on June 21, Friday

Registration Fee

Registered participants will receive a badge and tickets for social events giving them access to the conference venue as well as the conference materials. Participants are requested to wear their badge visibly at all times.

As usual, regular or student registration covers attendance at all sessions and conference materials as well as admissions to “Welcome Reception on Sunday”, “Outing on Wednesday”, “Conference Banquet on Thursday”, Lunches, and Coffee Breaks.

Accompanying person registration covers the same except the admission to sessions and conference materials.

Internet Access

You may connect to wireless internet via “eduroam” using your university credentials. Also, the participants will be provided a temporary “ITU/NET Misafir” account to access internet. The passwords will be given in the conference package.

Lunch and Coffee Breaks

Lunches are included in the registration fee and will be served from Monday to Friday in Ari Kovani. Tickets are required for lunches.

Coffee breaks will be at the second floor of Management Faculty.

Important Phone Numbers

Emergency Phone Numbers in Turkey:

- Police: 155
- Ambulance: 112
- Fire: 110

All three numbers are toll-free and do not require roaming plans.

Disclaimer

The organizing committee is not liable on any damage on health or property of any conference participant or accompanying person in the course of or resulting from participation in the conference. Participants are advised to have their own insurance. Authors are responsible for the content and copyright of their work.

MCDM 2019

Committees

Chairs

- İlker Topcu (General Chair, Istanbul Technical University)
- Özgür Kabak (General Co-chair, Istanbul Technical University)
- Özay Özaydın (General Co-chair, Doğuş University)
- Şule Önsel Ekici (Organizing Committee Chair, Doğuş University)
- Serpil Sayın (Program Committee Chair, Koç University)

Organizing Committee

- Sezi Çevik Onar (Istanbul Technical University)
- Bilal Ervural (Istanbul Technical University)
- Sait Gül (Beykent University)
- Gül İmamoğlu (Istanbul Technical University)
- Özgür Kabak (Istanbul Technical University)
- Çigdem Kadaifçi (Doğuş University)
- Berk Küçükaltan (Trakya University)
- Şule Önsel Ekici (Doğuş University)
- Özay Özaydın (Doğuş University)
- Başar Öztayşı (Istanbul Technical University)
- İlker Topcu (Istanbul Technical University)
- Seda Yanık (Istanbul Technical University)
- Özgür Yanmaz (Istanbul Technical University)

Scientific Program Committee

- Emel Aktaş (Cranfield University)
- Umut Asan (Istanbul Technical University)
- Adiel Teixeira de Almeida (Federal University of Pernambuco)
- Sarah Ben Amor (University of Ottawa)
- Matthias Ehrgott (Lancaster University)

- Gabriele Eichfelder (TU Ilmenau)
- José Rui Figueira (Technical University of Lisbon)
- Salvatore Greco (University of Catania)
- Zahir Irani (University of Bradford)
- Özgür Kabak (Istanbul Technical University)
- Birsen Karpak (Youngstown State University)
- Kathrin Klamroth (Bergische Universität Wuppertal)
- Murat Köksalan (Middle East Technical University)
- Banu Lokman (Middle East Technical University)
- Kaisa Miettinen (University of Jyväskylä)
- Enrique Mu (Carlow University)
- Özay Özaydın (Doğuş University)
- Serpil Sayın (Koç University)
- Hsu-Shih Shih (Tamkang University)
- Johannes Siebert (University of Bayreuth)
- Seyhan Sipahi Nişel (Istanbul University)
- Theo Stewart (University of Cape Town)
- İlker Topcu (Istanbul Technical University)
- Füsün Ülengin (Sabancı University)
- Jyrki Wallenius (Aalto University)
- Margaret Wiecek (Clemson University)
- Constantin Zopounidis (Technical University of Crete)

Awards

International Society on MCDM Awards

Since 1992, the International Society on Multiple Criteria Decision Making presents, at each of its international conferences, up to three awards to individuals in honor of their outstanding, long-lasting, and influential contributions to the field of MCDM.

The awards will be presented at the 25th MCDM 2019 Conference in Istanbul, Turkey. The awardees will be announced at the conference banquet on June 20, Thursday. Their talks will be held on June 21, Friday.

These awards are:

The MCDM Gold Medal

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

The MCDM Edgeworth-Pareto Award

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

The Georg Cantor Award

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

MCDM Doctoral Dissertation Award 2019

The International Society on Multiple Criteria Decision Making bestows the MCDM Doctoral Dissertation Award upon a scholar who has recently obtained a doctoral degree and demonstrated excellence in her or his doctoral dissertation research in Multiple Criteria Decision Making or a related field. The MCDM Doctoral Dissertation Competition identifies and recognizes outstanding doctoral dissertation research, completed on January 1, 2017 or later, in the development of theory, methodology, and/or the application of theory or methodology to MCDM. The finalists for this year are:

- **Fritz Bökler**, Osnabrück University, Germany
“Output-sensitive Complexity of Multiobjective Combinatorial Optimization Problems with an Application to the Multiobjective Shortest Path Problem”
- **Mohammad Ghaderi**, Pompeu Fabra University, Spain
“Preference Disaggregation: Towards an Integrated Framework”
- **Andreia Guerreiro**, University of Coimbra, Portugal
“Portfolio Selection in Evolutionary Algorithms”

Their talks will be given on June 19, Wednesday from 1:10pm to 2:25pm in Doctoral Dissertation Award Session at Mustafa Kemal Amfisi.

The final decision will be made after the talks and the result will be presented at the conference banquet.

Plenary Sessions

Plenaries from Monday to Thursday will be held in Mustafa Kemal Amfisi.

Plenaries on Friday will be held in ITU Management Faculty.

Opening Session

Opening session will be held on June 17, Monday between 09:00 – 09:40.

Invited Plenary Talks

The following four distinguished speakers have agreed to give a talk at MCDM 2019.

June 17, Monday 09:40 – 10:40	Pinar Keskinocak , Georgia Tech, USA “Quantitative models for decision-support in healthcare applications”
June 18, Tuesday 11:10 – 12:10	Kathrin Klamroth , Univ. of Wuppertal, Germany “Multi-Objective Combinatorial Optimization – Beyond the Bi-objective Case”
June 19, Wednesday 11:10 – 12:10	Tuomas Sandholm , Carnegie Mellon, USA “New Results for Solving Imperfect-Information Games”
June 20, Thursday 11:10 – 12:10	Luis Vargas , University of Pittsburgh, USA “Voting with Intensity of Preferences”

Doctoral Dissertation Award Session

Doctoral dissertation award session will be held on June 19, Wednesday between 13:10 – 14:25.

Business Meeting

Business meeting will be held on June 20, Thursday between 13:10 – 14:10.

Society Award Talks

Society Award talks will be given on June 21, Friday between 09:30 – 12:00.

Closing Session

Closing session will be held on June 21, Friday between 14:40 – 15:10.

Tutorial Sessions

There will be two tutorial sessions.

First one will be given by **Pekka J Korhonen**, Aalto University School of Business titled “MOLP vs. DEA – Relatives or Friends” on June 18, Tuesday between 16:00 – 17:40.

The second tutorial will be given by **Orrin Cooper**, University of Memphis titled “Improve Your Decisions by Learning and Experiencing the ANP Best Practices on June 17, Monday between 13:50 – 17:40. Orrin Cooper’s tutorial is also a special session sponsored by CDF and a tribute to Thomas L. Saaty & a great opportunity to learn ANP.

Parallel Sessions

Contributed Sessions

There are 151 talks assigned to 38 contributed sessions in the MCDM 2019 scientific program. They cover the following topics:

- Advanced Optimization Techniques
- Advances in MCDA
- Advances in MCDM Theory
- AHP/ANP

- Contemporary Approaches in MCDM
- Data Envelopment Analysis
- Evolutionary Algorithms
- Fuzzy sets and approaches
- Group Decision Making
- Interactive Multi-Objective Optimization
- Multi-Objective Metaheuristics
- Multi-Objective Optimization
- Multiple Criteria Decision Aiding
- Outranking Methods
- Preferences, Comparisons and Uncertainties
- Ranking or Sorting

Invited Sessions

Additionally, there are 48 talks assigned to 12 invited sessions in the scientific program. They cover the following topics:

- Building MCDM/A Models: Practical and Methodological Issues
- Continuous Multiobjective Optimization with Engineering Applications
- Data Science meets Multiple Criteria Decision Making
- Hybrid Approaches in MCDM
- MCDM in Solving Urban Problems using Big Data
- MCDM/A for Assessment Issues in Healthcare and LCA
- MCDM/A Models with Flexible and Interactive Preference Modeling
- Multiobjective Optimization Applications
- Multiobjective Route Planning
- New Approaches in MCDM
- Solution Methods for Various Multiobjective Optimization Problems
- Theory and Applications of ANP

Special Sessions

Finally, there are 10 talks assigned to 3 special sessions:

- AHP in Practice as “Decision Conference” in Turkey - sponsored by ARAMA
- AHP/ANP Applications in Industry 4.0 - sponsored by ÇİMTAŞ
- AHP/ANP Applications in Production and Manufacturing - sponsored by BORCELIK

Session Identifiers

Every session is identified with a 5-character code which means the following:

- The first three characters correspond to the day of the week when the session takes place: MON, TUE, WED, THU, FRI.
- The fourth character displays the time slot of the day. For instance, WED-1 means that all sessions with this identifier are assigned to the first time slot of Wednesday.
- The fifth character represents the type of the session as follows:
 - P corresponds to plenary talks
 - A, B, C, D, E, and F display different parallel streams including contributed, invited, and special sessions
 - O stands for opening session
 - M stands for International Society on MCDM award talks
 - U stands for business meeting
 - L stands for closing session

Instructions for Session Chairs

Each session chair will be given a session follow-up and evaluation form with necessary information for the session.

The volunteer responsible for the room will pick the form at the end of the session. In case of no-show presentations, Session Chairs are kindly requested to pause the session for the duration of the no-show presentation to allow cross-session participations.

Instructions for Presenters

Each presentation is given 20 minutes. An additional 5 minutes are allocated for questions and discussion at the end of 20 minutes. The slides should be in English. Please, bring your presentation on a USB memory stick and save it as a PDF or PowerPoint document. Find your room and meet the Session Chair before your oral presentation. Also make sure that you upload your slides on the computer before the session starts.

Publications

Springer Book Chapter



Selected abstracts that are presented at the conference will be invited to be considered as chapters in the book titled “**Multiple Criteria Decision Making Beyond the Information Age: Selected works from MCDM 2019 Istanbul**” within the Springer’s Book Series *Contributions to Management Science*.

Editors: Y. İlker TOPCU, Ozay OZAYDIN, Ozgur KABAK, and Sule ONSEL EKICI

Journal of Enterprise Information Management Special Issue

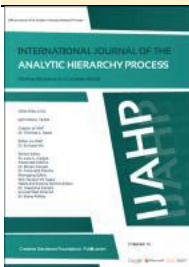


Abstracts that are presented at the conference will have the opportunity to be considered as articles in the Special Issue of Journal of Enterprise Information Management, a Social Science Citation indexed journal. Special issue title would be “**Contemporary**

Strategic Decision Making through Multiple Criteria Approaches in the New Industrial Era”

Guest editors: Emel AKTAS, Berk KUCUKALTAN, and Y. İlker TOPCU

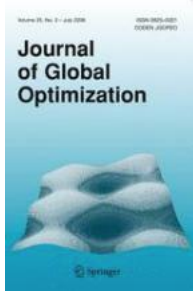
International Journal of the Analytic Hierarchy Process Special Issue



Abstracts that are presented at the conference will have the opportunity to be considered as articles in the Special Issue of International Journal of the Analytic Hierarchy Process (IJAHP), a SCOPUS-indexed journal, that publishes papers about research and applications of the Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP).

Guest Editors: Y. İlker TOPCU and Ozay OZAYDIN

Journal of Global Optimization Special Issue



Abstracts that are presented at the conference will have the opportunity to be considered as articles in the Special Issue of Journal of Global Optimization, a Science Citation indexed journal, that deals with theoretical and computational aspects of seeking global optima and their applications in science, management and engineering.

Guest Editors: Kaisa Miettinen and Serpil Sayin

Journal of Multi-Criteria Decision Analysis Special Issue



Abstracts that are presented at the conference will have the opportunity to be considered as articles in the Special Issue of Journal of Multi-Criteria Decision Analysis, a SCOPUS-indexed journal, that provides an international forum for the presentation and discussion of all aspects of research, application and evaluation of multi-criteria decision analysis, and publishes material from a variety of disciplines and all schools of thought.

Guest Editors: Thierry Marchant and Marc Pirlot

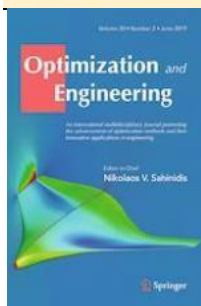
Annals of Operations Research Special Issue



Abstracts that are presented at the conference will have the opportunity to be considered as articles in the Special Issue of Annals of Operations Research, a Science Citation indexed journal, that deals with key aspects of operations research, including theory, practice, and computation.

Guest Editors: TBA

Optimization and Engineering Special Issue



Abstracts that are presented at the conference will have the opportunity to be considered as articles in the Special Issue of Optimization and Engineering, a Science Citation indexed journal, that promotes the advancement of optimization methods and the innovative application of optimization in engineering.

Guest Editors: Jussi Hakanen and Richard Allmendinger

Social Program

Welcome Reception

Welcome reception will be at Havuzbasi in Istanbul Technical University Macka Campus on June 16, Sunday from 18:00 to 20:00.

Group Photo

The group photo will be shot at the steps inside the building in front of the entrance of Mustafa Kemal Amfisi on June 18, Tuesday between 12:20 to 12:50.

Outing

The “Outing on Wednesday” will be on June 19, Wednesday at Sakip Sabanci Museum and Emirgan Park, followed by a dinner cruise on the Bosphorus.

Sabancı University's Sakip Sabancı Museum, a private fine arts museum, is located at one of Istanbul's oldest settlements on the Bosphorus. Sakip Sabancı Museum presents a versatile museological environment with its rich permanent collection, the comprehensive temporary exhibitions that it hosts, its conservation units.

Emirgan Park, tulip's homeland, is one of the biggest parks in Istanbul. Emirgan Park includes approximately ninety species of tree and three thousand varieties tulips. It is said to be the most beautiful park in Istanbul.

Boat ride on the Bosphorus, a splendid panorama, is a unique experience for seeing the beauties including palaces, monuments, and mansions accompanied by trees and flowers along the European and Asian sides of the Bosphorus.

Buses for the first section of the Outing will depart at 14:40 from in front of ITU Management Faculty. There will be an English speaking guide at the museum. Due to capacity constraints, half of the participants will start at the museum, while the other half will be taken to Emirgan Park. Later the halves will switch places.

First group visit of the museum will be between 16:00 – 17:00, while second group will visit the museum between 17:30 – 18:30.

After visiting both the museum and the park, the participants will be taken to the Emirgan quay for boarding the boat at 19:00. The boat will disembark the participants at Karaköy around 23:00.

Banquet

The conference banquet will be at Sait Halim Pasa Mansion on June 20, Thursday. The Mansion, located at the heart of the Bosphorus and overlooking the seafront, was built in 1878. Its decorative style is a mélange of French and Egyptian architecture. 19th-century architectural elegance meets with 21st-century service quality. Mesmerizing Bosphorus view will be the backdrop to our banquet.

The night will begin with a cocktail in the Mansion at 18:45. It will be followed by a dinner in the Garden at 20:00.

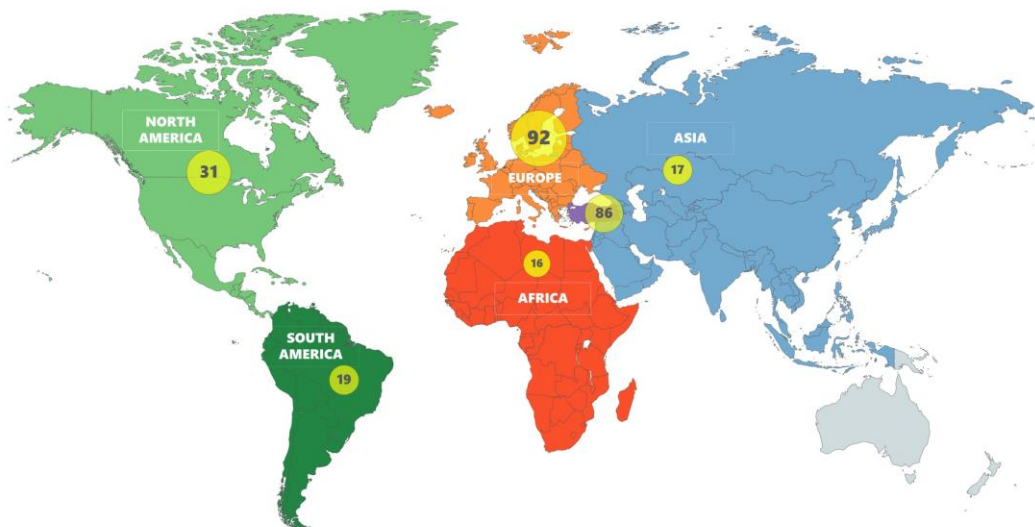
The busses will depart from in front of ITU Management Faculty at 17:45, they will depart from the Mansion around midnight to return to the same place to drop-off participants.

MCDM 2019 in Numbers

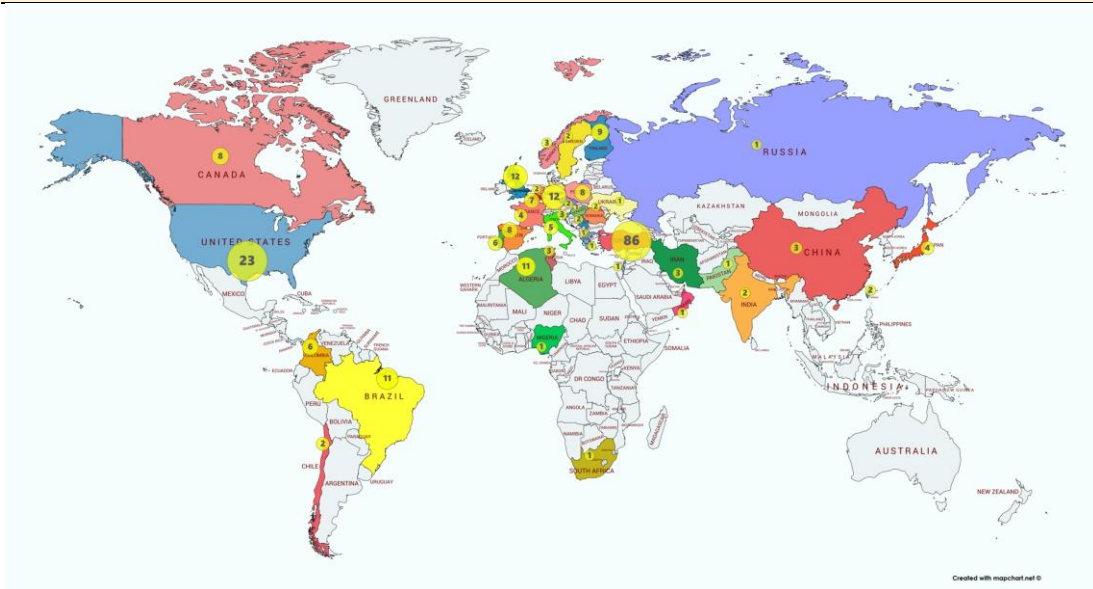
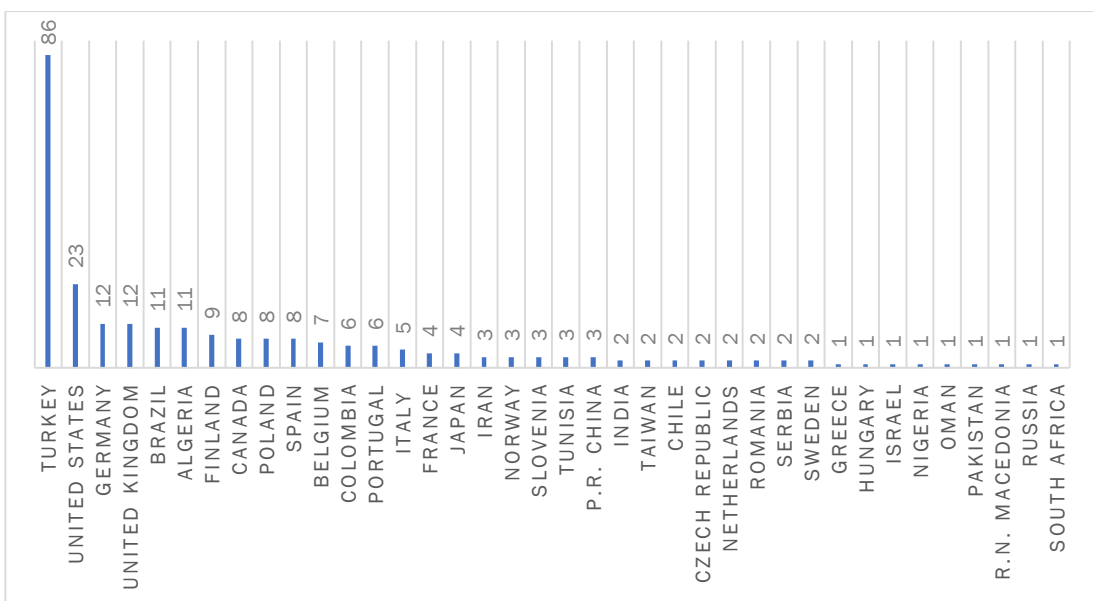
There are four plenary talk sessions; one doctoral dissertation award finalists' session, and one International Society on MCDM awardees' talk session. There are 211 talks scheduled in five or six parallel sessions. 38 of these parallel sessions are contributed, 12 of them are invited, while 3 or them are sponsored special sessions.

261 participants are coming from 5 continents and 39 countries. As expected, the largest number of participants are from Turkey with 86 participants, followed by United States with 23 participants. Germany and United Kingdom have 12 participants. The number of participants from Brazil and Algeria is 11.

Continents



Countries



Connecting Children with Nature

MCDM 2019 Organizing Committee is aware of the carbon footprint caused by the participants for their flights to and from Istanbul (approx. 580 tonne CO₂e). To even partially compensate for our effect, we made donations in names of all participants to TEMA Foundation - The Turkish Foundation for Combating Soil Erosion, for Reforestation and the Protection of Natural Habitats (www.tema.org.tr).

International Society on MCDM

MCDM can be defined as the study of methods and procedures by which concerns about multiple conflicting criteria can be formally incorporated into the management planning process.

The purposes of the Society are to develop, test, evaluate and apply methodologies for solving multiple criteria decision making problems, to foster interaction and research in the scientific field of multiple criteria decision making, and to cooperate with other organizations in the study of management from a quantitative perspective. These purposes are to be carried out by:

- facilitating communications,
- providing academic assistance with ideas, methods and contacts whenever and wherever needed,
- sponsoring international conferences for the dissemination of results,
- encouraging special purpose workshops and student exchanges,
- publishing the electronic newsletter and
- encouraging an environment of international collegueship and friendship across the globe.

Past Conferences

24th International Conference: July 10-14, 2017, Ottawa, Canada,

Sarah Ben Amor.

23rd International Conference: August 3-7, 2015, Hamburg, Germany,

Martin J. Geiger.

22nd International Conference: June 17-21, 2013, Málaga, Spain,

Francisco Ruiz.

21st International Conference: June 13-17, 2011, Jyväskylä, Finland,

Kaisa Miettinen.

20th International Conference: June 21-26, 2009, Chengdu, China,

Yong Shi, Shouyang Wang.

19th International Conference: 2008, New Zealand,

Matthias Ehrgott.

18th International Conference: 2006, Chania, Crete, Greece,

Constantin Zopounidis.

17th International Conference: 2004, Whistler, British Columbia, Canada,
Bill Wedley.

First MCDM Winter Conference (16th International Conference): 2002, Semmering,
Austria,
Mikulas Luptacik, Rudolf Vetschera.

15th International Conference: 2000, Ankara, Turkey,
Murat Köksalan.

14th International Conference: 1998, Charlottesville, Virginia, USA,
Yacov Y. Haimes.

13th International Conference: 1997, Cape Town, South Africa,
Theo Stewart.

12th International Conference: 1995, Hagen, Germany,
Günter Fandel, Thomas Gal.

11th International Conference: 1994, Coimbra, Portugal,
Joao Climaco.

10th International Conference: 1992, Taipei, Taiwan,
G.H. Tzeng, P.-L. Yu.

9th International Conference: 1990, Fairfax, USA,
Richard Soland, Ambrose Goicoechea.

8th International Conference: 1988, Manchester, UK,
A. Geoff Lockett, Gerd Islei.

7th International Conference: 1986, Kyoto, Japan,
H. Nakayama, Y. Sawaragi.

6th International Conference: 1984, Cleveland, Ohio, USA,
Yacov Y. Haimes.

5th International Conference: 1982, Mons, Belgium,
Pierre Hansen.

4th International Conference: 1980, Newark, Delaware, USA,
Joel Morse.

3rd International Conference: 1979, Knigswinter, Germany,
G. Fandel, T. Gal.

2nd International Conference: 1977, Buffalo, New York, USA,
Stanley Zionts.

1st International Conference: 1975, Jouy-en-Josas, France,
Herve Thiriez, Stanley Zionts.

Sponsors



TÜBİTAK (The Scientific and Technological Research Council of Turkey) supports MCDM 2019 with 2223-B Program.

Support for Students & Young Researchers



The Creative Decisions Foundation was established in 1996 by Thomas L. Saaty and his wife Rozann Whitaker Saaty to promote the cause of rational decision making and spread awareness of the Analytic Hierarchy Process (AHP) theory of decision making created by Dr. Saaty.

International Society on MCDM aims to develop, test, evaluate and apply methodologies for solving multiple criteria decision making problems, to foster interaction and research in the scientific field of multiple criteria decision making, and to cooperate with other organizations in the study of management from a quantitative perspective.



Outing Sponsor



Sabancı University Sakıp Sabancı Museum presents a versatile museological environment with its rich permanent collection, the comprehensive temporary exhibitions that it hosts, its conservation units, model educational programs and the various concerts, conferences and seminars held there.

Session Sponsors



Çimtaş Pipe Fabrication and Trading Ltd. Co., founded in 2002, is a market-leading company providing engineering, procurement, manufacturing, welded fabrication, machining, and painting services of LSAW pipes, fittings and pipe spools for the power, process, OEM piping systems and pressurized equipment to power, oil, gas and chemicals, water, mining and metals industries with a global vision to be the “best in class”. The strengths of the company are: focus on safety, excellence in services, world class quality, on time delivery, shortest cycle times and continuous improvement with Lean Production Approach.

Borçelik founded as the first private and second largest flat steelmaker of Turkey in



1990. Borçelik started its activities in 1994 to produce “cold-rolled steel sheet coils”. Borçelik continues its activities under the partnership of Borusan Holding and ArcelorMittal, one of the largest global steelmakers. The Company has a total production capacity of 1.5 million tons with the Borçelik brand and a metal processing capacity of 500,000 tons with the Kerim Çelik brand, making it Turkey’s biggest galvanized steelmaker, offering the highest quality. The company’s strong market position is based on dynamic labor force, innovative approach, continuous investment for self-development and growth, customer-oriented service and quality approach.



KATILIMLI YÖNETİM DANIŞMANLIĞI

ARAMA is a participatory management consulting company that pioneers participative methodologies in the renewal, restructuring and reconfiguring of organizations, institutions, industries, regions and other social systems including international and national bodies. The company was established in Istanbul and Ankara in 1995, and the Pennsylvania office was established in 1998. Since then, about 1000 participative methods have been applied in Turkey. Today ARAMA is

the only consulting company in Turkey that focuses only on the development and application of participative methods and processes.

Food, Beverage & Product Sponsors



Incorporated in Istanbul in 1991, today Mavi is recognized as a highly successful, global lifestyle brand. With strong denim roots, Mavi has evolved into an international apparel and accessories brand.

Anadolu Efes is the industry leader with 3 breweries, 2 malt factories, and 1 hops processing plant in Turkey. They are an international company that operates in Russia, Georgia, Kazakhstan, Ukraine, and Moldova in addition to Turkey. Their products are consumed in more than 80 countries across the world. They are Europe's 6th and World's 14th largest beer producer in terms of sales volume.



CCI is a multinational beverage company which operates in Turkey, Pakistan, Kazakhstan, Azerbaijan, Kyrgyzstan, Turkmenistan, Jordan, Iraq, Syria and Tajikistan. As one of the key bottlers of the Coca-Cola system, CCI produces, distributes and sells sparkling and still beverages of The Coca-Cola Company.

DİMES is founded in Tokat, the heart of Anatolia in the 1960s and it is the first local fruit juice brand in Turkey. DİMES is the biggest fruit juice producer with its 3 factories and the leading brand of the juice category in households in Turkey. They are exporting their products to over 100 different countries. DİMES is one of the leading and well-known fruit juice brand in Turkey.



Muratbey is a registered trade mark in approximately 60 countries. Patent of the original and similar forms of our innovative cheese Helix, which is created cleverly and of which its design is registered in approximately 60

countries, belongs to us. We are exporting our own trademarks to approximately 50 countries including all EU, US, Japan, Middle East, Northern African Countries, Balkans, TRNC, Turkic Republics.

VARTA is a key international manufacturer of consumer batteries. The company is the market leader in Germany, Austria and Switzerland, as well as in other European countries. VARTA Consumer identifies new market developments and the customers; needs early on and caters to them with new and innovative products.



Istanbul Metropolitan Municipality (IMM) is the administrative center of Istanbul, one of the world's most populous cities with a total population of around 15 million residents in its metropolitan area. IMM provides with emergency and social services, libraries and museums, investment and financial services, licensing and transportation services.

Springer is a leading global scientific, technical and medical portfolio, providing researchers in academia, scientific institutions and corporate R&D departments with quality content through innovative information, products and services.



Other Sponsors



International Association of Turkish and Ukrainian Businessmen (TUİD) is a businessmen association founded in 2004 by Turkish businessmen in Ukraine and with the auspices of the embassy of Republic of Turkey in Kiev.

Supporting Companies

Cormep is the Professional Conference Organizer for MCDM 2019.

Beyaz Event is the event planner for MCDM 2019.

Scientific Program

MONDAY

MON-0-0

Opening Session

Monday 9:00-9:40 - Room: Mustafa Kemal Amfisi

Chair: Ilker Topcu

MON-1-P

Plenary Session 1

Monday 9:40-10:40 - Room: Mustafa Kemal Amfisi

Chair: Murat Köksalan

Quantitative Models for Decision-Support in Healthcare Applications

**Pinar Keskinocak, Georgia Tech, United States, pinar@isye.gatech.edu*

Health systems focus on broad set of activities including prevention, screening, diagnosis, and treatment. Most health systems face multiple objectives and limited resources while striving to provide high quality care and promote health and well-being. Data-driven quantitative models, embedded into decision-support systems, have a significant potential for improving patient and population outcomes, efficiency, and effectiveness in healthcare. In this presentation we will discuss a few applications from organ transplant, vaccination, screening, and workforce allocation decisions.

MON-2-A

Contributed Session: Advances in MCDM Theory - Behavioral and Computational Issues

Monday 11:10-12:50 - Room: Galata Tower

Chair: Jafar Rezaei

1. On Rationality Conditions for Multi-Attribute Choice Behavior

**Pekka Korhonen, Aalto University School of Business, Finland, Pekka@Pulsedrive.fi
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Peng Xu, Aalto University School of Business, Finland, Peng.Xu@Aalto.fi
Tolga Genc, Marmara University, Turkey, Tolga95@Yahoo.com*

This paper deals with rationality conditions for choice behavior. It bears similarity to Samuelson's Revealed Preference Theory, although it deviates from it in significant ways. We explore two different types of choice settings: (1) win-win setting, where consumers consider which goods they want to add to their basket, (2) tradeoff setting, where consumers make pairwise choices between different (efficient) baskets, where they have to give up in some goods to gain in other goods. We study the decision-maker's rationality conditions in both settings. The perspective is that of an outside observer, who can use the conditions to judge, whether the choices are rational or not. The basket is filled either with different or identical goods. The key underlying theoretical assumptions in our paper are increasing and concave single dimensional utility (value) functions with decreasing marginal values (win-win setting) and the Kahneman-Tversky Prospect Theory model of choice with loss aversion (tradeoff setting). We use an empirical experiment to motivate and verify our considerations.

2. An Efficient Interactive Approach to Ordinal Pairwise Comparisons

**Elena Moshkovich, University of Montevallo, United States, moshbm@montevallo.edu
Alexander Mechitov, University of Montevallo, United States, mechitov@montevallo.edu*

Many multiple criteria decision methods rely on a decision maker's preferences to resolve

conflicts between different criteria and being able to rank order alternatives. Rather often a decision maker's preferences are elicited in the form of pairwise comparisons of objects. Some methods, like AHP or M-Macbeth elicit this information in a cardinal form, other methods require elicitation of preferences in an ordinal form, e.g., ZAPROS or ARACE. Research shows that people make mistakes in their judgments leading to inconsistency of preferences which results in an unstable solution to the problem. The question of eliciting consistent information is of utmost importance to the success of the decision aids so we need methods for discovering, reducing, and/or eliminating inconsistency in the pairwise comparisons even if the information is elicited in an ordinal form. Methods of Verbal Decision Analysis such as ZAPROS and ARACE require the decision maker to fill in comparison matrices of a rather substantial sizes (e.g., 12 x12 or even larger). Excel-based system ORCON helps find inconsistencies in such matrices and shows efficient steps in resolving contradictions in preferences through re-visiting some comparisons by the decision maker. At the same time a decision maker has to carry out many pairwise comparisons and then do additional evaluations in the process of elimination of inconsistencies. We propose an interactive approach to the process of pairwise comparisons by a decision maker. Transitivity of preferences is used to minimize the number of comparisons carried out by a decision maker. The procedure though does not provide enough information for verification of the validity of the results. The authors introduce the principle of "double check" and propose an algorithm for necessary additional comparisons to meet this principle. Efficiency of the proposed approach is evaluated through a computer modeling and is illustrated through several examples. ORCON-I Excel-based system may be used to carry out the process.

3. Group Best Worst Method Based on Belief Structure

**Fuqi Liang, Delft University of Technology, Netherlands, f.liang-2@tudelft.nl*

Jafar Rezaei, Delft University of Technology, Netherlands, j.rezaei@tudelft.nl

Matteo Brunelli, University of Trento, Italy, matteo.brunelli@unitn.it

In this research, we explore the uncertain input problem in Best-Worst Method (BWM), a promising pairwise comparison Multi-Criteria Decision-Making (MCDM) method which has received abundant attention by the research community since its proposal. By using BWM, the weights of criteria can be obtained by solving the linear or nonlinear program based on the paired comparison preferences provided by decision-makers. Compared with Analytic Hierarchy Process (AHP), BWM needs fewer comparison data but can generate more consistent comparisons and produce more reliable results according to previous analyses. In order to tackle the uncertain preferences provided by decision-makers, the belief structure is introduced to BWM, a concept of preference degree adopted by evidential reasoning approach. With their flexible distribution assessments, belief structures can effectively capture both precise data and various types of uncertainties such as ignorance and ambiguity in subjective judgments. A new approach is proposed to enable BWM to cope with this form of information, in which the belief degrees of the given preferences are taken into consideration. In real-world contexts, it is likely that group decision-making be preferred over individual decisions. In fact, many of the decision processes that are made in the real world occur in group settings to make the decision-making more comprehensive and reasonable. However, the uncertainty contained in the estimations provided by the group decision-makers and the inconsistency involved in the pairwise comparisons can and often lead to unreliable and unstable results. So it is necessary to measure the uncertainty and inconsistency degree of the given preferences to decide whether the result can be adopted or their evaluation should be turned back to the decision-makers to modify. In this research, a new consistency ratio measurement is proposed to examine the inconsistency degree of decision-makers in group decisions. Compared to the original consistency measurement proposed in the original BWM, this new consistency measure is easier to compute and has clearer algebraic meaning, interpretation and properties. To check the uncertainty degree

of decision-makers, we adopt the total uncertainty measure of belief structures proposed by Pal and Bezdek et al. in 1993, which has low computational complexity and satisfies a set of desirable axioms. The combination of inconsistency degree and the uncertainty degree of beliefs is then used to reflect the reliability of the decision-makers. Based on the weights of criteria obtained from the BWM and the reliability degrees of decision-makers, the assessments for alternatives provided by decision-makers are aggregated by Evidential Reasoning algorithm, which is particularly useful in dealing with belief structure information, and the alternatives are finally rated and selected. We conclude that incorporating the belief structure into group BWM enables decision-makers handle their beliefs in a flexible and versatile way, and combining evidential reasoning approach and BWM together considers the effect of belief degrees on decision-makers' consistency and the advantage of Dempster's rule, making this method a good option for decision aiding.

4. Best Worst Method: Robustness Analysis

**Jafar Rezaei, Delft University of Technology, Netherlands,
j.rezaei@tudelft.nl*

Best Worst Method (BWM) (Rezaei, 2015) is a pairwise comparison-based multi-criteria decision-making method that offers a structured way to make the comparisons. After identifying a set of relevant decision-making criteria by the decision-maker, the best (e.g. the most important) and the worst (e.g. the least important) criteria are specified by the decision-maker. Pairwise comparisons are conducted between the two reference criteria (best and worst) and the other criteria using a nine-point scale. The two input pairwise comparison vectors (best-to-others and others-to-worst) are used in a minmax optimization model to find the optimal weights of the criteria. The original BWM formulates the problem as a non-linear model, which may result in multiple optimal weights (optimal weight intervals). The reliability of the weights obtained from the method is checked using the consistency ratio, which is calculated after solving the optimization model. Since the non-linear model may provide more than one optimal

solution, it is also important to check the robustness of the results, which is the main aim of this study. Using analytical approach, we find the maximum theoretical sum of the interval ranges of the optimal weights. This theoretical value differs for problems with different number of criteria. The value is then used in a ratio to calculate the robustness index of a problem which has been solved by the non-linear BWM. The proposed robustness index, along with the consistency ratio of the model, provides enhanced insights into the reliability of the results. The findings show that (i) there is a high correlation between the consistency ratio of the pairwise comparisons provided by the decision-maker and the robustness index of the final results; (ii) pairwise comparisons with the worst consistency ratio, i.e. one, might be associated with extreme low and high values of robustness index, i.e. zero or one.

Rezaei, J. (2015). Best-worst multi-criteria decision-making method. *Omega*, 53, 49-57.

MON-2-B

Invited Session: Theory and Applications of ANP

Monday 11:10-12:50 - Room: Maiden's Tower

Chair: Orrin Cooper

1. The Development of a Conference City Selection Model as a Decision Making Managerial Support Tool Using AHP/ANP Best Practices

Enrique Mu, Carlow University, United States, emu@carlow.edu

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The goal of the present study is the development of an actionable model that can be used, in particular by executive directors and managers of professional associations, as a managerial decision support tool for conference city selection. While this topic has been sparsely addressed

in the literature, it has been typically discussed as a specific one-time event or as an academic study (Mu, 2006). This study will develop a usable conference city selection decision support tool using a practical decision making approach (Mu and Pereyra-Rojas, 2018a) and recently proposed AHP/ANP best practices (Mu, Cooper and Peasley 2017, 2018). This study is positioned within the stream of research to translate AHP/ANP studies into actionable managerial decision-making frameworks (Mu and Pereyra-Rojas, 2018; Mu and Pereyra-Rojas, 2018b, 2019) and will be illustrated with a case study in a professional association with long experience using AHP. Our first step has been meeting with the CEO and her top three directors to review and update an ANP model developed to predict conference attendance in 2009 (Mu, 2006). The results, at the time, predicted the conference would be a record success in terms of attendance and this was corroborated in the field. Unfortunately, it was the only time it was used since the model was designed to estimate participation for the 2009 meeting. Since it has been almost ten years since this study, the top directors in the organization (only one of them was present in the first study) considered it was time to review what had been learned since that time as well as to develop a new model that could be used as a decision support tool that could be used routinely. See model below (Table 1). Table 1 – Participation Prediction ANP Model CLUSTER (NODES) 1 Alternatives (City 1, City 2, City 3) 2 Risks (Public Safety) 3 Political/Strategic Factors (Political Stability, Economic Factors, Academic Alignment) 4 Costs (Airfare, Visa, Lodging, Living Costs) 5 Travel Factors (Travel Time, Time of the Year, Language, Touristic Appeal) Our next step has been meeting with the different directors separately to elicit their criteria for conference site selection as well as the associated weighting. Consistency was addressed with each director when needed. The different priorities were aggregated through a multiplicative process following standard procedure (Mu and Pereyra-Rojas, 2018a). Again, the goal was to develop a city selection model that could be used recurrently as a decision support tool for their annual meeting city selection. The model is shown below. Table 2 – Conference City Selection AHP Model CRITERIA (SUB-

CRITERIA) 1 City Logistics Business Best Practices, Hotel Room Costs, Meeting Venues, Policy Best Practices) 2 Travel Considerations (Airfare Costs, Visa Costs, Other Accommodations, City Appeal, Personal Safety) 3 Academic & City Financial & Political Support (Academic Alignment, Financial Support, Political Support) Our study contributions are as follows: • From a professional point of view, we are addressing the problem of selecting a conference city-a common but important decision in professional associations. • Furthermore, we are providing a simple to use everyday decision tool rather than approaching it as a one-time academic problem. • From a methodological point of view, we will be reporting this study using the recently developed best practice checklist developed for AHP/ANP models (Mu, Cooper and Peasley, 2018).

2. ANP to Ascertain Cooperative and Competitive Capabilities in the Context of Coopetition

Ramesh Dangol, Youngstown State University, United States, rdangol@ysu.edu

**Birsen Karpak, Youngstown State University, United States, bkarpak@ysu.edu*

The cooperative and competitive (coopetition) literature shows that firms can innovate and gain a competitive advantage by cooperating with competitors. For example, Gnyawali & Park (2011) show that fierce rivals Sony and Samsung cooperated to create new LCD screens and, consequently, increased their market share in the television market. Although the coopetition literature shows the benefits of cooperating with competitors, what is ignored in the literature is the extent to which firms can benefit from such relationships. We argue that the extent to which firms can benefit from coopetition depends on the relative differences in cooperating competitor's cooperative and competitive capabilities. When cooperating competitors possess different levels of cooperative capabilities, they would not be able to identify and acquire resources embedded in each other's operating routines essential for innovation. As a result, they would not be able to take a full advantage of cooperative

relationships. In contrast to cooperative capabilities, firms rely on competitive capabilities to appropriate benefits created by cooperating with competitors. Imbalances in competitive capabilities could allow a firm with high levels of competitive capabilities to appropriate the lion's share of benefits at the expense of its cooperating competitors. If imbalances in cooperative and competitive capabilities can limit cooperating competitors' ability to innovate and create the potentials for one firm to appropriate more benefits at the expense of the others, then we need develop methods that firms can use to accurately determine their capabilities and those of their competitors. Unfortunately, we are not aware of any research that shows how firms can accurately determine their own and their competitors' capabilities levels. Therefore, the primary goal of our study is to develop a method based on ANP that firms can employ to evaluate capabilities and, subsequently, form an enduring cooperative relationships. Our ANP model will take four elements into account when selecting a competitor with whom a firm wishes to establish a cooperative relationship – marginal benefits (B), opportunity costs (O), expenses (E) and transaction cost risks (R). Marginal benefits (B) is the excess benefits firms create by cooperating with competitors, whereas opportunity costs (O) is the marginal benefits firms would have created if they had formed a relationship with a different partner. Therefore, the net marginal benefit a firm realize is simply marginal benefits minus opportunity cost ($B - O$). Expenses (E) is amount of resources a firm devotes to cooperative relationship. Finally, transaction cost risk (R) is the potential costs resulting the likelihood that cooperating competitors decide to use resources created by cooperating in areas not covered by the contract and R will work to magnify E. Transaction cost risks vary from 0-1; risk equals 0 when competitors perceive no risk. Therefore, the total cost of forming relationship with a competitor can be expressed by $E + R$. The cost benefit ratio can be calculated by dividing $B - O$ by $E + R$ (or $(B - O) / (E + R)$), which is the basis for selecting a competitor from a choice set for establishing a cooperative relationship. Priorities of alternatives (different competitors) on B is determined by whether or not firms have similar levels of cooperative capabilities.

Competitors with similar levels of cooperative capabilities would be viewed as better alternatives compared to firms with dissimilar levels of the same capabilities. In contrast, transaction cost risks (R) are likely to be high when firms have dissimilar levels of competitive capabilities. Transaction cost risks equal "0" when firm are similar in their competitive capabilities. This paper shows that firms can use ANP to prioritize among competitors based on the marginal benefits they can generate by cooperating and the risks imposed by differences in competitive capabilities.

3. Centralized vs Decentralized Warehousing Configuration: An Analytic Network Process Approach

**Ozden Bayazit, CWU, United States, bayazito@cwu.edu*

Warehousing plays a vital role in providing the desired level of customer service at the lowest possible total cost and became a competitive resource for many companies. While some companies send their inventory to multiple warehouses to stay competitive and provide the desired level of customer service, the other companies choose to keep it in one centralized location. The most common warehousing configurations are either centralized or decentralized. As the number of warehouses a company uses increases, the system becomes more decentralized. On the other hand, if a company chooses to keep its entire inventory in one single, central warehouse, the system becomes centralized. In centralized warehousing, operation costs will be lower and customer service levels will increase; however shipping costs will be much higher when compared to a decentralized configuration. Very clearly, both systems possess advantages and disadvantages for the companies. Even knowing the pros and cons doesn't necessarily make the decision an easy one. Choosing the most optimal warehousing configuration decision involves both quantitative and qualitative factors and represents a multi-criteria decision-making problem. Due to interdependencies among the criteria that affect the companies' decision on choosing the most optimal warehousing configuration, we have decided to use the Analytic Network Process (ANP) to approach the problem. The ANP is a methodology for multi-criteria problems

where there are feedback and interdependence among decision attributes and alternatives. The ANP is a generalization of the Analytic Hierarchy Process (AHP) which is represented by a network. A network has clusters of elements, with the elements in one cluster being connected to elements in another cluster or the same cluster. Our network included four clusters namely, "Alternatives", "Costs", "Customer Service" and "Other". Each cluster had different criteria. For example "Costs" cluster included inbound transportation costs, outbound transportation costs, inventory holding costs, warehouse operating costs, and cost of rush delivery factors. Comparisons are made to evaluate both configuration alternatives with respect to many factors inside the clusters. The priorities derived from pairwise comparison matrices are entered as parts of the columns of the unweighted supermatrix. The final outcome presented interesting results. The proposed model is one of the first to apply the ANP in choosing the most optimal warehousing configuration. The major limitation of the technique is that it was applied for an illustrative example of a logistics company in the U.S. However, the results will provide guidance to companies that are trying to decide whether decentralization or centralization is best for them as the decision is a strategic one for many competing in today's global markets.

4. Coherency: Improving Data Quality and Reducing Comparisons in the ANP

**Orrin Cooper, University of Memphis, United States, olcooper@memphis.edu
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When developing the AHP, Saaty recognized the value of research that would improve the quality of decision data. The Linking Coherency Index (LCI) is a data quality check for ANP decisions. Engaging in data quality checks can not only increase the statistical likelihood of making a good decision; but it also provides an opportunity for important reflections about the decision and priorities that have been provided. Many decision makers have made pairwise comparisons, tested for consistency at the level of the pairwise comparison matrix, and needed to revise the comparisons. When revising the

pairwise comparisons, the decision maker will recognize that in the original comparisons an error was made; and believe the updated comparisons are not only more consistent but also make more sense and are a better representation of what they are measuring. Often times the revision process helps the decision maker clarify important points or definitions of the criterion and how it was being measured which improves the quality of the overall decision. In summary, by trying to improve the data quality by checking for consistency, not only can the consistency index be improved but it can also provide significant insights to the decision maker leading to revisions beyond new pairwise comparisons that are simply more consistent. The Linking Coherency Index (LCI) is an innovative method to test for coherency in ANP Supermatrices. Coherent data can be defined as self-consistent and non-contradictory with respect to a particular system. Coherency can also be thought of as a "super consistency test" or a test for consistency at the "system" level of the entire Supermatrix. By performing data quality tests at the level of the Supermatrix additional relationships and data are available to test for data quality than what is available only at the level of the pairwise comparison matrix. The consistency index can test for data quality among comparisons across a single unit of measurement. Coherency uses data from the comparisons across multiple units of measurement combined with the relationships between the different units of measurement that were provided by the decision maker to test for data quality. Coherency allows the decision maker to test the data both within a single unit of measurement and the relationships between the different units of measurement. Linking Estimates (LE) are an important component used when calculating the LCI. The LE can also be used to provide another advantage to decision makers by potentially reducing the number of comparisons that are required in ANP decisions. After reviewing the LCI, the value of this new data quality check, testing the coherency of the Supermatrix, and the value using the LE to potentially reduce the number of pairwise comparisons will be demonstrated through a neat interactive example.

MON-2-C

Contributed Session: MCDM for Group Decisions

Monday 11:10-12:50 - Room: Dolmabahçe Palace

Chair: Özge Şahin Zorluoğlu

1. Methodological Approach for a Group Decision-Making in Land Suitability for Agriculture

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This research presents a methodological approach to perform a spatial multi-criteria decision analysis based on the view of multiple experts or stakeholders and the importance of each criterion. It takes into account the impact of the policy makers. Twelve criteria (Water reserve easily utilizable, Drainage, Permeability, Potential of hydrogen (pH), Electrical Conductivity, Active limestone, Cation Exchange Capacity, Soil texture, Soil useful depth, Slope, Availability of labour, Proximity (roads)) grouped in five factors (agronomic, planning, land enhancement and improvement, soil conservation and environment protection, and socio-economic conditions) will be used in this study. Criteria will be evaluated with the Analytic Hierarchy Process (AHP) by experts in the subject area. The obtained weights will be introduced into a Consensus Convergence Model (CCM) to get consensual criteria weights which will be used to assess the land suitability for agriculture. Individual preferences of policy makers which include other factors that cannot be presented as maps or spatial data will be simulated in order to allow involved policy makers to rank the land units of the study area using a preferential method. All the required processing methods will be implemented into a GIS environment. The methodological developments are motivated by an application on land suitability for agriculture

in a study area of Mleta, regrouping 74 land units, in the western part of Algeria.

2. Implementation of Cumulative Belief Degree Approach to Group Decision-Making Problems Under Hesitancy

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In multi-criteria group decision-making problems (GDM), decision-makers may have hesitancy in their evaluations on assigning linguistic terms. This hesitancy may negatively affect the quality of the solution. Recently, the use of the Hesitant Fuzzy Linguistic Terms (HFLT) has increased rapidly due to the flexibility it provides to decision-makers. Using HFLT, decision-makers can assign more than one linguistic terms in their evaluations. There are a lot of studies in the literature for solving GDM problems with HFLT. However, when HFLT and other evaluation formats such as direct value assignment, classical fuzzy sets, linguistic terms etc. are used in the same problem, the methods in the literature are limited. The Cumulative Belief Degree (CBD) approach, based on fuzzy linguistic terms and belief structure, is a solution method applied in many complex multi-criteria GDM problems under different assessment methods. In this study, a multi-criteria GDM problem in which the evaluations are provided with different evaluations formats including HFLT is considered. A method based on CBD approach has been developed. Specifically, transformation formula for converting HFLT to CBD is proposed. The proposed method has been applied to a sales manager selection problem in literature. The method has been shown to be convenient for GDM problems with HFLT.

3. A Stochastic Multi-Actor Multi-Criteria Decision Analysis Approach to Evaluate Alternative Marine Fuels

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Selection of alternative marine fuels and power systems is a recurring decision problem for Norwegian ferry operators and concession authorities. When ferry crossings are tendered, perspectives of multiple stakeholder and decision-maker groups play into the overall credibility and acceptance of the final decision. Deployment of new and partly unproven technologies may also imply highly uncertain outcomes, which further adds to the complexity of the decision problem. We present an approach to tackle both these issues in ferry concession problems by combining principles from multi-actor multi-criteria decision analysis (MAMCA) with stochastic multicriteria acceptability analysis (SMAA). The multi-actor perspective allows to analyze alternatives from the view of stakeholder groups both separately and in concert to distinguish promising solutions. To ensure satisfactory handling of data, the approach also allows to utilize different multi-criteria decision making (MCDM) aggregation procedures. By modeling performance and preference information as stochastic parameters, rank robustness of alternative technology options are used to evaluate their overall performance. To illustrate the SMAA-MAMCA approach, a Norwegian ferry concession case study in a World Heritage Area is explored from the perspective of operators, concession authorities, and the local community. Due to the different nature of criteria sets for various actor groups, different MCDM procedures are utilized to ensure adequate handling of data. These encompass a value function method (TOPSIS), an outranking method (ORESTE) and a tender specific scoring model used for ferry concession evaluations by Norwegian Public Road Authorities. Nine fuel technology options are explored, including biofuels, fossil fuels, electricity, hydrogen and hybrid variants. Performance of alternatives across criteria for the three stakeholder groups are defined as stochastic parameters. Preferences are also modeled as uncertain, assuming complete lack of information on the relative importance of criteria for each stakeholder group. The results from the case study shows that different fuel technology alternatives exhibits first order stochastic dominance from the view of different stakeholder groups. This illustrates the point that even if preference information is missing, and performance information is

uncertain, it is possible to distinguish preferable alternatives for each stakeholder group thanks to the SMAA-component of the approach. When these results are combined using equal weighting of stakeholder groups, following the MAMCA method, we see that it is still possible to identify promising technology options by evaluating stochastic dominance based on robustness measures. This proves the point that even with diverging opinions, it may be possible to identify alternatives that are satisfactory from an overall stakeholder perspective. The composite approach may be a useful tool in public procurement or other large investment problems where outcomes are uncertain and the perspectives of multiple stakeholder groups needs attention. This includes problems where options must be qualified or disqualified prior to a tender call and problems where comparative performance needs to be evaluated once offers are submitted.

4. Hierarchical Group Decision Making Approach for Project Portfolio Selection

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Hierarchical Group Decision Making (HGDM) is a decision-making problem with a large number of decision makers (DMs) or experts organized in a hierarchical structure. In this problem, DMs not only propose alternatives but also provide evaluations of alternatives with respect to their own criteria. The objective of this study is to define a novel HGDM problem, a new perspective in group decision making. The characteristics of HGDM are described in four dimensions which are based on the position and number of stakeholders (DMs, experts, etc.), alternatives and criteria. The stakeholders are divided into hierarchical units. Some stakeholders may be located out of the hierarchy. A large number of people are involved in the process. Each hierarchical unit has its own alternatives and criteria. There are also common criteria that are evaluated by experts out of hierarchy. Furthermore, for this problem, a practical solution approach which is easy to

understand and apply by each stakeholder is proposed. HGDM problem involves a large number of DMs, alternatives and a few criteria sets. Therefore, it has a complex structure. Some difficulties may be encountered while explaining the whole structure to the stakeholders (DMs, experts, problem owner, analysts, etc.). That's why, a convenient solution methodology is proposed for the problem that is articulate for stakeholders. A solution methodology based on pairwise comparisons and ratings that are functional and frequently used multi criteria decision-making approaches are utilized for the newly proposed HGDM approach. One of the significant contributions of the study is the application of the HGDM structure to Project portfolio selection (PPS) problem. PPS is a process to obtain the best portfolio of projects for an organization under consideration of resource scarcity. Many stakeholders, who are classified in a hierarchical manner, propose projects and evaluate projects with respect to various sets of criteria. The aim is to form a portfolio of projects that will be performed. PPS problem is modeled time in the literature in various ways by considering one or more objective functions, resources or criteria, labor force, etc. However, most of the studies just consider the top management's preferences not the opinions of DMs or experts who propose these projects and others who will perform them. This could lead to bias in the selection process. It is important to consider preferences of all levels within the hierarchy. Therefore, it seems quite appropriate to apply the HGDM approach to the PPS problem. Properties of the HGDM are discussed based on the application. It is seen that HGDM approach improves efficiency with fewer questions. More accurate results are achieved with the participation of DMs from different levels of the organization.

MON-2-D

Special Session: AHP in Practice as "Decision Conference" in Turkey - sponsored by ARAMA

Monday 11:10-12:50 - Room: Topkapi Palace

Chair: Özey Özeydin

AHP in Practice as "Decision Conference" in Turkey

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This symposium is designed to offer the practice side of an age old multi criteria decision making methodology; analytical hierarchy process (AHP). AHP has been applied in more than 100 situations ranging from the choices Galatasaray Sports Club faced in the 2005, the future of the Topkapi Palace, to solve the organ transplantation bottleneck in İstanbul, many challenges confronting different municipalities, industry organizations and regional development agencies, UNDP Turkey strategic plan, for associations' priorities and to navigate between the strategic projects and choices confronting many different Turkish and international corporations operating in Turkey. AHP in practice takes the form of "Decision Conference" which is a form of conference that is designed to enable the participation of the relevant stakeholders to the setting and to the projects to be evaluated and prioritised. We have found that it is much better to generate the model and the the projects through another participatory methodology called "search conference". The decision conference typically follows the search conference and a commitment conference follows the decision conference. The triangulation of a variety of conferencing methodologies facilitates the participation of large numbers of stakeholders and a logical strategy formation and decision making track to engage them. We will go over one such process of collaboration to address the organ transplantation problem situation in İstanbul. The collaboration process that embodied search, decision and commitment conferences resulted in the increase of transplantation cases from 500 to 5000 in a period of a couple of years. Together with the sponsor of the whole process Mrs Derya Köker, the marketing manager of a different company at the time, we will discuss the trials and tribulations as well as the outcomes of the real life case.

MON-2-E

*Invited Session: Data Science meets
Multiple Criteria Decision Making*

Monday 11:10-12:50 - Room: Hagia Sophia

Chair: Jussi Hakanen

1. Benefiting the Target Relations in Supervised Learning: Multiobjective Extensions vs Space Expansion Methods

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In our study we consider supervised learning problems for data sets with multiple outputs (targets). The targets may exhibit scale differences and a combination of different scales require either data preprocessing or model modifications to keep the learning process avoid from being dominated by a specific target. Data preprocessing is criticized as it may result errors in measurements and may change the statistical properties of the data. Hence, we aim to develop classifiers so that they are insensitive to scale of the data. In addition, we further aim to augment the prediction quality of the classifiers by exploiting the target relations. Derivation of alternative ways towards the given concerns, is the theme of this study. The first strategy adapts an existing single objective multitask learning (MTL) model to its multiobjective MTL version. The objectives consist of indicators of learning quality, i.e. mean squared error. We changed the standard multitask design of tree classifiers that considers the quality criterion as an equally weighted sum form. We proposed several tree derivation heuristics so that we can take advantage of approximated Pareto optimal solutions. The second strategy benefits from the idea of transforming the learning problem. Noting that, our study is in a multiple target setting, and in the former strategy targets take place in the learning process merely as elements of output space. As a second strategy, we transform the problem so that targets have dual roles as inputs and outputs. In order to treat the targets in isolation as additional inputs we preferred gradually expanding (or chaining)

the input space. Considering a target, its order of joining the input space is a point to pay attention. Undoubtedly, the optimal configuration can be revealed via exhaustive search. However, we do not want either generalization performance degradation or process overhead. To cope with these issues, we create a routine that screens the best learned target and prioritizes it. We used a byproduct of the tree ensemble classifiers, that is out-of-bag-errors, that does not require any extra computational effort or data. In addition, it helps to capture the nonlinear relations between targets. We set up a series of experiments to test out our methods both in terms of time complexity and predictive performance. We compared the proposed methods with their state of the art. Initially, we compared the multiobjective methods for further analyses. We carried out another series of experiments to test the proposed methods against different and competitive chaining strategies. The results suggest that, our chaining strategy outperforms the multiobjective methods and the difference between their predictive performance is statistically significant. Moreover, though the predictive performances of our chaining method and its state of the art are not statistically significant, still our chaining method yields the best rank. In addition, we empirically showed that theoretical time complexity of our method is consistent with the calculations. We performed the aforementioned tests on a regression setting. In other words, all the targets are homogeneously continuous in the experiments. However, the targets of a data set may exhibit difference in terms of scales. To clarify, a mixture of categorical and numerical targets is a typical instance of such case. We did an additional experiment by using an artificial data set with one categorical and one numerical target. Clearly, the targets do not agree in terms of scale. We compared the predictive performances of the selected multiobjective method and our chaining method with a weighted sum policy. The results suggest that, our multiobjective design performs slightly better than the rest.

2. A Grid-based Algorithm to Generate Well-Dispersed Nondominated Solutions for a Three Objective SVM Formulation for the Imbalanced Data Classification Problem

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Classification problems in which instances that belong to one class outnumber the other class of instances significantly is referred to as the imbalanced data classification problem. These imbalanced data sets are commonly encountered in real-life problems; however, performance of well-known classifiers is limited in such cases. Various solution approaches have been proposed for the class imbalance problem using either data-level or algorithm-level modifications. We build on a three objective L1-norm SVM formulation that was suggested by Aşkan and Sayın (2014). Their key idea is to treat the sum of empirical errors for the two classes separately in the SVM formulation. Their solution methodology is based on reducing the three objective problem into biobjective ones by parameterization of one of the error sums. At the chosen level of a parameter value for one type of empirical error, the remaining bicriteria problem is solved for its entire Pareto frontier. This leads to cross-sections of the original three-dimensional Pareto set in the outcome space. The classifiers obtained in this way are evaluated on a validation set and a best performer is picked. In this study, we propose obtaining a representation of the three dimensional nondominated set directly, without using the cross-sectional grid structure. We experiment with a representation that is obtained by using a grid of both error sums simultaneously and solving a subproblem based on the achievement scalarizing function. The proposed approach does not provide quality guarantees on the representation that is delivered and it relies on the ability of the achievement scalarizing function to target a specific region in the outcome set. Numerical experiments demonstrate that the approach can deliver

good classifiers for difficult imbalanced classification problems and a comprehensive treatment of distinct positive and negative error levels may lead to important classification performance improvements. References Aşkan, A., & Sayın, S. (2014). SVM classification for imbalanced data sets using a multiobjective optimization framework. *Annals of Operations Research*, 216(1), 191-203.

3. Application of the Choquet Integral in K-Means Clustering Method

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Preference models often represent the overall degree of utility of an alternative in terms of the aggregation of several degrees of local utility, each of which relates to a specific criterion. Methods for learning preference models from observed preference data have focused mainly on adjusting the aggregation function while assuming the local utility functions that need to be given. This article presents the Choquet integral as a mathematical tool for learning classification. Although it is widely used as a flexible aggregation function in areas such as multi-criteria decision making, the Choquet integral is much less known in machine learning so far. The Choquet integral combines monotony and flexibility in a healthy and elegant mathematical way, but also has additional features that make it attractive from a machine learning point of view. For example, it provides measures to quantify the importance of individual predictors and the interaction between groups of criteria, which promotes the interpretability of a model. In the same concept, we can interpret the Choquet integral in a multi-criteria distance from clustering algorithms based on the most delegated partitions, namely k-means. When this aggregation function takes into account the interaction between criteria without losing the information of the criteria. In addition, the proposed approach is rather modest in multi-criteria aggregation, compared to the classical Euclidean distance that makes the combination with the k-means aggregation and the famous Choquet

Integral aggregation function. A generalised data has been illustrated in the problem which is compared with the usual k-means algorithm. The results of this practical approach were compared and found to be more accurate, easier to understand and, most importantly, require less time to process.

4. New Approach to Speech Signal Enhancement via Multicriteria Optimization and Adapted Metaheuristic

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This paper proposes a new contribution in the field of speech signal enhancement. This is the development of a method combining a multi-criteria approach to optimization with a suitable metaheuristic. Indeed, there are several methods dedicated to the improvement of the speech signal which is often corrupted by a noise. The classical spectral subtraction method introduced by Boll causes a distortion of the signal and gives rise to an annoying musical noise in the ear. To solve the problem Berouti introduces two parameters alpha and beta, of control that it fixes experimentally. Also, for us, it is a question of finding a compromise between distortion and musical noise by resorting to a biobjective optimization method combined with a metaheuristic of the type optimization by swarm of particles. The implementation of this study aims to compare the performance of the algorithm developed with the classical methods enhancement speech signal corrupted by additive noise present in hostile environments in a single channel context. Objective and subjective evaluation of the proposed method is performed using quality and intelligibility measures (SNR, PESQ ...). The performance of the algorithm is studied in the Airport, Babble, Car..., noise environments and the results obtained show that the improvement is better, even superior to the classical algorithms of spectral subtraction developed by Boll and Berouti, with a clear improvement of the

measurements from the point of view voice quality and intelligibility.

MON-2-F

Contributed Session: MCDM for Project Selection

Monday 11:10-12:50 - Room: Basilica Cistern

Chair: Jose Rui Figueira

1. A Multi-Objective Mathematical Model of the Multi-Period Substitutable Projects Location-Allocation Problem

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Today, the formulation of some combinatorial optimization problems revolves on the combination of several existing models. In this paper we formulate a multi-objective model of the multi-period substitutable projects location-allocation problem. This problem combines three sub-problems which are the multi-period substitutable resources allocation problem, the two dimensional bin-packing problem and the plant location-allocation problem. In order to treat the formulated multi-objective model, we present the goal programming approach and we obtain a goal programming model. we propose a general procedure to solve the obtained goal programming model.

2. Integrating Case-Based Analysis and Fuzzy Optimization for Selecting Project Risk Response Actions

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This article proposes a method based on case-based analysis and fuzzy optimization to provide decision support in project risk response. The main steps of the method are: 1) the formulation of alternative risk response actions (RRAs) based on case-based analysis, and 2) the determination of

the optimal set of RRAs using a fuzzy optimization model. Based on the method, project managers (PMs) can find out alternative RRAs and further determine an optimal set of RRAs. Compared with the existing RRA selection methods, the method proposed in this study makes two contributions. First, the case-based method and the optimization method are integrated for decision support in project risk response. The alternative RRAs can be obtained by using the case-based method; while the optimal set of RRAs is further selected out from the alternatives with the optimization model. Second, the fuzzy set theory is applied to evaluate the risk probability, risk impact and the similarity between risks in the RRA selection process. The advantage of using the fuzzy set theory is that the PMs and experts can make the evaluations with linguistic terms, which is more suitable for human perception in actual situations. And the quality of the adopted method of measuring the fuzzy distance is over most of the existing methods through ambiguity and fuzziness which are two main attributes of fuzzy numbers. Some managerial suggestion and implication are drawn from the results of the article. First, to perform better risk response in future, it is suggested that organizations should always capture a long-term perspective, with an awareness of keeping documents of all handled historical projects. Second, since each RRA obtained from alternative historical cases needs to be adapted in accordance with the current situations, adaptation costs should also be considered when allocating budget for selecting RRAs.

3. Assessing Development Impact to Guide Investment Decisions – Lessons from Implementing TOMS at the EBRD

**Pawel Krasny, EBRD, United Kingdom, krasnyp@ebrd.com*

The European Bank for Reconstruction and Development (EBRD) is an International Financial Institution (IFI) supporting private sector development and market economies in Europe, the Middle East North Africa (MENA) region, Central Asia and the Caucasus. It does so mainly by providing funding to projects that support its policy goals. The decision to approve a project is in

part based on its Expected Transition Impact (ETI) that signals the strength of its expected development outcomes. Over the past 3 years, the institution has been developing a methodology and an IT application to score the ETI of projects based on a coherent set of criteria. The presentation will present the methodology and link it with the MCDA (Multi-Criteria Decision Analysis) framework to discuss the core decisions made. In doing so the principal scientific contribution will be (i) to provide an applied example of a decision-making methodology and its application and (ii) to bridge the gap between theory and practice by discussing to what extent MCDA principles can be directly applied in a large organisations with a legacy of adhoc, expert-based decision-making. Specifically, we will explain how economists assigned scores to different criteria, the structure of the score aggregation, how we approach concepts such as independence of preferences, compensation, or uncertainty, and how IT systems may support or limit efficient decision-making. An interesting feature of the tool is that it combines decision-making criteria and a set of incentives for bankers to increase development outcomes. Moreover, it is embedded in the EBRD's wider project cycle by linking decision-making to monitoring. We connect criteria (or project objectives) to indicators that will be tracked throughout the life of the project. In doing so we hope to improve future decisions by having data on the delivery of past projects (feedback loops). There may be different ways to enter information about a project in the application and this may lead to different scores. Moreover, a committee reviews project submissions on a weekly basis and has the possibility to amend scores. Hence the ETI (development outcomes score) is the result of the application/methodology, decisions taken by the Banker in entering the project in the application, and the review by economists. We will discuss how project scoring is embedded in a wider institutional setting and is a result of a compromise between sound decision-making, internal constraints and legacy. We will also present issues in implementing this approach across the EBRD. Development outcomes assessment systems are increasingly used in development institutions but are often seen as bespoke and not transferable/comparable tools. The presentation will aim at setting a frame for a

discussion between such organisation and with specialists in MCDA and we will give a few examples on how other IFIs approach the assessment of development outcomes.

4. A Multiple Criteria Methodology for Prioritizing and Selecting Portfolios of Urban Projects

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This paper presents an integrated methodology supporting decisions in urban planning. In particular, it deals with the prioritization and the selection of a portfolio of projects related to buildings of some values for the cultural heritage in cities. In particular, our methodology has been validated to the historical center of Naples, Italy. Each project is assessed on the basis of a set of both quantitative and qualitative criteria with the purpose to determine their level of priority for further selection. This step was performed through the application of the Electre Tri-nC method. This method is a multiple criteria outranking based model for ordinal classification (or sorting) problems and allows to assign a priority level to each project as an analytical 'recommendation' tool. A set of resources (namely budgetary constraints) as well as some logical constraints related to urban policy requirements have to be taken into consideration together with the priority of projects in a portfolio analysis model permitting to identify the efficient portfolios and to support the selection of the most adequate set of projects to activate. The process has been conducted thanks to the interaction between analysts, municipality representative and experts. The proposed methodology is generic enough to be applied in other territorial or urban planning

problems. More precisely, given the increasing interest of historical cities to restore their cultural heritage the integrated multiple criteria decision aiding analytical tool proposed in this paper has an important potential of being used in the future.

MON-3-A

Contributed Session: Advances in MCDM Theory - Applications in Diverse Industries

Monday 13:50-15:30 - Room: Galata Tower

Chair: Nitin Harale

1. A Fuzzy Analytic Network Process Approach for Healthcare Service Quality Evaluation by Using Neutrosophic Sets

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Service quality has always been debatable in order to investigate how to improve and how to find deficiencies. Especially in healthcare sector, not only for quality improvement but also patient satisfaction, service quality is perceived to be increased step by step but which factors to be improved, renovated or taken into consideration are not always obvious and not easy to decide. In the literature, there exist many decision-making methods that are being used to prioritize different alternatives. These methods are very important when a strategic decision will be made at a big organization. In hospitals, seen as complex systems, there are many different factors for the evaluation of service quality, including internal and external factors. Thus, it is necessary to prioritize which factors should be improved in order to provide an efficient service for patients. In this case, Multi Criteria Decision Making (MCDM) tools are very useful to prioritize service quality. On the other hand, the method of Analytic Network Process (ANP) is widely used in MCDM problems. Especially, even if the factors affecting service quality in hospitals, are seen as objective, Fuzzy ANP

can be considered as a very effective method as the factors are generally evaluated under uncertainty. Thus, fuzzy MCDM methods are very suitable but depending on the set which is used during MCDM process, the priorities can change based on the method and fuzzy sets. There exist different sets which are used in fuzzy MCDM methods. In 1998, Smarandache has introduced neutrosophic sets as a general view of intuitionistic fuzzy sets, incorporating a new parameter in order to define the concepts of a membership and nonmembership. In this study, it is aimed to put forward A Fuzzy Analytic Network Process Approach for Healthcare Service Quality Evaluation by Using Neutrosophic Sets to prioritize service quality in hospitals. Neutrosophic sets will provide a different prioritization of service quality factors affecting especially patient satisfaction in hospitals. Furthermore, it is aimed to define which factors should be improved in order to reach the desired patient satisfaction.

2. A Closed-Loop MCDM Method Learning Model for Intelligent Manufacturing

**Jei-Zheng Wu, Soochow University, Taiwan, jzwu@scu.edu.tw*

To accomplish next-generation intelligent manufacturing, developing complete sets of measurement and a framework is critical to ensure effective multi-criterion decision-making (MCDM) decisions. Research on these topics is lacking. As a result, this study aims to develop a closed-loop learning model to implement decisions based on selected MCDM methods that are trained and validated as effective methods. Through a extensive literature review, this study summarizes well-known MCDM methods for effectiveness comparisons. Various normalization and aggregation methods and parameters settings will be discussed. A illustrative case in the semiconductor manufacturing is conducted. The results of this study demonstrate how selection process of MCDM methods can become automatic and intelligent by integrating novel machine learning methods.

3. A Fuzzy Cognitive Mapping Approach to Turkish Football Industry

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Football is attracting a considerable amount of people around the world. According to the Nielsen Sports survey in 2018, 43% of the 1.7 billion participants indicate that they are either interested or very interested in football. Being the top sports capturing the interest worldwide, it has a 75% share among Turkish participants. Besides the popularity, football is a developing industry considering the financial results. The annual financial report of Deloitte demonstrates that European football market size is €25.5 billion in 2017, where 58% is generated by “big five” European leagues (Premier League, Bundesliga, La Liga, Serie A, and Ligue 1). Turkish Super League is the sixth largest market in Europe with €734 million revenue. Under these social and financial circumstances, football clubs are turning into corporate companies. In order to improve the quality of football, to maintain financial stability and/or to increase their profitability, they have to adapt to the dynamic nature of the industry. Even international associations enforce football clubs to be more transparent and financially mature through the restrictive regulations, a systematic tool is needed to support the strategic actions and sustain both the sports and financial achievements. To address this issue, a Fuzzy Cognitive Mapping (FCM) method is proposed to examine the objectives of football clubs in Turkey. Eighteen objectives are determined based on a detailed literature review and expert opinions. The objectives can be classified into three groups: administrative, financial, and sports. FCM allows to represent the causal relationships between the objectives and to examine the long term behavior of the system based on the current circumstances. By using the method, a decision support tool to Turkish football industry is provided to build a strategic framework.

4. Supplier Selection in Data-Driven Fashion Industry by Using MCDM Methods

**Nitin Harale, Ecole centrale de Lille, France, nitin.harale@ensait.fr*

In fashion supply chain management, selection of suppliers is a critical and integral part of overall business processes. By selecting potential suppliers, who provide high quality products to the customers at the right time, fashion companies ensure their business growth, efficiency and profitability. However, due to the ever changing customer choices and the multitude of qualitative and quantitative criteria based on which fashion retailers often select their suppliers, supplier selection process entails highly complex decision making. Moreover, due to the advent of e-commerce business models and advanced database technologies, it is increasingly becoming challenging to select the appropriate criteria among many conflicting, inconsistent, and contradictory ones based on which supplier selection can be achieved. In this paper, authors aim to address this challenge by using MCDM methods, viz. Fuzzy-AHP, TOPSIS, PROMETHEE, VIKOR methods. MCDM methods are popular for solving multi-criteria and group decision making problems. The research problem in this paper revolves around the challenge of selecting the best possible suppliers considering the range of criteria and sub-criteria from both retailers' and customers' point of view. A questionnaire based survey approach is adopted to evaluate and identify highly important qualitative and quantitative criteria. The participants were supply chain managers from four European fashion companies who specialize in range of customized fashion products. Given the increasing trend of big data technologies in major industries, fashion retailers are now able to gauge as to what predominant choices their customers are making with respect to the products and services retailers are offering to them. This study aims to address the complexity of involving information from a big data environment. The responses provided by the participants in this respect are representative of rapidly varying customer's choices. Furthermore, participants evaluated their suppliers based on each relevant criterion. The responses

then encoded into numerical scale according to the applied MCDM method. The software packages authors used to conduct this study include Python, R, MATLAB, and Excel depending on the suitability and flexibility of their libraries. Authors' main objective in this paper is to identify the best performing MCDM method for the selected research problem considering the complexities it involves. Authors expect that the results from this study will provide well suited and accurate approach for dealing with high dimensionality of supplier selection criteria and sub-criteria, and the pool of competing suppliers in the market. It is also expected that this study will address the conflicting information generated in the big data environment of companies' business models while making group decisions for local as well as global sourcing. Authors envisage that this paper will provide valuable insights and contribute to the enhanced group decision making in the fashion industry in regard to supplier selection. Moreover, it will provide a proper direction for the further research in this area.

MON-3-B

Contributed Session: Consistency Issues in AHP

Monday 13:50-15:30 - Room: Maiden's Tower

Chair: Jorge I Romero

1. The Accuracy of the Consistency-Compatibility Relationship in the AHP Context

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An extensive review of the scientific literature on consistency and compatibility indexes in the context of ANP theory, together with author's previous research points to the lack of undisputable numerical threshold values, able to act as goodness of judgement's jackknives. This paper illustrates a method of meta-analysis of the paired relationship between the previously two mentioned indices. Building on the previous author's experiments which revealed the existence of a linear association in between consistency and compatibility, the concept of accuracy-usually applied in the medical

decision making, is adapted and extended to point sensitivity of accuracy in order to filter out the outliers in this association. Results indicate that although a threshold of 0.1 for consistency index(ratio) might be arbitrary, scale dependent and also dependent on various types of senses involved in a decision making problem (vision, somatic sensation, logical /mathematical , existential, linguistic) filtering judgments through the accuracy test diagnostic as adapted hereafter offer a more reliable tool in heterogeneous decision making problems.

The paper is organized as follows. In the first section is provided a critical analysis of the literature regarding the appropriateness of the usual 0.1 threshold for the consistency ratio as well as for the various types of compatibility indices available to measure the closure of a derived priority vector to a certain "true" priority vector, which is determined outside the current process of decision making. In this context, the scale dependency of the consistency ratio, methods of improving on consistency with effects on the priority vectors as illustrated in the relevant scientific literature and brought together with author's own calculations about the chances to fulfill consistency as the dimension of the decision matrices increases. About the compatibility index, aside of Saaty's one, it is also reviewed Garruti compatibility index and another slight adjustment of Saaty's compatibility index is introduced. A comparison in between the three compatibility indexes is performed through a Monte Carlo experiment and the existent critical comparisons are re-interpreted. In the second section, the concept of test accuracy, as it appears in medical decision making is presented, together with an original analytical determination of the accuracy's point sensitivity. The second section is devoted to the analysis of the paired relationship between consistency and compatibility in the context of calibration curve, allowing for the evaluation of the linearity and homoscedasticity. The concept of accuracy , as the most important aspect of the validation of the calibration curve in the medical domain is extended to the concept of point sensitivity of accuracy and in this section is proved how several concerns in the detecting of outliers applying accuracy are favorable flicked with this new analytical derivation of the accuracy concept. This new concept is further applied in the

third section where results of several experiments are presented and the goodness of the link between the consistency and compatibility is casted and sorted favorable, in terms of point sensitivity of accuracy. Conclusions of this paper point to a broad range of applications of this idea, once validated.

2. Pairwise Comparison Matrices in Accordance with Saaty's scale

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This study investigates the number of possible consistent Pairwise Comparison Matrices (PCMs) where all matrix elements belong to Saaty's scale (the set of integers from 1 to 9 and their reciprocals). Many studies consider PCMs in Saaty's scale, but the problem of determining the total number of these matrices that are consistent has only been mentioned briefly by a single study (J. A. Alonso and M. T. Lamata, 2006). The number of $n \times n$ PCMs with elements in the scale is 17 raised to the power $n(n-1)/2$. However, of these matrices, only a small fraction satisfy the criteria for consistency. Our starting point was the fact that the rank of a consistent PCM is one, and all of its rows are proportional to each other. In addition, all diagonal elements are equal to one. Therefore, the elements of the first row completely determine all other matrix elements. By inspecting all possibilities for the first matrix row, we determine 1. a method to generate all the consistent PCMs in Saaty's scale and 2. a closed-form formula for computing their number as a function of n . For $n = 3$, there are 4,913 PCMs in Saaty's scale, among which only 85 are consistent. Similarly, for $n = 4$, there are 24,137,569 PCMs of which only 353 are consistent. For $n = 5$, there are 2,015,993,900,449 PCMs and only 1,381 are consistent. Our results differs from those reported by J. A. Alonso and M. T. Lamata (2006). We validated our formula for $n = 3, 4$ and 5 by generating all the PCMs in Saaty's scale and checking the consistency conditions for each. In each case, the check confirmed the result of our formula. For n equal or greater to 6, the

number of PCMs to be checked becomes intractable.

References Alonso, J. A., & Lamata, M. T. (2006). Consistency in the analytic hierarchy process: A new approach. *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems*, 14(4), 445–459. Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology*, 15(3), 234–281.

3. Inconsistency of Incomplete Pairwise Comparisons Matrices

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The pairwise comparisons method is the well-known procedure of ranking creation. In the basic model, experts compare each of the two alternatives, thus, form the matrix of comparisons (the pairwise comparisons matrix), next, they use the mathematical methods to prepare the final ranking. Probably the most popular method based on this approach is the Analytic Hierarchy Process (AHP). Nevertheless, such a procedure, although simple, has two disadvantages. The first of these is inconsistency. As experts do the individual assessments, they may not always be consistent. The level of inconsistency of paired comparisons is determined by so-called inconsistency indices. It is widely accepted that the higher the inconsistency, the lower the credibility of the ranking. The second disadvantage of this approach is the need to compare all alternatives against each other. On the one hand, this may require much work, on the other hand, it may not always be possible. Therefore, more and more often in practice, only a part of all possible comparisons are made, and the ranking is calculated using incomplete pairwise comparison matrices. Despite this popularity, it seems that the problem of the inconsistency of incomplete pairwise comparisons matrices is not well represented in the literature. The presented work aims to (at least to some extent) bridge this gap. In the paper, we discuss several well-known inconsistency indices such as Saaty's CI, GCI (Geometric Consistency Index), GWI (Golden-Wang Index) and others, and present their extensions to the incomplete pairwise comparisons matrices.

These indices allow assessing the degree of inconsistency of the incomplete pairwise comparisons matrix. Thus, they can be used to assess the credibility of such a ranking. Theoretical considerations will be accompanied by Montecarlo experiments during which we study the performance of the modified inconsistency indices.

4. A Set Cover Problem Approach for Improving Consensus and Consistency in Large (AHP) Group Decision Making.

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The purpose of this work is to show a way to improve consensus and improve consistency in group decision making problems, using AHP, matrix similarity comparison and simulated annealing. The main goal of this work is contributing to the challenges and open questions proposed by Cabrerizo et al in 2013 highlighting the following areas: counseling, visualization and verbalization of the process, dynamic decision contexts, and persuasion. A hybrid approach is proposed to address the issue of dealing with a large group of decision makers or several stakeholders, and then search for the problem consistency changing the minimum number of judgment values, also evaluate the agreement of their judgments in every pairwise comparison and for the whole model. The evaluation of the agreement level is performed in order to rank the consensus level or level of agreement of every decision maker to all others, and calculate a global consensus index for the problem. Once the specific pairwise comparisons with no agreement are identified, a persuasion attempt is performed in these comparisons, trying to change the minimum number of judgments in order to reach a established consensus level. Decision model start using AHP to construct the decision matrices for all decision makers, given that this work uses AHP a consistency analysis is performed in every triad of values for all pairwise matrix,

based on the work proposed by Kendall and Babington in 1940 "On the method of paired comparisons" and extended by Kulakowski in 2018. This initial approach for improve consistency consists in a variation of set covering problem proposed by karp in 1972 called triad covering problem, and considerate every circular triad as an individual point of consistency (according to the axioms given by Kendall in 1940 and kulakowski in 2018). The algorithm for perform evaluations in every pairwise comparison matrices are performed by using the JULIA language. Once have consistency in the problem, the first consensus index is calculated and if don't have reach the desired consensus index, a second algorithm is performed to search the minimum number of changes in decision makers judgments in order to reach the appropriate level of consensus for the problem (the consensus control is based on the previous work of Romero-Gelvez and Garcia-Melon in 2016). The algorithm for consensus control is performed also with JULIA programing language. The validation of this approach is proved in three different scenarios: The first application is ranking the main airports of Colombia dealing with 85 decision makers, the second one is an environmental application for ranking eco-tourism in Colombian Amazonia dealing with 8 decision makers. And the last one is an educational application to improve performance in undergrad students of engineering programs, dealing with 30 decision makers.

MON-3-C

Invited Session: Building MCDM/A Models: Practical and Methodological Issues

Monday 13:50-15:30 - Room: Dolmabahçe Palace

Chair: Caroline Mota, Cristiano Cavalcante

1. Quantification of Acceptability Level for Donations in Case of Natural Disasters

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According to the International Federation of Red Cross and Red Crescent Societies, a disaster is a sudden and calamitous event that seriously disrupts the functioning of a community or society. This event causes human, material, economic and environmental losses, which exceeds the capacity of the community or society to use their own resources and therefore generates an appeal to Humanitarian Assistance. In all the work of humanitarian assistance there is a very important factor called donation. A donation is a voluntary delivery of one or more goods, by a donor, which may or may not be accepted by the donee. Donors can be different humanitarian organizations, companies or individuals, who are encouraged to donate for two fundamental reasons: by request of collaboration or by natural reaction to the event. Donations have an appearance before, during, and after the disaster. In the "before" of disaster, standard kits are made with items such as kitchen utensils, tools, clothes, hygiene and others. Once the disaster has occurred, the entities must give a quick response to the affected population, complementing the aid inventory with the donations that are starting to be received at that moment. People have an unfortunate perception of what should be donated when a disaster occurs, since most believe that it generates more help by sending everything it can as quickly as possible. These types of perceptions can generate large amounts of waste both from donations and from the resources that must be used to receive, maintain and transport inappropriate or unsolicited donations. To mitigate this negative impact in some way, it is important to be able to identify when a donation is efficient and can really help. Therefore, through the characterization of appropriate donations and the establishment of fundamentals criteria, it is intended to develop a methodology to quantitatively qualify the level of acceptability of donations in a case of natural disaster (flooding) in the city of Santiago de Cali (Colombia). In Colombia, the National Disaster Risk Management Unit has

established the different topics that make up the assistance: water and sanitation, food aid, non-food aid (cooking kits, hygiene and bedding), temporary accommodation and health days. For this research, only food and non-food aid issues will be considered, since they are the ones that are most closely related to donations and donors. Quantification of acceptability level of donations is made through five criteria: Proximity to expiration, use time, quantity, size and product appearance. These criteria allow to evaluate all the basic elements that make up a food kit, toilet kit, kitchen kit and bed kit. The AHP multicriteria methodology was developed to obtain the criteria prioritization. This was achieved thanks to the participation (surveys) of possible affected people, donors and experts from some entities. Then the donations receive a score depending on the theoretical acceptability they have. Finally, the resulting percentages give a global score, which is equivalent to the level of acceptability of the donation. All the above is done with the help of a macro in Excel. Once the prioritization has been obtained, it is evident that when the product is perishable, a large part of the judgment is concentrated in the proximity to its expiration. In the absence of this criterion, the appearance of the product will take on a greater weight. In addition, in all cases, it is well known that quantity criterion acquires great importance in donations evaluation. The methodology is proposed as an educational tool that generates a culture of "good donation" in the city. When validating the methodology, there is a change in people's perception of what a donation is and what is appropriate to donate, as well as feeling more secure and more willing to help others.

2. Comparative Analysis of VDA Methods and Techniques

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Multiple Criteria Decision Analysis (MCDA) deals with decision making tasks which require to find the best or a group of the best alternatives while taking into consideration

multiple criteria. In majority of MCDA tasks, the decisions are based on subjective information about a decision maker's preferences. Numerous descriptive studies examined different ways of eliciting such human preferences and their comparative consistency. As a rule, they conclude that preferential information from the decision makers in the ordinal form is more consistent and thus more reliable than one obtained by using quantitative (interval or ratio) scales. Verbal Decision Analysis (VDA) is a framework for multicriteria decision making methods, based primarily on using subjective preferences in the verbal, ordinal form; and this study reviews the main ideas and methods developed under this framework. Oleg Larichev and Helen Moshkovich in 1997 first proposed and outlined VDA approach with first three methods – ZAPROS, ORCLASS, and PARK based on VDA paradigm. The main idea that a decision maker should be allowed to express his/her evaluations and preferences in a verbal form and that final decisions should be based entirely or primarily on these verbal ordinal preferences without transformation into a quantitative form in some arbitrary way. Another important idea of VDA was incorporation into the decision analysis special dedicated procedures for verification of the consistency of a decision maker's preferences. Following these principles makes the decision process transparent to a decision maker by providing easy to follow explanations of the final results. The first three methods, based on VDA approach, were developed for different types of tasks. Method ZAPROS was designed for rank ordering alternatives, ORCLASS was developed for an ordinal classification of alternatives, while method PARK helps to select the best alternative. As VDA approach becomes more popular, many new methods, based on VDA principles, were proposed as practical tools to solve multicriteria decision making problems, including ARACE, CLARA, etc. In this study we outline the main peculiarities of these methods, classify them, and discuss the current trends in VDA development.

3. A Multicriteria Model to Evaluate Opportunistic Maintenance Policies Subject to Imperfect Inspection

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This paper presents a multicriteria approach to evaluating opportunistic maintenance policies subject to imperfect inspection. Opportunistic maintenance refers to the strategy of carrying out preventive maintenance actions on a particular sub-system at the time of an opportunity generated by a failure or preventive action on another sub-system that is part of the same system, which can lead to savings in terms of cost and downtime. In this work we present a delay-time model for a hybrid inspection and preventive maintenance policy subject to imperfect inspections, and which also considers the possibility of opportunistic maintenance after a certain time of operation. Since maintenance decisions often involve objectives other than cost minimization, given the possibility of impacts on non-financial dimensions, multicriteria decision-making approaches can be appropriate for these contexts. In this paper we explore the impact of imperfect inspections on the maintenance policy performance for two criteria: expected cost per unit of time in the long term (cost) and mean time between failures (MTBOF - a good measure of reliability) resulting from the adoption of the maintenance policy. These criteria are conflicting because there is no maintenance policy that presents the optimum performance for both, thus a multicriteria approach based on the Multi-Attribute Value Theory (MAVT) was considered for the evaluation of maintenance policies. MAVT was chosen because compensatory rationality is compatible with the problem, and even when there is no complete knowledge of the state of nature of the problem, the method can bring important insights. A numerical application is presented, and the results show the impact of the imperfect inspection, the mistakes that can be made when this factor is not considered, as well as the importance and adequacy of the multicriteria

approach to evaluation of maintenance policies.

4. A Spatial Multiple Criteria Decision Model for Vulnerability Analysis

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This study highlights the benefits of using a spatial MCDA approach to evaluate the vulnerability of places at crime level. The model was supported by a Dominance-based rough set approach to join preference learning and Geographic Information Systems. The approach requires a priori knowledge from decision-makers for holistic assessment to analyze individual results. Additionally, we explored an approach for aggregation of those individual results for obtaining a final output recommendation. The approach aims to decrease the cognitive effort of decision makers, in which their preferences is assessed in an interactive and incremental way. We present an application of the proposed approach to evaluate places according to its vulnerability to crime occurrence and to identify areas that deserve more resources to combat crime. As a result, the model may help policy-makers and planners to develop public policy interventions.

MON-3-D

Tutorial: Improve Your Decisions by Learning and Experiencing the ANP Best Practices- Part I

Monday 13:50-15:30 - Room: Topkapı Palace

Chair: Birsen Karpak

Improve Your Decisions by Learning and Experiencing the ANP Best Practices- Part 1 of 2

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This tutorial is an Analytic Network Process (ANP) Best Practices experiential learning activity because we learn best by doing.

Beginners with no prior experience will make their first ANP decision. Experts, and those in between the two extremes, will acquire valuable tools and techniques to improve the validity of their ANP decisions. Attendees should come prepared with an interesting decision, big or small, that has at least 3 alternatives and 2 clusters, i.e. groupings, of criteria, with multiple criteria in each cluster to build a decision model during the tutorial. The fundamentals of the ANP will be addressed, just in time, as we build our individual decision model. The ANP Best Practices will serve as our checklist to make sure that we address the critical components of an ANP decision. A review of ANP studies, that were published in the Social Science Citation Index (SSCI) over a one-year period, revealed that over half of the published ANP models had errors or omissions that were serious enough to bring the validity of the published model into question. These findings contributed to the development of the ANP Best Practices. The most common or critical omissions will be covered in greater detail at the specific times that they should be addressed when we are building our decision models. Tools and techniques will be provided to help decision makers: to check for the convergence of the Supermatrix, to identify and adapt a disjoint Supermatrix, to recognize and accurately capture the desired level of dependency in the Supermatrix, to test and improve the Coherency of the Supermatrix, and to conduct and report meaningful sensitivity analysis. By the end of this tutorial, beginners will have “experienced” an ANP model from beginning to end; and experts will have more tools and techniques to improve the validity of their decisions.

Please bring your own laptop to this special session

MON-3-E

Contributed Session: Recent Advances in Multiobjective Optimization

Monday 13:50-15:30 - Room: Hagia Sophia

Chair: Petra Weidner

1. Robustness Indicators for Multi-Objective Integer Linear Programming

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Decision uncertainty is a robustness concept in continuous single and multi-objective optimization, which takes into account the inaccuracy of the implementation of a solution (also called implementation error). Due to technical limitations a solutions might not be feasible for implementation. Implementing a solution in the neighborhood of the computed optimal solution can lead to a smaller or larger loss in solution quality. To limit this loss one can, for example, optimize the worst solution in the neighborhood (minmax). Eichfelder et al. (2017) investigate decision uncertainty for continuous multiobjective problems using set-valued optimization problems as robust counterpart. We transfer this concept to multi-objective combinatorial optimization problems. In the discrete context decision uncertainty is due to the fact that certain items (edge, element, ...) of a Pareto optimal solution might turn out to be unavailable in the implementation phase. Instead of reoptimizing the problem one is interested in repairing a solution by substituting the flawed item. Thus, the originally selected Pareto optimal solution is substituted by a neighboring solution. The neighborhood structure is thereby defined by a combinatorial adjacency structure of the problem. We propose robustness indicators, which are based on those neighborhoods. They are mainly of two types, cardinality indicators and quality indicators. In a first case study we evaluate the robustness indicators on randomly generated instances of the cardinality constrained knapsack

problems. Furthermore, by using these indicators as a quality measure for the representation problem we construct representative subsets of the non-dominated set that are robust against decision uncertainty.

2. A New Algorithm for Optimization over the Efficient Set

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Optimization over the efficient set of a multi-objective optimization problem is among the difficult problems in global optimization because of its nonconvexity, even in the linear case. In this paper, we propose a numerical method to tackle this problem when the objective functions and the feasible set of the multi-objective optimization problem are convex. This algorithm penalizes progressively iterates that are not efficient and uses a sequence of convex nonlinear subproblems that can be solved efficiently. The proposed algorithm is shown to perform well on a set of standard problems from the literature, as it allows to obtain optimal solutions in all cases.

3. A Differential Evolution Reference Point Method for Set-based Robustness by Means of the Averaged Hausdorff Distance

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In this work, we propose a method to find efficient solutions in the context of set-based robust multi-objective optimization. In this setting, a solution in decision space maps to a set, which represents the worst possible outcomes given the set of uncertainties. Thus, the task is to find the set of best-worst solutions. This set is highly attractive when the decision maker has an aversion towards risk and would like to perform the decision making from a worst-case approach.

Moreover, when the decision maker has an aspiration vector, then we can use reference point methods where the objective is to find the solution whose image minimizes the distance to the aspiration vector. For set-based robustness, that is finding the solution whose set of worst cases is the 'closest' to the aspiration vector. The proposed method has three key components. First, since the image of the solutions is a set, we use the averaged Hausdorff distance to measure the distance from the image of a given solution to the aspiration vector. This formulation reduces the problem to a single-objective optimization problem. The averaged Hausdorff distance has been used by the evolutionary multi-objective community to compare the solutions found by different algorithms, and it has also been used as a selection mechanism for evolutionary algorithms. Next, for every solution in decision space, it is required to find the set of worst-cases. For this purpose, we use the weighted Tchebycheff method to find a good representation of the set. Finally, to find the solution that minimizes the averaged Hausdorff distance, we use a global search method that enables to avoid local optima. Namely, we use the differential evolution algorithm (DE/rand/1/bin) as the search engine. DE has been extensively used when tackling single-optimization problems in continuous spaces with good results. We test the method on an academic test function based on the bi-objective Lamé super-spheres with linear, convex and concave fronts. The results show that the method is capable of finding good solutions from the problem at hand given different aspiration vectors.

4. Scalarization Depending on the Purpose of Multiple Objectives in Optimization

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When looking for the best solution in practical applications, multiple objectives can come into existence by different reasons. They can express values of attributes, various scenarios in decision making under uncertainty or evaluations of multiple decision makers. This should be taken into consideration for the choice of a scalarizing problem. This aspect is discussed in the presentation. Moreover, it is shown that the

different scalarizations can be visualized in the same framework, which also delivers statements about their properties. The presented framework is an extension of the scalarizing method by Pascoletti and Serafini. It is applied to the Hurwicz rule for decision making under uncertainty, to problems with different weighting vectors originating from multiple decision makers and to decision problems with domination sets which are not necessarily cones.

MON-3-F

Contributed Session: MCDM for Facility Location and Logistics

Monday 13:50-15:30 - Room: Basilica Cistern

Chair: Özay Özaydın

1. Multi-Criteria Facility Location Planning and Development under Consideration of Municipal Developments in Metropolitan Regions

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The increasing development of metropolitan regions and the associated changes of spatial structures are the main consequences of globalization and urbanization trends. Metropolitan regions are characterized by a multitude of different spatial structure types. These differ significantly regarding the quality and the development of economically relevant regional location factors. However, the differences of spatial structures offer potentials to increase a company's competitiveness and to ensure a sustainable company's success. In order to exploit the identified potentials, companies must consider relevant future dynamics in the course of location developments. To date, the dynamics in regional location developments are not yet considered in existing facility location planning approaches. This especially holds for

company-driven measures to develop spatial structures. As a result, there is no appropriate decision-making approach of location planning in metropolitan regions, that fulfills the requirements with respect to regional dynamics. There are three types of relevant regional dynamics. First, dynamics in regional location planning includes over the time changing corporate location requirements. These generally increase due to organizational, economic and technological advances. Second, the characteristics of regional location factors are not temporally constant but underlie changes over time. On the one hand, these changes result from municipal decisions in the course of location developments, influencing the characteristics of regional location factors. On the other hand, companies are able to allocate appropriate development measures to improve the characteristics of regional location factors in a target-oriented manner and according to their own location requirements. Third, municipal and company induced location developments may cause synergetic or conflicting interdependencies between regional location factors. By now, these dynamics are not considered in regional location planning. Thus, an appropriate model formulation for regional location planning considering development measures and regional dynamics is missing. In this contribution, a multi-period weighted goal programming model for the integrated location planning and development in metropolitan regions is developed. The integrated decision model allows to simultaneously select a compromise-optimal location and to generate a strategic development plan for the allocation of optimal company-driven measure sets to develop locations in a target-oriented manner. Furthermore, the model takes into account that location construction investments as well as investment payments for location development do not exceed a restrictive overall budget. Comparing existing location planning models with this novel integrated location planning model, findings of the latter show a better achievement of the decision-makers targets by approximately 43% due to the company-driven measure allocation. Therefore, significantly better location factor characteristics are achieved according to the company's requirements and long-term

optimal location decisions under consideration of municipal developments in metropolitan regions can be ensured.

2. Using Multicriteria Decision Making in Emergency Situations – Case Study: Bucharest City

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Bucharest City is the capital of Romania and it's one of the most vulnerable European capitals to earthquakes. The vulnerability towards earthquakes resides from its geographical position, the age of the buildings and the high population density. The earthquakes that affect Bucharest City have the origin in Vrancea Region. These earthquakes have the hypocentre at depths between 70 and 200 km and can reach a magnitude of M7.0 – M8.0. The waves propagate on a northeast – southwest direction from the epicentre. The major earthquakes that affected Bucharest in the last century were registered in 1940, 1977, 1986 and 1990 causing many victims and economic losses. Based on the scientific evidences, it is very probably that a new major earthquake is yet to strike the city. Many of the city's buildings are very old, with damaged structure, that passed through many major seismic events, being a real danger for their inhabitants and for their surroundings. The city is also highly populated, many neighbourhoods developed in the communist period have blocks of flats with 4, 8 and 10 storeys. During the working hours, to the residential population is added the population that lives outside Bucharest, but that works or studies in the city. Another factor that contributes to the high vulnerability of the city are the narrow streets that surround the highly dense areas. All of these added to the more and more intense traffic, can contribute to the scene of a disaster in case of a new major earthquake occurrence. The firefighters, the

ambulances, the police and other entities involved in emergency situations would face difficulties in reaching the most affected areas and in acting effectively to limit the losses in post-disaster phase. For these reasons, the preparedness is an extremely important component for risk reduction. The present paper aims to apply a multi-attribute decision making for identifying suitable areas in the city, that can be used as local centres for conducting the rescue missions, for sheltering the population and for giving the first aid in the post-disaster phase. The criteria considered are those regarding the physical vulnerability of the city, the social vulnerability and the capacity of intervention of the authorities. The results can be used by the local authorities for improving their preparedness and for limiting the human losses.

3. Prioritization of Areas for High Volume Loading and Unloading. Case: Santiago de Cali

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The freight consolidation's is defined as the process of grouping different shipments of suppliers into a large shipment within a consolidation center. The main objective of freight consolidation's is to reduce the total cost of transport between an origin and a destination. Some authors classifies in three forms of consolidation: consolidation of inventories, consolidation of vehicles and consolidation of terminals. Another authors make a similar classification, but adds a form of consolidation called independent, in which small shipments are attended directly to each client independently. To this classification denominates consolidation of shipments, route of vehicles and consolidation of network respectively. Urban freight transport is an extremely important and quite disturbing activity. Increasingly, one observes efforts to measure and control the movements of cargo within city centers. The vast majority of public sector initiatives aimed at urban cargo aim to reduce their negative social and environmental impacts, which are typically the result of freight vehicular activity. This approach is a natural response to the participation of cargo vehicles in the

generation of negative externalities. Meanwhile, urban logistics is a fundamental aspect for the development of a social environment and more when you have a high volume of commercial activity and freight transport, for a broad population density; so urban logistics is defined as the process through which the private transportation and the logistics activities in urban areas are optimized; considering traffic, congestion and energy consumption within the structure of a market economy. The Valle del Cauca's region is located at southwest of Colombia, its socio-economic development has been mainly determined by coffee, sugar and, agricultural production of inputs for agro-industry.. Additionally, the city of Cali has different areas with commercial, residential, academic and health activities, some clustered and others mixed together. This condition makes the cargo vehicles circulate throughout the city looking to deliver their goods as close as possible to the final distribution, generating congestions and accelerated deterioration of the internal roads due to heavy traffic. Considering the territorial analysis and the concept of urban logistics, with the help of the Multicriteria Decision Analysis (MCDA), such as Analytic Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methodology, it is intended to provide a ranking of proposals on areas in the city with current and future possibilities to be considered as a high volume loading and unloading areas, considering different criteria, include in Economic, Technical and Social dimensions

4. Determining Leading Research on Transportation and Logistics Performance through Social Network Analysis and TOPSIS

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The primary aim of this research is to determine pioneering literature on logistics performance appraisal and evaluation. Although the most common assessment system is the cost-benefit analysis, it lacks to take temporal dynamics, qualitative logistics performance dimensions such as speed, on-time performance and quality into

consideration. Initially, a preliminary survey is conducted using Web of Science, Scopus, and Science Direct databases for 2007-2019. Keywords "logistics," "assessment," "performance," "evaluation," "supply chain," "transportation" are used as corresponding search strings. The resulting articles are further re-classified into 15 groups, namely: appraisal, big data, cost-benefit analysis, collaboration, decision, infrastructure, optimization, performance, supply chain management, service, simulation, sustainability, transportation, competitive advantage, and scenario. Within this classification, social network analysis is performed among the mentioned articles using ORA software. Degree centrality is used to find the articles having the most significant number of direct links to-and-from other articles. This is used as an indicator for leading articles. Betweenness centrality is used to find the amount of control that paper has over the others. This shows whether there is an article that controls access to all other articles in the network. Eigenvector centrality is used to measure how well a paper is connected to other well-connected papers. Additionally, the density of the network, its diameter, its degree centralization are analyzed. Degree centrality is used to specify the relative dominance of a single article over all other articles in the network. Networks with a high degree centralization are subject to fragmentation if these highly connected nodes are removed. The density represents the ratio of the number of links presents the total number of links possible: the higher the density, the more complex the structure with many links. The diameter measures the connectedness of the network, and it represents the amount of effort needed for information to move from one end of the network to the other. Through this analysis, the changing trends in the performance assessment methods are revealed, and finally, this paper proposes new research areas in this field. Finally, TOPSIS analysis is performed to indicate the most important articles and therefore to underline the recent research areas. The criteria used in TOPSIS is composed of centrality measures as well as the impact factor of the corresponding journal.

MON-4-A

*Contributed Session: Advances in
MCDM Theory*

Monday 16:00-17:40 - Room: Galata Tower

Chair: Theodor Stewart

1. Integrating MCDA with Strategic Planning

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We have previously made the assertion that MCDA deals with aid or support for decisions that are complex enough to “matter”. Many reported examples of MCDA applications, however, are decidedly operational in nature and some border on the trivial. The thrust of this paper is to urge the MCDA community to become more involved in messy strategic level problems. Of course, many such have been reported, but even then very often the MCDA content has focused more on the final selection phase, of choice between action alternatives, with very little information on the origin and development of the alternatives. We have previously argued that MCDA can and should be viewed not only as an analytical tool, but also as a problem structuring method (PSM). As such, the approaches and tools of MCDA have relevance as a guiding principle throughout the entire process of strategic planning. In order to clarify this assertion, and to provide a framework for the implementation of MCDA in this context, we follow the three-phase structure of the strategic planning process as identified by Mintzberg, namely: (a) Identification (recognising problems and diagnosing cause effect relationships leading to action opportunities); (b) Development (generating or designing potential solutions to the problem or crisis); (c) Selection (comparison, screening and choice of actions). We examine the roles and types of MCDA intervention that apply at each phase, and discuss the naturally dynamic and iterative nature of the process. MCDA can and should play a guiding and integrative role throughout. The presentation concludes with an illustrative example, which is a hypothetical case but broadly based on a real-world situation in water resources planning.

2. Multiple Criteria Benchmarking: A Strategy of Improvement

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This paper is related to the benchmarking problematic in a multiple criteria context where the alternatives of a given set are compared on the basis of a given set of criteria, through any method, which allows to provide a partial or complete ranking when applied to a performance table. In this context, a Decision Maker (DM) is willing to improve the performances of a certain alternative. The aim of this study is to provide her/him with an improvement strategy that consists of: A final performance for each criterion that should and could be reached, and step by step guidelines to reach the final criteria performances. Moreover, our method is built with the help of a theoretical framework that we develop that aims at consolidating and defining notions that are used in the benchmarking literature but not clearly settled or defined, in our opinion.

3. Experimental Evaluation of Multiple Criteria Utility Models with Veto Related Preference Structures

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A fundamental and widely applied approach to decision-making is the multi-attribute utility theory. Because it aggregates preferences in the compensatory manner, it has been recently extended with the concept of veto function, which has been adopted from the outranking approach and models full or partial non-compensation of unsatisfactory preferences. Within the scope of our past research work, the underlying methodological foundations and approaches to express non-compensation in the utility based multi-criteria decision models have been systematically studied and analysed, with the focus on the veto criterion, veto function and aggregation operators. The

main contribution of the presented research work pertains to the investigation and evaluation of forms and properties of veto functions in multi-criteria decision models that incorporate utilities as well as discordance related information. Particularly, the risk aversion of veto functions is studied and correlated with the risk aversion of utility functions, which are aggregated in the same multi-attribute model and exhibit common complementary preference structures of the decision-maker. Outcomes of risk averse, risk seeking and risk neutral veto functions are analysed and compared. The study aims to assess the influence of risk aversion on the decision, to identify possible anomalies in preference structures, to determine the suitability of different risk aversion formats and intensities for various problem settings, and to derive key characteristics. The experimental model is based on the simulation study. Several evaluation factors are observed, such as the ability to efficiently discriminate alternatives, richness of output data, extremeness of results, validity of results, correctness and relevance of judgements, and robustness. Partial results of the study have already been presented in the past. However, the scope has been limited to ranking, additive aggregation and complete rank-orders only. In this presentation, the completed research is addressed. Different problem solving problematics, aggregation models and types of rank-orders are considered. The simulation model is extended to deal with (1.) ranking and sorting, (2.) additive and multiplicative aggregation operators, and (3.) complete, weak and partial rank-orders. Based on the steepness, various shapes of utility and veto functions are modelled that exhibit different risk aversion characteristics, ranging from very risk seeking and slightly risk seeking to neutral, slightly risk averse and very risk averse. Several specific scenarios are also defined to cope with mixed, uniform, conflicting and predominantly good/weak alternatives. The outcomes of risk averse, risk seeking and risk neutral veto functions are compared to standard ordinal preference specification methods, such as ROC (Rank Order Centroid) and RS (Rank Sum) weights. It is shown that very risk averse veto produces similar results as RS weights, while other forms of veto approach ROC weights. On the other hand, fully compensatory (utility only) models are

unable to discriminate alternatives as efficiently as either ROC or RS weights. The obtained results indicate that the specification of veto can enhance the efficiency and credibility of decisions. Several quality factors potentially improve, including the accuracy and validity of results, ability to discriminate optimal from suboptimal alternatives, and robustness of judgements. This is a consequence of the fact that additional preferential information increases the expressiveness and completeness of quantitative models. Finally, the effect of veto functions in multi-criteria utility models is analysed in comparison to the notion of constraints in multi-objective optimization models. A couple of applications are assessed.

4. ELECTRE Score: A first Outranking Based Scoring Method

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We present an outranking method to assign a score to a set of actions. It is a method of the Electre family, and we will call it ELECTRE-Score. Differently from the Multi-Attribute Value Theory (MAVT) methods, ELECTRE-Score does not construct a value function for each criterion, and then proceed to the aggregation into a single value. It, rather, makes use of an outranking relation to make a comparison with reference sets of actions, to which we assign a score with a deck of card method, and proposes a score range for each action, instead of a single value. Given the fragility of a single punctual score, the interval score assigned by the proposed method seems a more robust way of proceeding. The sets of references actions satisfy the same properties of ELECTRE Tri-nB. The fact of being able to use outranking relations makes it also possible to take into account the imperfect knowledge of data and to avoid systematic compensatory effects. Some fundamental theoretical results guaranteeing the consistency of the method and an illustrative example are provided.

MON-4-B

Special Session: AHP/ANP Applications in Production and Manufacturing – sponsored by BORCELIK

Monday 16:00-17:40 - Room: Maiden's Tower

Chair: Irem Duzdar Argun

1. A Comparative Application of AHP and ANP in the Supplier's Choice of a Capital Spare Part in a Small Industry

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The current reality of Industry 4.0 and digitization increasingly requires a much more accelerated and adaptive evolution in business processes and enterprises. As a direct consequence, their key leaders are pushed to make decisions in a shorter time frame and at a higher level of accuracy. This is only possible with the help of multi-criteria decision-making methodologies (MCDM), already consolidated in the literature and tested in companies of many economy segments globally, such as Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP). This article presents a case study of the comparative application of these two approaches in a small industry (production company dealing with development and production of system parts) for the decision between 3 suppliers of a capital spare part (SP) with 3 decision makers inherent in the process. For this model, 6 attributes (supplier lead time, availability, spare part unitary purchase price, part quality, aftersales customer service and sustainability) were grouped into 2 hybrid criteria (Logistics-Economic and Quality-Environment). The main goal of this research is to expand the knowledge base of MCDM comparing outputs from 2 reliable methods, which there is still a lack in the literature and can serve as a basis to a further study and conception of hybrid models combining multiple methodologies, suitable to many other decision processes. The research methodology used to conduct

this case study consists of the following steps: a brief literature review of recent applications of MCDM methods; identification of the motivation for this work and decision of using AHP and ANP as two relevant approaches; selection of the company and its current key decision process; conception of the AHP model, criteria and attributes; interviews with involved decision makers; processing of the collected data and discussion of the results outputted from the model. The authors conducted interviews with the 3 senior managers (maintenance, production and quality) connected to the aforementioned SP and its purchasing process. Furthermore, historical data of a few Key Performance Indicators (KPI) directly connected to this process are incorporated into the model and their impacts are analyzed and discussed. Concerning the attribution of the weights, Saaty's fundamental scale was considered, but only using the odd scores for relative importance (1, 3, 5, 7 and 9) and the reasons for assigning them by each decision maker are also presented and discussed. The results obtained through the decision process using the AHP and ANP are compared, since the interviewees also assigned relative weights between the 2 criteria. Some limitations of this research are due to confidentiality required by the company and there was also a lack of KPI historical data from the purchasing department. Future research coming from this article is possible, especially concerning multi-criteria group decision making (MCGDM) and hybrid MCDM models, since these methodologies have many variations and applications and could be combined with adaptive computational tools or with Machine Learning techniques, for example. Those approaches could generate even more significant results and promote this decision-making process even more robust.

2. Methodology for Assessing the Degree of Automatism of an Operational Control Center in a Sanitary Company

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Companies indistinctly of their magnitude and purpose, face a series of difficulties that can affect the achievement of their objectives. The different areas or activities, as well as strategic initiatives, operations, processes and projects may have individual or strategic objectives, and these influence their results. This can have a direct or indirect impact: The stakeholders, the environment and society in general. In order to control the difficulties or problems when meeting an objective, it is necessary for companies to establish an adequate risk management process to allow them to anticipate, manage and control the possible negative impacts and their consequences. Hence, it is very important to ensure survival, prestige and financial stability. This study introduces the development of a methodology that uses a multicriteria approach to select the procedure for identification, analysis and evaluation of risks and thus determine the scope of the automation of an Operational Control Center (CCO). In this case, the Analytic Hierarchy Process (AHP), is used, resulting helpful to find the risk management procedure that best fits the needs and for the problem situation understanding. The expected results will indicate whether it is cost-effective to automate the CCO, in order to reduce the risk of affecting the continuity of supply of drinking water. The contribution is estimated in two aspects, introduces the topic of risk management and provides a useful methodology based on AHP. In this context, it allows to extend this type of analysis and evaluations to any area that requires it. Keywords: AHP, Risk Management, Sanitary Company.

3. An MCDM based Dynamic Patch Sensing Cycle for Agent-Based Modeling and Simulation of Global Facility Location

**Hafiz Khurram Ali, University of Engineering and Technology, Pakistan, khurram.ali@uettaxila.edu.pk*

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The Global Facility Location (GFL) is a fundamental but complex decision for top administration of the worldwide business firms, exploring the countries or nations as potential future markets. The multidimensional nature of the GFL problem requires an extensive investigation of the criteria affecting the decision. There are only a limited number of GFL studies available in the literature which concurrently emphasize on real world uncertainties, future horizons and interactions of the stakeholders in GFL issues. This work is a part of an on-going research project in which the agent based modeling is merged with the analytical hierarchy Process (AHP) to make a more flexible and dynamic analysis of the GFL problem by taking into account the real world uncertainties in a stochastic way. It focusses on proposing an Agent Sensing Cycle (ASC) where the investor agents move to patches representing the countries and make an AHP based decision to land on one of them to install a new production plant. These patches are initially assigned the Country Objective Functions (COF's) which were calculated from a Fuzzy-AHP study. A roulette wheel aiming approach is proposed in the cycle of agent movements. The selection decision is thus made based on the analysis of a broader spectrum of influencing parameters combined with the stochastic themes and a focus on the uncertainties inherently present in information databases and expert sentiments. Priorities of the investor agents are changing during the simulation which make it a dynamic as well as stochastic MCDM analysis. The proposed study, therefore, makes GFL results more reliable, comprehensive and exciting as compared to other available traditional approaches.

4. Prioritization of Digitalization Criteria for the Product Design and Development

**Irem Duzdar Argun, Duzce University, Turkey, iremd82@gmail.com*

Digitalization is defined as the integration of digital sources in all areas for improvement of digitalized firms and increasing their values. Digitalization is the development of new job models, integrating the sources and materials with new combinations to form customer experiments, produce new goods, and apply the technology to sources for using them efficiently. Integration of the digitalization with the organizational strategy is very significant for the future competitiveness and success. The firms should have a strong digital strategy are known as the established the right way for their digitalization studies, and positioned better at their digitalization route. In the literature survey, it is required that all of the goods developed and designed must be adapted to the digital age. The digitalization success will be reached when the design is focused on the customer experience. In this empirical study, a literature survey is performed to categorize the criteria for success in digitalization to define the factors affecting the contributions of digitalization to the product design. ANP is a practical MCDM method and offers the advantages of decision-making models, based on tangible and intangible factors. It allows creating weights for different criteria to make the model stronger. In this study, the suggested model balances the economical, technological, infrastructural criteria considering product design and development. The aim is to prioritize these criteria are evaluated by expert firms having R&D departments. These results are analyzed using the ANP to prioritize the digitalization criteria. By this way, it is expected to establish a route of action for the firms planning the digital applications to their products.

MON-4-C

Contributed Session: Multiple Criteria Decision Aiding

Monday 16:00-17:40 - Room: Dolmabahçe Palace

Chair: Isabelle D. Martins

1. Analysis of the Volumes of Foreign Trade for Turkey and the EU Countries via Multi-Criteria Decision Making Methods

**Ezgi Demir, Piri Reis University, Turkey, edemir@pirireis.edu.tr*

European Union countries are the main trading partners of Turkey. Foreign trade is performed in two ways as import and export in terms of delivery of trading transactions. Export has an important role for the development of national economies. Hence, raising exports and as well as reducing imports are the vital targets for countries. The decisions and precautions made by countries to achieve these goals form the basis of foreign trade policy. On the other hand, international conjuncture affects economic data. In this study, a sorting has been performed among EU Countries and Turkey by defining six main criteria which affect the volume of foreign trade. These criteria include both maximization and minimization values. For the study, weights of the criteria, has been determined via Entropy method by using the 2018 data of 29 countries. Entropy method is preferred because of an objective method which does not require an expert opinion according to the data related to alternatives. After determining the weight values of the criteria, the countries were sorted by using the Copras method, which is the performance-indexed evaluation method. The Copras method was used because it was the method that provides the complex proportional assessment that incorporates the maximization and minimization criteria. It is expected that the study is going to present a new approach to the literature, as there exists no related study with the foreign trade data by using the Entropy based Copras method.

2. Multi-Criteria Assessment of Organizational Servitization Readiness

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Servitization, which is a concept that especially applies to the competitive

environment of developed economies, implies a shift in a firm's business model from manufacturing to services. The rationale behind such a shift can be divided into two perspectives. First, firms may choose to undergo such a change and include services in their product-based portfolios because they would gain financial benefits. This is mainly because the non-transactional based nature of services can increase turnovers significantly and stabilize the revenues. The second perspective is regarding the strategic and marketing benefits. Competitive strategies that are purely based on products -such as enhancing and innovating the products- do not lead to a long-term advantage nowadays since such efforts are becoming more imitable due to fast technological advancements and decreasing product life cycles. Offering services along with the physical products enables a long-lasting competitive advantage for the firms. Therefore, manufacturing firms that adapt to services are more likely to gain benefits through increased differentiation of offerings and customer satisfaction. On the other hand, the process of servitization has its own big challenges. A significant question here is again financial. For example, the concept of service paradox implies that a firm wishing to expand its service business confronts higher costs for the benefit of more diverse service offerings, yet it fails to get the expected financial returns. Another challenge of servitization is related to the differences between goods and services. Manufacturing firms are often inexperienced in managing the significant characteristics of services, which fundamentally are intangibility, variability, inseparability and perishability. Some other critical challenges include the organizational ones, for instance, the transformation of the organizational culture and the organizational structure to fit better the new business model. Considering both the benefits and challenges of servitization, manufacturing firms face a new imperative decision to make. That is, if they would implement services to their product-based portfolios, or not. Similarly, they would also need to identify the degree of services to implement, which can vary between the basic helpdesks or maintenance services and the risk-sharing agreements. Before making these decisions, firms would want to assess their organizations' readiness for

such kind of business model change. Therefore, this study is especially aimed at the topics of organizational change to help the manufacturers better understand their internal status-quo and make better decisions about their servitization strategy. It is certain that multiple criteria need to be assessed before making the final decision about an organization's readiness for servitization. In this study, to determine the related criteria, several organizational diagnosis models are examined including McKinsey's 7S model, Galbraith's Star Model and Burke-Litwin Model. All of these models consist of different elements that can be used to explain the current situation of an organization. While assessing the models, the ones with an open system approach were prioritized. The Burke-Litwin Model was prominent in that matter. Based on this model, different criteria categories are selected which are environment, culture, leadership, current business model, and so on. A tool is also designed based on a modification of the weighted sum model. By using this tool, it is possible to ask questions to an organization member to capture the perceived benefits of the criteria. As a final outcome, the tool presents a decision of whether the particular organization is ready for the servitization process or not. Unlike several similar tools in the literature, this designed tool utilizes from multi-criteria decision making approaches and analyzes the servitization readiness from an organizational point-of-view.

3. A Review of the Multicriteria Decision Analysis Applied to Oil and Gas Decommissioning Problems

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Due to the maturity and short time span of some economic activities, the demand for decommissioning processes is rising steeply over the last years. That rise is particularly important in the oil and gas sector. Since such a sector often involves high complexity and large amounts of investment, a careful process is needed for a proper evaluation of decommissioning alternatives. In addition, since we are dealing with an economic activity that affects many other sectors and disciplines, a careful mapping of the stakeholders is necessary and a holistic attention must be given to their needs and concerns. Due to both the problem complexity and the need to involve multiple stakeholders, often with conflicting interests, the existence of a reliable and informative tool to assist the decision-making process becomes essential. Especially tailored for such problems, multi-criteria decision analysis (MCDA) methods can be a natural fit for decommissioning problems. The aim of this paper is to provide a review of the MCDA methodologies that are commonly used for decommissioning activities in several economic segments with a focus on the oil and gas sector. In this sector, decommissioning processes date back to the 1970s. The decommissioning process generally takes place when the oil or gas field becomes uneconomical. It is often a time-consuming process. This is partly because it may involve the partial or total removal of very complex structures, and partly because it is subject to many regulations from different government bodies. An overview of decision support tools applied to decommissioning in both academic papers and industrial reports is presented in this paper. The MCDA methods are not designed to search for the best alternative with respect to all criteria, the so-called ideal solution. Instead, they seek compromises in real-world situations when there are conflicting criteria and no such alternative exists. Among the available methods, one can find some standard approaches, such as Analytic Hierarchy Process (AHP), Preference Ranking Organization Method (PROMETHEE), Simple Additive Weighting (SAW), Technique for Order of Preference by Similarity to Ideal

Solution (TOPSIS), Elimination and Choice Expressing the Reality (ELECTRE), and Multi-Attribute Utility Theory (MAUT). The strengths and weaknesses of each models is discussed for the decommissioning activities after a presentation of available software's. The review emphasized that AHP is one of the most used methods in decommissioning studies. There is also various application of outranking methods, such as PROMETHEE, which aim to translate the preference relations established by decision makers. However, it is clear that the Oil and Gas industry is not yet applying these methodologies and prefers simpler techniques such as the comparative assessment. Such a method employs a weighted sum of the evaluations with respect to each criterion with a view to select the alternative with the best overall evaluation. It is a technique that is easy to apply and allows compensation between the criteria, but which may fail to integrate multiple preferences. The outcome of the review shows that the comparative assessment developed in several Oil and Gas industrial cases is probably not adequately representing the complexity and the diversity of technical and environmental situations. In these terms, the development of a MCDA decision-making methodology using integrating technical, environmental, life cycle assessment, social, economic, safety, risks, as well as regulatory, licensing and legal security issues is strongly recommended.

4. Dimensionality Reduction Approach for Multi-Criteria Problems: An Application to Oil and Gas Subsea Decommissioning

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The end-of-life of oil and gas structures has become a worldwide concern. In many of the producing countries, decommissioning has been largely discussed and several regulations and guidelines were generated or are being elaborated. Among the diversity of structures that are part of the offshore system, subsea installations demand a special attention due to both their sensitive nature and the logistic challenges associated to the decommissioning process. In addition, decommissioning is becoming more complex as time lapses due to the increased number of pieces of equipment operating in deep waters. Initially, possible end-of-life measures includes in-situ abandonment and total or partial removal. In addition, total or partial removal can be achieved by means of different alternatives, which depend on the available removal techniques. Given the distinct impacts and a possibly large number of criteria to consider, selecting a decommissioning alternative becomes a rather challenging problem. To address such a problem, one must account for the great variety of technologies and materials available, as well as the distinct environmental and socio-economic conditions of each locality. In order to evaluate the alternatives, a multidisciplinary approach is needed which involves economic, environmental, technical, social and safety aspects, among others. Furthermore, the possibly large number of stakeholders and their potentially conflicting interests can result in a very controversial process. The majority of published decommissioning processes so far have relied on a methodology called comparative assessment, often based on subjective judgments by stakeholders with respect to a number of pre-selected criteria. Generally, the alternatives are ranked by means of weighted sum of the evaluations with regards to the selected criteria. However, the process must be applied to each individual piece of equipment, in a process that can become rather cumbersome for large offshore systems. In this work, we propose a classification technique to define groups of similar pieces of equipment for which a joint analysis would be applied. Therefore, this paper is focused on reducing the problem dimension, while also ensuring the selection

of the most appropriate decommissioning alternatives. The proposed approach makes use of machine learning techniques and multi-criteria decision analysis (MCDA) tools to generate groups of similar structures, for which similar rankings are expected for the decommissioning alternatives. The similarity is evaluated with respect to both the attributes of the structures and the evaluations with respect to each criterion within a training set, with a view to generate clusters for future application of the MCDA tools. We evaluated the predictive accuracy of decision trees, random forests, gradient boosting machines and support vector machines. After selecting a model, the variables influence on the alternative selection was also analysed in order to reduce the number of features required for the study. Despite the arrival of the so-called big data era, some fields still lack massive datasets and, unfortunately, decommissioning is among them. Hence, our study makes use of bootstrapping and statistical analysis to generate synthetic datasets with a view to validate the proposed techniques. To demonstrate the benefits of the approach, this study is applied to a study on decommissioned pipelines in the North Sea. The results are promising and suggest that classification techniques can assist the decision making process with little impact to the overall accuracy of the MCDA technique. Preliminary results indicate better performance for gradient boosting machines with mean accuracy of 82%.

MON-4-D

*Tutorial: Improve Your Decisions by
Learning and Experiencing the ANP
Best Practices- Part II*

Monday 16:00-17:40 - Room: Topkapı
Palace

Chair: Birsen Karpak

Improve Your Decisions by Learning and Experiencing the ANP Best Practices- Part 2 of 2

**Orrin Cooper, University of Memphis,
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For details see Section MON-3-D

Please bring your own laptop to this special
session

MON-4-E

Invited Session: Solution Methods for Various Multiobjective Optimization Problems

Monday 16:00-17:40 - Room: Hagia Sophia

Chairs: Özlem Karsu, Firdevs Ulus

1. Representation with Respect to Hypervolume: A Scalarization Method for Bi-Objective Optimization Problems

**Britta Schulze, University of Wuppertal, Germany, schulze@math.uni-wuppertal.de*

The hypervolume indicator is a quality measure for representations of the nondominated set of multi-objective optimization problems. It measures the hypervolume of the region that is spanned by the points of the representation and an a priori given reference point. Its main drawback lies in its computational cost. Therefore, approximation algorithms have been proposed that reduce the computational effort. While the hypervolume is heavily used in the context of evolutionary multi-objective optimization algorithms to evaluate the fitness of solution candidates, its application as quality measure in combination with exact methods is rather unusual. In this talk we present a scalarization method for bi-objective optimization problems that allows to build a representation, with a quality guarantee with respect to hypervolume, in an a priori manner. Theoretical properties and algorithmic aspects are discussed in the context of selected multi-objective combinatorial optimization problems.

2. On the Efficiency of Benson-Type Approximation Algorithms for Convex Multiobjective Optimization Problems

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Benson-type approximation algorithms for convex multiobjective optimization problems generate an inner and an outer

approximation to the whole Pareto set for a given approximation error. In general, these algorithms solve a Pascoletti-Serafini (P-S) scalarization model in each iteration. P-S scalarization has two parameters: a reference point that is chosen from the objective space and a direction vector chosen from the ordering cone. The choice of these parameters affects the overall efficiency of the algorithm. In the original algorithm the direction parameter is fixed and the reference point is taken as one of the vertices of the current outer polyhedron. We propose different variants of the algorithm where the direction parameter changes in each iteration and different selection procedures are applied for choosing the reference point. We compare the efficiencies of the variants through numerical analysis.

3. An Improved Hyperboxing Algorithm For Multi-Objective Non-Linear Optimization Problems

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A popular way to solve a continuous multi-objective optimization problem is to compute an inner and an outer approximation to sandwich the Pareto front in between. While particular sandwich algorithms exist for convex problems, we can also define a very general sandwich algorithm in the non-convex case by only using the properties of non-dominance. Since the part of the outcome set that is sandwiched between the inner and outer approximation can be represented as a union of rectangular sets, we call this general sandwich approach hyperboxing algorithm. We base our hyperboxing algorithm on previous work presented in Teichert (2014). Therein, it was already shown that the algorithm results in a very good coverage of the Pareto front. However, the computational burden of the algorithm was shown to be very high which made the algorithm impractical for dimensions higher than five. In this talk we show how to incorporate recent ideas from the discrete context to speed up the algorithm. More precisely, we use improved techniques to update the inner

approximation in the discrete context. These techniques can be translated in a straightforward way to the continuous case. We use the improved update of the inner and, analogously, outer approximation within the hyperboxing algorithm. We present the main ingredients of the hyperboxing algorithm and show improvements with respect to computational time compared to Teichert (2014). Our numerical results are based on test problems with up to 10 objectives. We show that the algorithm results in a very good coverage at reasonable times for a set of various test problems.

4. Solution Approaches for Equitable Multiobjective Programming Problems

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We consider multi-objective optimization problems (MOP) where the decision maker (DM) has equity concerns. We assume that the preference model of the DM satisfies properties related to inequity-aversion, hence we focus on finding nondominated solutions in line with the properties of inequity-averse preferences, namely the equitably efficient solutions. We discuss two algorithms for finding good subsets of equitably efficient solutions. The first approach is an extension of an interactive approach developed for finding the most preferred nondominated solution when the utility function is assumed to be quasiconcave. We find the most preferred equitably efficient solution when the utility function is assumed to be symmetric quasiconcave. In the second approach we generate an evenly distributed subset of the set of equitably efficient solutions to be considered further by the DM. We show the computational feasibility of the two algorithms on equitable multi-objective knapsack problems that fund projects in different categories subject to a limited budget. We perform experiments to show and discuss the performances of the algorithms.

MON-4-F

Contributed Session: Multiobjective Metaheuristics for Challenging Applications

Monday 16:00-17:40 - Room: Basilica Cistern

Chair: Alfonso Mateos

1. Multi-Objective Grouped Genetic Algorithm for the Joint Order Batching, Batch Assignment and Sequencing Problems

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This article aims to solve the joint order batching, batch assignment and sequencing problem (JOBASP) considering multiple picking devices in warehouse systems. The JOBASP groups several customer orders in a single picking list or batch, as well as assigns batches to the multiple picking devices according to their load capacities and schedules the batches assigned to each picking device in order to achieve a high picking efficiency and minimize the tardiness. To solve the JOBASP, we propose a multi-objective grouped genetic algorithm (GGA) to minimize total travel time and total tardiness. The proposed encoding scheme is composed of three levels: picking devices, number of the batch, and customer orders assigned to each batch. An order group procedure is used to create the initial population. It uses an order pool to place orders that have not been assigned yet to a batch. This procedure chooses randomly a picking device and assigns it to a gene, then customer orders are randomly chosen from the order pool and assigned to each batch. The fitness function is defined as the weighted sum of the total travel time and total tardiness. The selection of parental chromosomes for the crossover operator is

based on the linear selection ranking method. Pairs of solutions are chosen as parents using the roulette wheel selection. Two crossing points delimit the crossing section to be exchanged between each pair of parents. A correction mechanism is applied to fix infeasible offspring. Orders that have not yet been assigned to a batch complete each chromosome by means of the order group procedure. The survival mechanism ensures that individuals with better performance prevail in each generation. Immigration defines the number of new individuals to create using the order group procedure. In the mutation operator, two genes are randomly selected and then deleted, and new genes are created using the order group procedure. The genetic algorithm will stop when the number of generations is satisfied. We produced several test instances based on parameters such as customer orders, warehouse configurations, and weighing parameters. The combination of experimental parameters makes 27, and we have generated 10 instances for each scenario, providing 270 test problems. The performance of the GGA is compared to adapted heuristics based on the FCFS and EDD rules respectively. The proposed GGA outperforms the FCFS rule-based heuristic providing average savings of 25.4%, and maximum savings up to 46%. Likewise, the proposed GGA outperforms the EDD rule-based heuristic providing average savings of 10.2%, and maximum savings up to 28%. Likewise, computational experiments provide an average of 54.2 seconds for each scenario. As a conclusion, the proposed GGA provides important savings on travel time and tardiness. The implementation of the GGA is feasible in real warehouse environments due to the computing times obtained in the computational experiments.

2. A Many Objective Optimization Approach for Distribution System Asset Planning Integrated with Network Reconfiguration

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This research proposes an approach for handling electricity distribution system asset planning that is integrated with many objective reconfiguration problem of the network topology. The distribution systems supplying the electricity to consumers include various important assets such as distribution lines, tap-changing transformers, and switchgears. Many remote and manual switchgears are located on the distribution lines to keep supplying the electricity to consumers even in case of faults and maintenance of the assets. Since the network topology is radial to avoid the failure extension, there is a single route of the electricity between the substation and consumers in a normal state. By opening and closing the switchgears in a proper order, alternative routes of electricity can be made flexibly in the emergency conditions. The reconfiguration problem by controlling the switchgears has many objectives to be minimized: (#1) capacity of consumers with power outage, (#2) total travel distance of technicians to control the manual switchgears on site, (#3) the total length of time to control the switchgears, (#4) the operation times of switchgears, and (#5) the operation times of tap-changing transformers. There are trade-off relationships between these objectives. Although the objective #1 is the highest priority needless to say, the other objectives are also considered to be important for the distribution system management. This problem is a many objective optimization problem. If there are n switchgears with two states (opened or closed) in the distribution system, total number of network topology including infeasible solutions is $2n$. Since the reconfiguration problem has heavy computational burden, many-objective

evolutionary algorithms (MaOEAs) are effective to find non-dominated solutions approximating the true Pareto front. We have developed the MaOEA based on NSGA-III in our previous research to solve the many-objective optimization problem for the large-scale distribution system within the practical computational time. The distribution lines have the reserve capacity for redundancy. Due to the redundancy, the distribution system operator can choose a reconfiguration procedure among candidates. In this research, we integrate the reconfiguration problem with curtailment of the redundant line capacity because the curtailment can reduce the cost of money, if possible. In our proposed method, a set of the non-dominated solutions S_i as the reconfiguration procedures for maintenance of the asset i is computed by the developed MaOEA. Based on a set of the line current of line j in case of the reconfiguration for maintenance cases $i = 1, 2, \dots, L$, the curtailable capacity of line j and corresponding objective values are computed. If the distribution system operator does not satisfy the objective values, he/she can specify upper bounds of the objective values. After the specification of the upper bounds, the proposed method provides him/her with alternative curtailable capacity of line j satisfying the constraints. In order to validate the proposed method, realistic computational experiment is performed using a large-scale distribution system model of Chubu Electric Power Co. Inc. in Japan. This model has 142 switchgears (remote: 29, manual: 113), three feeders, 16 tap-changing transformers, ($L =$) 193 nodes, and 200 lines. The above five objectives are considered in the experiment. The developed MaOEA gives more than 2,000 non-dominated solutions to us within 30 h. The line current flowing through line $j = 1, 2, \dots, 200$ is computed based on the obtained sets of non-dominated solutions S_i , $i = 1, 2, \dots, 193$. The proposed method successfully compute the curtailable line capacity by reconfiguration of the network topology.

3. A Real Time Adaptation of the ATC Work Shift Scheduling Problem to Deal with Incidents in Airports Control Centers

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A very important problem in air traffic control (ATC) is to determine the minimum number of air traffic control operators (ATCo) necessary to cover an airspace sector configuration, while satisfying certain ATCo labor conditions, including, for instance, resting and working time distributions. Alternatively, the number of ATCos could be fixed. The aim then would be to distribute ATCos to cover the corresponding airspace sector configuration. This problem is known as the ATCo work shift scheduling problem. A great number of constraints accounting for ATC labor conditions have to be taken into account in that optimization problem. In Spain, all these conditions were compiled and published in the Official State Gazette (Boletín Oficial del Estado, BOE), Royal Decree 1001/2010, and Law 9/2010, regulating the provision of air traffic services. These labor constraints refer to ATCos minimum and maximum resting and working periods, number of sector changes, times in the same sector... Besides, a multi-objective perspective is incorporated into the problem to account for different conflicting objectives. First, the ATCo work and rest periods and positions should be as close as possible to fixed values. Second, the solution structure should be similar to the previous template-based solution. This makes the solution more understandable for the control center staff and would facilitate any possible hand-made changes. Additionally, the number of control center changes should be minimized. Finally, the ATCo workload distribution should be balanced. A three-phase problem-solving methodology was proposed to deal with such problem. In the first phase, a heuristic is used to derive infeasible initial solutions on the basis of templates. Then, a multiple independent run of a metaheuristic

is conducted aimed at reaching feasible solutions in the second phase. Finally, in the third phase, a multiple independent metaheuristic run is again conducted from the initial feasible solutions to optimize the objective functions. To do this, we account for ordinal information about the relative importance of objectives and transform the multiple to a single optimization problem by using the rank-order centroid function. The performance of using simulated annealing (SA) and variable neighborhood search (VNS) has been analyzed on the basis of four representative and complex instances of the problem corresponding to different airspace sectorings provided by the Spanish ATM Research, Development and Innovation Reference Center (CRIDA). We conclude that both metaheuristics have a similar performance but VNS is faster than SA. In this paper, we consider a variant of the above ATC work shift scheduling problem. We assume that a solution derived from the above methodology is being used at any moment at the Control Center in an airport, i.e. an airspace sector configuration has been identified and ATCos have been assigned to position and are currently working (or resting). Now, we assume that an incident happens. For instance, one several ATCos get sick and can not do their job, a nearby airport may close for meteorological reasons and the traffic is redirected to our airport... In such situations, the current airspace sector configuration should be changed from that instant to the end of the work shift and, consequently the ATCos must be reassigned accordingly to the new configuration but taking into account the part of the working shift they have already made. In this new problem, the response time is crucial since planes are in the air and must be controlled and sometimes no feasible solutions are possible, leading to the sacrifice of some ATCo labor conditions. We have again compared the performance of SA and VNS to deal with this variant of the ATC work shift scheduling problem, aimed at achieving the less unfeasible solution in few seconds. For this, the experts from CRIDA have provided ordinal information about the ATCo labor conditions.

4. A Hybrid Algorithm to Solve the Multi-Objective Spanning Tree Problem

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The multi-objective minimum spanning tree problem (MOST) has been shown to be NP-hard even with two criteria. We propose an algorithm that exploits the advantages of both "Non-Sorting Genetic Algorithm" (NSGA-II) and "Variable Neighborhood Search" (VNS) metaheuristics to find a good approximation to the Pareto front of the MOST problem. Taking into account the specificity of the problem, this algorithm first adopts novel two point crossover operator and a heuristic mutation operator in NSGA-II to obtain the first approximation of the Pareto front, front 1. In the second phase, the VNS based algorithm is called for further improvements of front 1. It allows finding good individuals to counterbalance between the diversification and the intensification during the optimization search process. Experimental comparison studies show to promising results and indicate that the proposed algorithm does not have the limitations of previous algorithms because of its speed, its scalability to solve MOST problem considering complete graphs with more than 200 nodes, and its ability to find both the supported and non-supported solutions.

TUESDAY

TUE-1-A

*Invited Session: MCDM/A for
Assessment Issues in Healthcare and LCA*

Tuesday 9:00-10:40 - Room: Galata Tower

Chair: Sarah Ben Amor

1. Decision Framework for Drug Formulary Design Using Multiple Criteria Decision Analysis

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Reviewing new drugs to determine coverage or reimbursement level is a complex process that involves significant time and expertise. Review boards gather evidence from the provided dossier, input from clinicians and patients, and results of clinical and economic reviews. This information consists of assessments of the drugs on multiple criteria that often conflict with one another. We use a recent extension of the UTilitiés Additives DIScriminantes approach, UTADIS-GMS (the suffix refers to its authors) which is based on the preference disaggregation paradigm. The UTADIS approach has the ability to deconstruct a portfolio of elements such as a set of drugs that have been reviewed and decisioned. It derives criteria weights that are consistent with the preferences exhibited by the review boards in their recommendations. The GMS variant of the UTADIS approach provides a flexible decision framework that considers various forms of preferences for the decision making bodies and yields richer information in terms of both necessary and possible assignments. It also offers more flexibility notably because it accepts imprecise assignments. We show how to adapt the methodology to the context of formulary decisions and apply it to oncology drugs reviewed in Canada between 2011 and 2017. We also illustrate how to conduct scenario analyses and how the method can be applied for predictive purposes.

2. Application of Multi-Criteria Decision-Making Methods in Healthcare Management: A Comprehensive Literature Review

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Healthcare involves several complex decision-making situations, from decisions directly related to medical treatments to those regarding public-health policies and financial reimbursements. Multi-criteria decision making (MCDM) tools are increasingly used in the healthcare sector. The purpose of this paper is to conduct a systematic literature review on the application of MCDM techniques in healthcare over the last twenty years. About 130 papers were selected from Scopus for analysis. Those papers, published in more than 80 international journals between 1998 and 2018, were classified according to the following criteria: method used for preference modeling, method used for aggregation, source of the data used in the modeling, uncertainty modeling, sensitivity analysis, participatory approach/group decision, hierarchical criteria, interaction among criteria, context of application, publication year, scientific journal and country of case-studies. The results show that in healthcare, group decision-making dominates over single-person decision making: about 80% of the papers selected considered multiple decision-makers. Unlike sectors in which the application of MCDM methods involves the evaluation of one or a few decision-makers (such as supplier selection, sustainable manufacturing and portfolio project selection), in healthcare, almost half of the papers conducted surveys whose results became the source of the data used in the modeling. In addition to the fact that most papers considered group decisions, we observed that in healthcare, it is important to consider several opinions from different experts instead of focusing on one or a few assessments. The cases that considered the preferences of only one decision-maker are typical of situations in which the decision concerns only one patient such as using an app to select a physician) and not to decisions that may impact multiple patients (such as public policy or

patient prioritization in a hospital). The main contexts of MCDM application are clinical decision-making, including diagnoses and treatments, and healthcare waste management followed by health technology assessment. Other application contexts are public health and policy, site selection for healthcare facilities, reimbursement decisions, risk assessment, decisions linked to professional practices, resource allocation and schedule planning. AHP was identified as by far the most frequently applied method for preference modeling. It is also the main method used for aggregation, with TOPSIS and its fuzzy versions also widely applied. Almost half of the papers considered uncertainty in the decision process, mainly due to the vagueness inherent in the linguistic terms used by the experts involved in the decision-making process. To model uncertainty, fuzzy-sets theory was the main technique applied. We concluded that MCDM can provide a more comprehensive and transparent approach in healthcare to systematically capture patient, expert and stakeholder concerns, to elicit their value preferences, to assess various criteria and to reconcile all competing interests and trade-offs. We also identified these abilities as the main reasons for the growing application of MCDM in the healthcare context. The methods generally applied in healthcare do not take full advantage of recent developments in the MCDM field. Methods such as AHP have limitations which new methods have overcome. Therefore, in future research, decision-making in healthcare may integrate the application of new MCDM techniques that represent the decision process in a more realistic way and lead to more robust results. These techniques may include volume-based methods to elicit preference information (e.g. SMAA), methods that allow for the modeling of hierarchical criteria (e.g., MCHP), methods that consider multiple types of uncertainty concurrently or methods that consider interaction among criteria (e.g. Choquet Integral).

3. Agent-Based Algorithm for Dynamic Criteria Weight Assessment in Multi-Criteria Decision Making for Obsolescence Management

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Multicriteria decision making tools in technological obsolescence management are becoming crucial in the current highly competitive market. Parts obsolescence is a complex problem involving many factors and stakeholders. Its impact on the manufacturing system can be minor (obsolete part not critical), medium (medium criticality) or high (high criticality). Managing parts obsolescence is a multi-criteria decision making problem in which different strategies such as last time buy, redesign or salvage are assessed in regard to different criteria such as cost, life cycle assessment, environmental impact or obsolete parts characteristics. Obsolete parts characteristics are an important factor in the risk impact scale and management. Considering the wide variety of obsolete parts and their extremely variable characteristics, classical weighting methods seem unable to handle the model's criteria weight dynamic adjustments with respect to the manufacturing system performances. In this paper, an agent-based method is developed to assess, dynamically, the criteria weights based on the parts' specifications. However, it is difficult to directly compare the proposed algorithm performance with existing methods in the literature, as there is no benchmark for dynamic criteria weighting in obsolescence management. An illustrative example is presented based on a static example from the literature. The results are then compared for validation.

4. The Integration of Multicriteria Decision Aiding with Life Cycle Assessment from Methodology to Practice – A Critical Review

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In this work we provide a critical review on the integration of Multicriteria Decision Aiding (MCDA) with Life Cycle Assessment (LCA) and Life Cycle Sustainability Assessment (LCSA). LCA/LCSA are proposed both to characterize present situations, and to recommend future policies. Two questions should be raised: (1) Is LCA/LCSA useful in decision aiding? (2) Can MCDA help in making compatible LCA/LCSA and decision aid science, in order to obtain fruitful recommendations? This review involves a classification of the literature and a discussion on the proposals and/or of the results. Different types of life cycle concepts and issues are considered – from the well characterized classical LCA, on which ISO norms were formalized in 2006 to help in the implementation of a tool dedicated to the environmental impact assessment (LCIA), to the Life Cycle Sustainability Assessment involving two other dimensions: Social Life Cycle Assessment (SLCA) and Life Cycle Costing (LCC). Note that, SLCA introduces subjective and complex modelling issues which are not yet well regulated and which depend on epistemological assumptions, and that the use of LCC is far from consensual. We also analyse the relevance in literature of some complementary concepts and related approaches, namely: Life Cycle Thinking, Life Cycle Management, Consequential Life Cycle Assessment and Dynamic vs Static Life Cycle Assessment. We noticed that decision aiding structuring techniques can be used in the first phases of the LCA process, namely: in the definition of the objectives and in the Life Cycle Inventory, taking into account challenging uncertainties and lack of information. The characterization and modelling of the process seem crucial to evaluating the success of LCA/LCSA in practice, particularly with regards to study goals and boundaries, data collection and management, the definition of impacts, as well as indicators/criteria and alternatives. In addition, a large number of papers were dedicated to the aggregation of the multidimensional output of the LCA/LCSA processes. Although in general multi-attribute approaches are adequate, in some situations multi-objective methods were used. Typically, the aggregation of outputs is carried out using weighted sums of normalized outputs. Many recent works have cautioned that the fully compensatory use of weights raises several questions and/or

produces errors. Moreover, it must be noted that the direct use of weights involves a normalization of the terms, which may also contribute to the distortion of the results. Multi-Attribute Utility Theory (MAUT) can help in eliciting the weights in a more rigorous way, but it does not overcome the root of the problem. Some authors have proposed avoiding the full compensatory approaches by using outranking methods based on partial order relations, such as those of the ELECTRE family, followed by some kind of aggregation and exploitation of the results. Although avoiding the complete compensation, these methods involve fixing several parameters and changes in these parameters can drastically influence the results. Finally, simple non-compensatory procedures have also been used in the aggregation of outputs in LCA/LCSA. Inter-criteria aggregation is particularly sensitive in LCSA, as data is highly diverse in nature and can be either quantitative or qualitative, involving uncertainty and lack of information. As subjects deserving of further research we highlight the following: comparison of the use of different MCDA and holistic approaches in life cycle evaluation of products and services, namely dealing with uncertainties; sensitivity analysis, robustness analysis and visualization tools; association of system tools with MCDA; combination of participatory approaches with MCDA; development of MCDA group decision approaches; using MCDA to compare LCA with other approaches regarding environmental evaluation and exploiting connections among LCSA, MCDA and Circular Economy.

TUE-1-B

*Contributed Session: AHP/ANP
Applications in Academia and Education*

Tuesday 9:00-10:40 - Room: Maiden's Tower

Chair: Monica Garcia-Melon

1. Selection of Part-Time Employed Students with MCDM Approach: A Case Study in KDPU

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In this study, an analytical approach is proposed to select the part time employed

students for various departments of the university. In the first step, criteria are determined by regarding the previous experience of the commission members of Metallurgical and Materials Engineering Department, the procedures and principles which are listed in the Administration Guideline and expected qualifications stated in the Application Form by Kütahya Dumlupınar University (KDPU). Secondly, the evaluation of the alternatives has been analysed by two different multi-criteria decision making (MCDM) method by taking into account the experience of the decision-makers who work as lecturers. The results obtained by analytic hierarchy process (AHP) and simple multi-attribute rating technique (SMART) have been compared. With the part-time employment of students in various departments of KDPU, such as engineering faculty and the (centre) library etc., it is aimed to help students contribute to their individual skills, like productivity and labour discipline, by employing them in accordance with their interests and skills. It is detected that the current procedure is performed by using a number of intuitive and subjective assessment processes by departmental commission members. This procedure is insufficient to achieve fair, sustainable, and peer-conflict preventive outcomes among students who belong to different socio-economic background, and are in the same success level. From this point of view, it is aimed to have objective evaluation for the part-time employed student selection by using multi-criteria decision making. In the literature, there are a lot of studies related to personnel selection in several industry and student selection problems for changing purposes. Yeh (2003) formulated a scholarship student selection problem as an MADM problem and proposed a MAVT-based MADM method as a solution. Afshari et. al. (2010) studied on personnel selection problem by using simple additive weighting (SAW) approach. Khorami and Ehsani (2015) reviewed the main MCDM approaches for personnel selection problems. Deliktas and Ustun (2017) proposed a fuzzy multiple criteria decision making approach to select an industrial engineer in a manufacturing environment. For SMART and AHP technique, the weights of criteria was determined by using brainstorming method. SMART technique was applied by using MS Excel templates and the hierarchical structure

created for AHP process was solved by using packaged software Expert Choice 11. In this paper, an MCDM methodology is used consisting of AHP and SMART techniques for part-time employed student selection. The obtained results show that AHP methodology can be more useful to determine the best candidate for part-time employed student because of its providing aggregation of individual priorities.

2. Using Analytic Hierarchy Process, Consistent Fuzzy Preference Relations and Best Worst Method to Construct Peer Assessment Method

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Group report is a form that teachers often use in school teaching, but teachers usually only score the group and it is difficult to rate individuals. The method used in the past was to convert the group's grades into individual scores through the contributions of the students. The purpose of the AHP (Analytic Hierarchy Process) method is to obtain the sequence of the elements (refers to students in the group) through pairwise comparison. Therefore, some scholars have proposed to use AHP to solve this problem. However, the main task of education is to learn, not to "give points". Therefore, AHP still has problems with too many items. Consistent fuzzy preference relationships can also identify the order of elements, but the number of items can be greatly reduced. Therefore, some scholars have refined the measurement and calculation methods of peer assessment with this method. BWM (Best Worst Method) is another technique to get the order of elements with fewer problems, but no one has used this method to explore it in the past. Therefore, the purpose of this paper is to use these three methods to improve the peer assessment method, so that teachers can judge the contribution of students in a simpler but more accurate way.

3. Knowledge Sharing Limitations among Academia: Analytic Network Process Approach

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The purpose of this paper is to estimate the relative influences and implications of knowledge sharing limitations among academia on the university missions (Academic-industrial research, quality of teaching and entrepreneurship engagement). The study aims at providing an understanding of application of multi-criteria decision making analysis through Analytic Network process (ANP) for the evaluation of knowledge sharing limitations among academia showing complete ranking with scores. The study employed a quantitative approach in line with positivism tradition. Data were collected through an ANP-based self-administered questionnaire to academia on the pairwise comparison of clusters in the network (individual and organisational factors) and nodes (university missions). Sample for the study were drawn through a three-stage multi-stage sampling procedures in order to capture different academic discipline across faculties and levels. Data generated were analysed through ANP procedure using super decision software for generating the super matrix (unweighted, weighted, and limit) which finally yield the relative priority of components within the network system. The study reveals that components of the individual barriers (cultural difference, fear of loss of knowledge power, knowledge hoarding culture, lack of communication skills, and lack of trust and time) have almost equal influences on knowledge sharing limitations while strong depth of politics within the work place was moderately perceived as the most influencing hindrance to knowledge sharing among academia with one-third (33%) among other organizational barrier factors. This was followed by influential differences

among the other influencing group of barriers which are 23.5%, 22.4%, 21.2% for unhealthy rivalry among institution units, loose and weak institutional structure, and lack of knowledge strategies respectively. This study provides assistances to policy maker in formulating and implementing effective knowledge sharing strategies that can reverse ugly influences of organizational and individual factors on knowledge co-creation in order to improve the productivity of academics towards actualizing university missions. Thereby, it proffers insight into the extent which organisational and individual factors impede knowledge sharing in the process of actualizing the university missions. Keywords: Knowledge sharing, Knowledge sharing limitations, Analytic network process, Academia.

4. Indicators for Monitoring Responsible Research and Innovation in Spain: The Case of Science Education

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This research seeks to contribute to the proposal of a framework for the development of indicators of Science Education through involving in the decision-making processes discussions among the different agents of the scientific and innovation systems in Spain. The research is frame-worked in the current promotion of the term Responsible Research and Innovation (RRI) in Europe and its impact on national scientific and innovation policies. As a result, two European-based sets of indicators for the six areas related with RRI (governance, public engagement, gender equality, science education, open science/access and ethics) have been proposed. To facilitate the monitoring of these areas, the selection of smaller set of indicators adapted to the reality of each R&D context has been

suggested (Expert Group on Policy Indicators for Responsible Research and Innovation, 2015). This study aims to propose and test a decision model to weight the most relevant indicators for public engagement to monitor national R&D initiatives using the case of Spain as an example. In the case of Spain, the recent published National Plan for Scientific and Technical Research and Innovation (2017-2020) includes in its fifth objective “Promotion of an open and responsible model of R&D+I supported by the participation of the Society” references to open access and open science, ethics, gender and public engagement. Science Education (SE), as one of the key areas proposed by the EC, refers to both: - better equip future researchers and other societal actors with the necessary knowledge and tools to fully participate and take responsibility in the research and innovation process and, - boost the interest of children and youth in maths, science and technology so they can contribute the researchers of tomorrow and contribute to a science-literate society. This work is based on three hypotheses: 1. Indicators to monitor and evaluate SE initiatives and policies might not have the same relevance in different contexts. 2. Indicators to monitor and evaluate SE initiatives and policies can be prioritized. 3. The AHP methodology might be a useful tool to propose a strategy to adapt and select the more relevant context-based sets of indicators to specific contexts that allow stakeholders to propose new indicators. The methodology proposed for our work is based on three steps: 1. Identification of the most relevant actors in SE (Social Network Analysis) 2. Generation of a list of context-based SE indicators (Experts panel) 3. Prioritization of the list of indicators proposed (AHP) We rely on the opinion of experts and stakeholders in the area of Science Education in Spain to provide different weights for the list of agreed indicators. The panel of experts will include representatives with competences in science and innovation policies from the local, regional and national governments, academics with background in research on science education and with practical experience in its implementation (science museums, science centres, schools, academies, science magazines, science blogs and living labs). Once the experts have agreed a set of relevant SE indicators for the

Spanish R&D+i systems, AHP questionnaires to pairwise compare the relevance of such indicators will be answered by them. With the information obtained from these questionnaires, the more relevant indicators for this specific group of stakeholders will be identified. The application of such a technique, will allow policy-makers and decision-makers to identify the more relevant indicators for a specific context and select reduced sets of indicators to gather information on Science Education performance.

TUE-1-C

Contributed Session: Preferences, Comparisons and Uncertainties

Tuesday 9:00-10:40 - Room: Dolmabahçe Palace

Chair: Matteo Brunelli

1. Multiple Criteria and Social Influence Analysis for Voluntary Vaccination Decision Making

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The achievement of widespread immunity to infectious diseases like influenza by vaccination is very important for public health. Thus, it is essential to understand the drivers that contribute to voluntary vaccine uptake for the purpose of developing interventions to increase vaccine coverage. Previous studies have shown that there are multiple factors affecting an individual's intention to vaccinate, including safety of vaccines, severity of diseases, potential side effects and so on. However, limited studies have considered how individuals' perception, judgement and decision on voluntary vaccination may update due to the spread of social influence. In this work, an integrated model is proposed to analyse the dynamics of social influenced voluntary vaccination decision making, which takes into account both the formulation of individuals' subjective judgements and the characterisation of influence spreading in a social network. It is assumed that individuals in social networks can explicitly and independently express their perceptions of vaccination. In the meantime, those who fail to make a firm decision initially can be

influenced by their social neighbours. As a result, individuals' subjective judgements on vaccine uptake are characterised by belief distributions in the context of multiple criteria decision analysis (MCDA), whilst social influence is reflected in the form of belief spreading and updating against each of the decision criteria. The evidential reasoning (ER) rule, as a further development of the seminal Dempster-Shafer (D-S) theory of evidence, is then applied to aggregate multiple pieces of uncertain information resulted from both subjective judgements and social influence. A series of experimental simulations are conducted to analyse the dynamics of voluntary vaccination decision making under social influence in a social network. The effects of information flow and the sensitivity of individuals' preference towards certain criteria are explored in a systematic manner. This exploratory work provides a novel perspective to analyse social influenced decision making, and the research findings can be useful for disease control departments to better understand the dynamics embedded in an individual's vaccination decision as well as observe the trend of vaccinating behaviours in a social community.

2. Supporting Decisions by Unleashing Multiple Mindsets Using Pairwise Comparisons

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Inconsistency in pairwise comparison judgements is often perceived as an unwanted phenomenon and researchers have proposed a number of techniques to either reduce it or to correct it. We consider Spanning Trees Analysis which is a recently emerging idea for use with the pairwise comparison approach and which represents the plurality of mindsets in terms of a plurality of prioritisation vectors. Until now, the multiplicity of prioritisation vectors supplied by the Spanning Trees approach have been amalgamated into a single priority vector, losing the information about the

plurality of mindsets. With this in mind, we propose a novel methodology taking an approach similar to Stochastic Multi-criteria Acceptability Analysis. Considering all the rankings of alternatives corresponding to the different mindsets, our methodology estimates the probability that an alternative attains a given ranking position together with the probability that an alternative is preferred to another one. Since the exponential number of spanning trees makes their enumeration prohibitive, we propose computing approximate probabilities using statistical sampling of decision trees. Our approach can also be applied to incomplete sets of pairwise comparisons. We demonstrate the methodology's usefulness with the famous example of the school selection problem. We estimate the probabilities of each school attaining a given ranking position together with the probabilities of one school preferred over other. The usefulness of statistical sampling is further demonstrated with the help of another real-life policy making issue involving the selection of telecom networks in rural areas.

3. SURE: A Method for Decision-Making under Uncertainty

**Richard Hodgett, University of Leeds, United Kingdom, r.e.hodgett@leeds.ac.uk*

Managerial decision-making often involves the consideration of multiple criteria with high levels of uncertainty. Multi-attribute utility theory, a primary method proposed for decision-making under uncertainty, has been repeatedly shown to be difficult to use in practice as it specifies uncertain outcomes by means of probability distributions which are not typically known. This talk presents a novel approach termed Simulated Uncertainty Range Evaluations (SURE) (DOI: 10.1016/j.eswa.2018.08.048) which helps decision makers in the presence of high levels of uncertainty. SURE has evolved from an existing method that has been applied extensively in the pharmaceutical and speciality chemical sectors involving uncertain decisions in whole process design. The new method utilises simulations based upon triangular distributions to create a plot which visualises the preferences and overlapping uncertainties of decision alternatives. It facilitates decision-makers to

visualise the not-so-obvious uncertainties of decision alternatives. SURE has been compared to other known methods such as AHP and ELECTRE and has been shown to perform better than these existing methods. The SURE method has been implemented in R as a part of the MCDA package. A demonstration will be shown of how to apply SURE (using the MCDA package in R) in a real-world case study for a large pharmaceutical company.

4. Distance-based Measures of Incoherence for Pairwise Comparisons

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In our research we deal with pairwise comparison matrices. They have been mainly employed in the Analytic Hierarchy Process (AHP), but their use is important in many other MCDM methods too, as for instance Multi-Attribute Value Theory (MAVT). Once the preferences of a decision maker have been collected into a pairwise comparison matrix, testing their coherence is a crucial step. The most widely used and tested condition of coherence is the condition of consistency. Many inconsistency indices have been proposed in the literature to estimate the rationality of preference. Their final goal is to isolate preferences which are too irrational and possibly ask the decision maker to rethink them. In real-world situations, it is almost impossible to reach full consistency. Thus, conditions weaker than consistency have also been formulated. Among them, one can consider various transitivity conditions. So far, the violation of these conditions has been measured with simple counts of how many times a given condition is violated by a set of preferences. It is reasonable to say that, when we deal with cardinal preferences, this remains a simplistic approach, since it calculates how many times a condition is violated, but not the extent to which it is violated. That is, a simple count only employs ordinal information discarding the precious information contained in the cardinal preferences. In this research we propose a cardinal approach to the measurement of the violation of transitivity conditions. To do

so, given a pairwise comparison matrix A , we devise some optimization problems to find its closest transitive approximation X . The distance between the matrices A and X can then be used as an estimation of the degree of intransitivity of the matrix A . In other words, we consider the distance between A and the set of all transitive pairwise comparison matrices as an index of intransitivity. This new approach is justified by means of some numerical examples and the optimization problems used to find the closest transitive approximation to a pairwise comparison matrix A can be formulated as mixed-integer linear programs. In our study, we consider the usual condition of transitivity but also restricted max-max transitivity and weak consistency. Finally, we test and validate our approach from a numerical point of view and we use it to calculate the intransitivity of some pairwise comparison matrices which have already been analyzed in the literature. With our approach we hope to offer a more natural methodology to quantify the degree of intransitivity of cardinal preference relations and pairwise comparison matrices.

TUE-1-E

Invited Session: Multiobjective Optimization Applications

Tuesday 9:00-10:40 - Room: Hagia Sophia

Chair: Banu Lokman

1. Forming a Collaborative and Productive Team of Experts

**Mehdi Kargar, Ryerson University, Canada, kargar@ryerson.ca*

The success of any project is directly related to the team that perform and execute the project. Forming the most effective team of experts is a challenging task for many institutes and organizations. When forming a team, collaboration and productivity are among the most important factors that guarantee the success of the team. Given a social network of experts, we tackle the problem of forming a team of experts that covers a set of required skills. An expert possesses a set of skills. These skills are obtained by the expert through training or past experience. Furthermore, based on past collaboration among experts in various projects, a graph among experts can be built.

If two experts have past collaboration (e.g., work on the same project), there will be an edge between them in the underlying graph. This graph can be weighted. If two experts collaborated in more than one project in the past, the edge weight between them will be smaller than two experts that only collaborated in one project. Given a project that needs a set of required skills (i.e., expertise), the goal is to form a team of experts that together cover the required skills and have past collaboration. Past collaboration can be measured by the weight of the sub-graph that connects experts together. In this case, the weight of the sub-graph is called the communication cost among experts. The smaller the communication cost, the better the team. The problem of finding a team of experts while minimizing the communication cost has been studied in the past. However, each expert has a level of productivity. Productivity of each expert can be obtained by the number of projects that have been completed by her or the quality of the projects that she has delivered in the past. In this case, each expert will be assigned with a productivity score. It is desired that a team of experts for performing a given project has high productivity. Optimizing both productivity and communication cost turns the problem into a bi-objective optimization problem. This problem has not studied in the past. Since optimizing each of these objectives are NP-hard, we propose a knowledge-based evolutionary algorithm to find a team of experts that optimize both these objectives. We also propose a greedy algorithm solve this bi-objective optimization problem. To demonstrate the effectiveness and efficiency of our approach, we compare it with the results of the exact algorithm that is achieved by the exhaustive search algorithm. The experiments are performed on the real DBLP and GitHub datasets. DBLP is a publication dataset that contains information about authors of scientific papers. The experts are researchers that publish papers. If two authors publish together, they will be connected in the underlying graph. Productivity can be measured by the number of papers that are published by each author. GitHub is a hosting service for IT projects. Nodes of the GitHub graph are developers that participate in different projects. Two experts are connected to each other if they participate in the same

project. The expertise of an expert is extracted from the titles of the projects she participated in. The results suggest that the proposed evolutionary algorithm is more stable in terms of run-time than the greedy algorithm when the frequency of the required skills changes. Furthermore, the results of our proposed method achieve high accuracy when compared to the exact algorithm (exhaustive search).

2. Incorporating Robustness in Interactive Multi-Response Surface Optimization of Product Design Parameters

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Several factors affecting quality of a product have to be considered to determine settings of design parameters that yield high quality with minimal variation (design robustness). The quality of a product need to be defined by multiple responses where optimal design solution for a response is typically not optimal for another due to the conflicting natures of responses. These problems can be referred to as Multi Response surface Optimization (MRO) problems. The relationships between responses (or performance measures) of interest and relevant design parameters are modeled as empirical relationship functions. Finding meaningful solutions requires considering such multiple response functions simultaneously as objectives or constraints in optimization models. Many of the existing approaches in the literature optimize a specific function of the responses, implicitly assuming that all DM's have the same preferences. Others assume the preferences of the decision maker (DM) can be represented by a specific function and its parameters are known exactly at the outset. These are strong and unjustified assumptions in practice. There are a few studies that employ interactive multi objective optimization (MOO). Although these approaches incorporate the DM's preferences into the solution process, they

typically ignore model uncertainty. The uncertainty inherent in the structure and/or parameters of the response surface models is important and solutions that do not take this into account may result in designs that are unstable and hence undesirable to the DM. Another common assumption in the literature is that responses have constant variances at different settings of the controllable design parameters. This assumption may not be realistic for MRO problems and the solutions obtained based on these assumptions may have properties that could be substantially different from the estimated properties. We develop an interactive approach for the two-response product and process design optimization problem, considering DM's preferences under model uncertainty associated with the parameters of response surface models and heterogeneity of response variances. We use several controllable properties of the responses, such as the distance of the estimated response means from their respective target values and the estimated response variances, to control the performance of the solutions in our models. In order to provide relevant information on the consequences of solutions to the DM, we produce visual aids on performance measures such as joint response confidence and prediction regions of selected solutions together with lower and upper specification limits and target values of the responses. The performance measures and visual aids facilitate the communication with the DM in extracting preference information. Although some general knowledge on the effects of changing the controllable properties on the performance measures exist, the exact magnitudes of those effects are not known since they are determined by the complex problem characteristics. It is not possible to know the exact effects of sacrifices on some performance measures with certainty. Therefore, we involve the design analyst (DA) in the search process to help the DM converge to his/her preferred solutions quickly. At each iteration, the DA converts DM's verbal preferences into mathematical expressions that have the potential to lead the search towards regions containing solutions that are desirable to the DM. The DA systematically searches the relevant solution space utilizing Pareto frontiers considering only the distances of the estimated response means from their

respective target values. The DA identifies solutions that may be attractive and presents several of them to the DM. The procedure continues until the DM is satisfied. We demonstrate our approach on the Polymer experiment, a two-response problem widely used in the literature.

3. A Multi-Objective Approach to Cluster Ensemble Selection Problem

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Clustering is an unsupervised learning method that partitions a dataset into groups. The aim is to assign similar points to the same cluster and dissimilar points to different clusters with respect to some notion of similarity. It is applicable to a wide range of areas such as recommender systems, anomaly detection, market research, and customer segmentation. With the advances in the computational power, a diverse set of clustering solutions can be obtained from a dataset using different clustering algorithms, different parameter settings and different features. Clustering ensemble has emerged as a powerful tool for combining the strengths of these multiple clustering solutions and generating a consensus solution. It improves the quality of clustering in terms of accuracy, robustness and stability. In this study, we address the cluster ensemble selection problem, and propose a multi-objective approach to generate a consensus clustering solution. The proposed algorithm selects a representative subset of clustering solutions, and produces a consensus clustering solution by combining these representatives. Different from the existing approaches, we design the representative selection approach based on three criteria: quality, diversity and size of the representative set. Before the representative selection, we apply a preprocessing procedure to analyze the characteristics of the clustering solutions in the full ensemble and eliminate the ones that may mislead the consensus function. We test the performance of the proposed approach on benchmark datasets. The results show that the proposed approach works well, and it

outperforms the existing methods. Furthermore, we observe that regardless of the ensemble generation mechanism and consensus function, the preprocessing procedure increases the accuracy of the final consensus clustering with respect to true cluster labels. Keywords: Cluster ensembles, consensus clustering, multi-objective clustering

4. A Web-based Decision Support System for Multi-Objective Mixed Integer Programs

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Multi-objective mixed integer programs (MOMIPs) are widely used to represent and model the decision problems in many organizations. It is typically hard to characterize the nondominated set of MOMIPs especially in complex systems. In this study, we develop a web-based decision support system that provides users with the tools to solve multi-objective integer and mixed integer programming problems. Our first algorithm in the web-based solution platform is designed to generate all nondominated points for a given multi-objective integer program. In order to reduce the computational burden, we also develop algorithms to generate representative nondominated points for any given MOMIP. These algorithms are designed to generate a subset of nondominated points that represent the whole nondominated frontier with a desired quality level. We also develop visualization tools that provide users with the opportunity to analyze the distribution of the nondominated points over the objective function space and to visualize the tradeoffs between the objective functions. We also maintain a digital library that provides a collection of test data sets and make their inputs and outputs available to researchers.

TUE-1-F

Contributed Session: Understanding Consumers and Markets

Tuesday 9:00-10:40 - Room: Basilica Cistern

Chair: Fusun Ulengin

1. A Comparative Analysis of Entrepreneurial Success of Advanced and Emerging Economies: A SEM Approach

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Today entrepreneurship and start-up companies are the most important source of innovation and economic growth. Thus, the ecosystems to foster entrepreneurship is emphasized more and more in almost all economies. Efforts for increasing the entrepreneurship can only be successful when the root causes and their relationship with the entrepreneurial success are understood. This paper is an investigation of the main factors of creating successful new businesses and a comparison between two main country groups of Europe. Countries with advanced economies and, emerging and developing economies will be set side by side to understand whether the pre-indicated factors can be generalizable for these groups. In this study, we hypothesize the definition of entrepreneurial success as a highly relatable indication to main five factors. These are the infrastructure, economic situation, educational structure, culture and market dynamics of a country and is investigated to form the basis of success in new ventures. We propose a model with the interrelationships of these factors. We estimate the model using structural equation modeling and test our hypotheses. Historical data is used to test whether the chosen variables of five main factors create a significant relationship with entrepreneurial success. According to the results of the model estimation, variables with no effect are taken out and a final result is reached. Data that is used in this research is obtained from Global Entrepreneurship Monitor's (GEM) two databases: National Expert Survey

(NES) and Adult Population Survey (APS). NES provides the national perspective on new businesses and Adult Population Survey (APS) supplies the social viewpoint of individuals towards entrepreneurship. We estimate the model separately for the data of the country cluster of advanced economies and for the data of the country cluster of emerging economies. Then, we compare the relationships of the factors that lead to entrepreneur success for these two different clusters of countries. Our findings can be used by policy makers to identify the potential improvement areas for increasing the entrepreneurship and its success. Moreover, the results can also provide a benchmarking basis for emerging countries.

2. A Bi-Objective Cost-Comfort MILP Model of Demand Response to Dynamic Tariffs

**Carlos Henggeler Antunes, University of Coimbra, Portugal, ch@deec.uc.pt
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Dynamic time-of-use (ToU) tariffs are expected to become a common pricing scheme in smart grids, by conveying price signals reflecting generation costs, e.g., involving the availability of renewable energy, and grid conditions, e.g., congestion. Therefore, ToU tariffs offer consumers incentives to adopt energy usage patterns different from habitual behaviors. In this setting, ToU tariffs can bring benefits for: - grid operators by contributing to accommodate larger shares of intermittent renewable generation and alleviate congestion in networks adopting a “load follows generation” paradigm; - electricity retailers by enabling to manage wholesale buying and retail selling prices; - consumers by engaging in demand response actions to reduce the energy bill with jeopardizing comfort. Consumers react to dynamic tariffs by resetting thermostat setpoints or rescheduling appliance operation to profit from lower priced periods, thus balancing the cost and comfort evaluation dimensions associated with the provision of energy services. This work presents a bi-objective mixed integer linear programming model (MILP) to optimize demand response in face of dynamic tariffs, considering the minimization of energy and power costs and

the minimization of the discomfort associated with changes regarding most preferred settings or operation time slots. The model considers different types of loads: - shiftable loads, i.e., loads for which the operation cycle cannot be interrupted such as dishwashers, tumble dryers or cloth washers; - interruptible loads, i.e., loads whose operation cycle can be interrupted, given that a certain amount of energy is supplied before a specified instant, such as electric water heaters or electric vehicles; - thermostatic loads, i.e., appliances controlled by a thermostat device switched by the indoor temperature, which is determined by a thermal model of the space being conditioned, such as air conditioners. Constraints are related to operational issues, such as avoiding load diagram peaks, and quality of service / comfort requirements, such as respecting time slots for appliance operation or bounds for indoor comfort temperature. Scalarizations of the model instantiated with realistic data can be solved with a commercial solver for 15-minute discretization of the planning period, enabling to characterize the nondominated front. For finer time discretization, the model cannot be solved exactly due to its combinatorial nature and, therefore, customized meta-heuristic approaches are necessary to obtain good quality solutions in an acceptable computational time, which is compatible with (near) real-time implementation as an automatic home energy management system. In a smart grid setting, these systems using a low-cost microcontroller are expected to be deployed in the premises of consumers to control end-use loads by responding to different grid requests while considering end-users’ preferences. Computational results are presented displaying the characteristics of solutions on the nondominated front, emphasizing the trade-offs between the economic and comfort dimensions for different consumer profiles. The detailed operation of appliances is presented as well as comfort indicators such as indoor temperature along a one-day planning period. It is shown that shiftable and interruptible loads are easily dealt with by the solver, but the control of the air conditioning system imposes a significant computational effort. Also, the MIP gap increases with the weight assigned to the indoor temperature

comfort objective, which may impair real-time applications.

3. Assessing CLV Scores of the Customer Segments Through a Weighted RFM Decision Model

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This study is related with a significant stage of a research project, which aims to provide a DSS that analyzes the big data related to retail consumers in order to describe and predict their purchase behaviors and propose managerial insights for the retail sector managers. These insights are expected to improve the business processes of the companies and their performances, create new markets and opportunities as well as ensure sustainable competitive advantages. In the context of that project, a case study was conducted on datasets consisting the transactions of individual and business members of Sam's Club, a division of Walmart Stores, Inc. In this study, after clustering individual and business members of Sam's Club into customer segments utilizing descriptive and predictive analytics, we aimed to estimate the customer lifetime value (CLV) of the clusters based on the purchasing behaviors of the members in each cluster. Companies can use CLV as a metric for determining which customer segments are more profitable and loyal as well as developing efficient and appropriate marketing and sales strategies for each segment with respect to financial and operational perspectives. To compute CLV score for each cluster, we used a weighted RFM (recency, frequency, monetary) decision model. In the first step, to assess the relative weights of RFM variables, we assessed judgements of the experts by asking pairwise comparison questions, formed a pairwise comparison matrix using those judgements, and used the values of the eigenvector as relative weights extracted from that matrix. In the second step, we constructed two decision matrices, one for individual customers and the other for business customers. Matrices have clusters at the rows; recency, frequency, and monetary

variables at the columns; and average RFM values of the customers in each cluster at the entries. In order to compute the CLV scores of the clusters; obtaining a global score by adding weighted contributions from each variable is frequently preferred in the literature. Hence, at the last step, we used Simple Additive Weighting (SAW) method for this purpose. As a result, we came up with CLV scores of each cluster. Those scores are used to differentiate the corresponding clusters and to suggest managerial insights for each of them.

4. Analysis of Marketing Strategic Planning in Furniture Industry by Applying ANP, Case of the Study: Iran Furniture Industry

**Majid Azizi, University of Tehran, Iran, mazizi@ut.ac.ir*

This study was carried out due to the severe dearth of research on strategic planning in the country's furniture market. Accordingly, this research represents a decision-making model developed to select the best solution for strategic planning in the industry. Four possibilities can be considered as potential solutions: Entrance to the foreign market (S1), Increase portfolio (S2), Emphasis on scientific management of mixing elements of marketing (S3), Generate research and development units (S4). The Analytic Network Process and the Super Decision software were used to synthesize and analyze the model. It was found that all calculated decisions were influenced by strategic criteria. A value-weighted competency model was calculated in the first stage with the influence of strategic criteria on the competency model. Hierarchical designs decisions were made for each of the competencies and their subsets (144 sub-criteria and 22 middle indices). Paired comparison matrices associated with the degree of importance of each of the competencies were achieved in the second stage. In the final stage, subsets of competencies' weights and their sub-options were identified with the combination of the competencies' networks. The results showed after collecting questionnaires, evaluating and correcting the incompatibility rate of comparative matrices, with respect to competencies of benefits, opportunities, and costs, third solution (S3) has the highest

priority, while regarding the competency of risks, first solution (S1) has the highest priority. The final results showed that the third solution (S3) is the best alternative among the alternatives proposed in the marketing strategy of the home furniture industry.

TUE-2-P

Plenary Session 2

Tuesday 11:10-12:10 - Room: Mustafa Kemal Amfisi

Chair: Serpil Sayın

Multi-Objective Combinatorial Optimization – Beyond the Bi-Objective Case

**Kathrin Klamroth, University of Wuppertal, Germany,
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Multi-objective combinatorial optimization (MOCO) is a quickly growing field that is highly relevant for a multitude of application areas and at the same time highly challenging due to its inherent complexity. Typical examples of MOCO problems include multi-objective knapsack and assignment problems, the multi-objective TSP, and network problems like multi-objective minimum spanning tree, shortest path, and minimum cost flow problems. Starting from a review of recent developments in the field of MOCO, we will analyze the main drivers of the complexity of MOCO problems and identify cases where MOCO problems are actually easy. We discuss general solution concepts such as generic scalarization based algorithms, branch and bound methods, and upper and lower bound sets. This leads to the question of concisely describing the search region and efficiently updating intersections of polyhedral cones in higher dimensions.

TUE-3-A

Contributed Session: Multiple Criteria Ranking or Sorting

Tuesday 13:50-15:30 - Room: Galata Tower

Chair: Dalel Amami

1. Entrepreneurship Education: Towards The Validity of an Impactful and Effective Framework for Business Schools

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The nature and characteristics of entrepreneurial competencies have been widely investigated and applied to many fields, such as entrepreneurship research (Man et al 2002), competency and competence theory or business performance and growth (Mitchellmore and Rowley 2010). The most common entrepreneurial teaching model of a business school is a combination of entrepreneurial theoretical courses, engagement in practical oriented activities, offering of innovative spaces or mentoring support, among other features (Sirelkhatim and Gangi 2015). Based on the existing literature, there is no blueprint on a valid structure or hierarchy of these elements with respect to their relevant importance regarding the impact on the future entrepreneurial path of students (Lorz et al 2013). The objective of this paper is to investigate, in a business school context, the influential variables and sub-variables of an education model that effectively enhance and promote entrepreneurial competences among students. The list of variables presented below is the result of a process of information gathering, compiled through 12 deep interviews to academic experts in the field. Variable 1: Curricula (Sub-Variables: Specific knowledge on Entrepreneurship; the use of business cases; the use of inspirational sources (bring testimonials to class); Business Plan as a final project). Variable 2: Institutional support (Sub-variables: Innovative physical spaces and related resources; Clubs or student associations; Alumni networking; Institutional financial support). Variable 3: Real (outside) immersions (Sub-variables: Visits; Study tours o Immersion trips). Variable 4: Participation in challenges (Sub-variables: Challenges and competitions

proposed by real companies; Simulated challenges and competitions). Variable 5: Participation in practical activities (Sub-variables: Service Learning; Internships in start-ups). These variables are ranked with respect to their impact and effectiveness to enhance and promote entrepreneurial competences. Data is obtained from the Entrepreneurship Institute of ESADE Business School in Barcelona. The groups of decision makers considered are: First, Alumni Entrepreneurs who have set up their own start-up. Second, Alumni intra-entrepreneurs or intra-innovators, within a bigger company. And, finally, "Life" Alumni who started an entrepreneurial project related to civil society, sports or personal life, beyond their professional scope. All respondents will have the possibility to assign hesitant values if they are not sure about their judgment.

2. Electric Fleet Selection for Last Mile Delivery

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Last mile delivery is the ultimate chain in urban logistics. It refers the micro-level logistics activities from the delivery center to the end-user. It has a very complicated relationship with urban transportation, and it needs to be evaluated together with city transportation to be efficient and sustainable. E-commerce, which is the powerful catalyst for last mile delivery, is overgrowing day by day. This growth uncovers the need for more effective and on-time deliveries for the companies. Delivery companies try to distribute the good to the right place at the right time. The one that delivers it faster takes a competitive advantage; therefore having a rapid and efficient last mile delivery is a very crucial strategy for the company. Also, the more technology is integrated with the delivery process; the more customers want to be flexible and connected to the on-time information. Besides the competitive

advantage, natural adaptation strategies push companies to obtain more sustainable policies facing climate change. Low CO₂ emissions, less harm to the environment, etc. become the new strategical challenges to overcome. Having a high tech delivery service with maximum information share with the customer in addition to the minimum harm on nature is the most important trend in last mile delivery. To be able to reach that, different strategies have been suggested. Electric vehicles (EVs) are one of the most powerful solutions. EVs are the energy efficient choice for inner-city traffic. Transformation of conventionally fueled vehicles to EVs aids to reduce both emissions and noise for the urban congestion. On the other hand, EVs are not highly preferable for the delivery companies due to insufficient infrastructure for charging network, high investment costs and lack of information. However, technology continues to grow, and smart cities are not just future dreams. Strong charging networks have been developed in various cities, and they will be more reachable shortly. Therefore, this paper focuses on the electric fleet selection problem for a delivery company. It is undeniable that EVs are the future vehicles and many European countries prepare to stop fueled vehicle sale by 2025. Getting ready for the future with competitive strategies are very critical for delivery companies. In this study, the main focus is to determine the evaluation criteria for the electric fleet selection and approach this selection procedure as a multi-criteria decision making (MCDM) process. Evaluation based on distance from the average solution (EDAS), which is firstly introduced by Ghorobae et al. in 2015, tool has been provided for the selection problem. It has been used with its 2-Tuple extension in order to create a convenient environment to use linguistic variable during evaluation. EDAS method has been preferred thanks to its efficient and straightforward computational steps while handling multiple criteria. The most suitable alternative is selected according to the average solution that is determined by arithmetic mean. By extending the classical EDAS method with a 2-Tuple linguistic model, it becomes more suitable for group decision-making (GDM). Usually, fuzzy extensions of EDAS also provide convenience for GDM; but when different levels of knowledge are included in

the group different linguistic levels are needed. Hence, the 2-Tuple linguistic model has the power and simplicity to aggregate different granulated information raised from various decision makers (DMs). To conclude, this study proposed an MCDM approach for electric fleet selection subject. 2-Tuple integrated EDAS has been used to select the most suitable alternative. Also, Best Worst Method (BWM) has been suggested with its 2-Tuple extension to weigh the criteria for the selection problem. Finally, a case study is conducted to see the plausibility of the suggested MCDM methodology. The results and the discussions are provided in the study.

3. Assessing Smartness and Urban Development of the European Cities: An Integrated Approach of Entropy and VIKOR

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Contemporary flows put urban areas at the forefront as the main bearers of economic growth and prosperity. The accelerated expansion of urban areas in last decades poses the issue of their sustainability and growing infrastructural, ecological and social problems. The concept of smart cities is one of the potential responses, strived at increasing the competitiveness of local communities and urban areas, through the application of innovative technological solutions in order to improve the quality of life for its citizens providing better public services and a healthier environment. The paper is aimed to perform ranking of the European cities according to their smart and urban development indicators. The research results are determined based on the data collected through four cycles of the Eurostat's Urban Audit Perception Survey conducted in the period 2006-2015. The data refer to perceived urban performances of cities by inhabitants living in them, including different aspects of sustainability and development of urban areas such as economic, social, environmental and

governmental dimensions. The citizen's perception of quality of life within the city is an important information, which serves as a basis for improving certain urban performances, which citizens perceive as insufficient in their cities. For the analysis of various attributes of cities' urban performance, a multi-criteria model is developed, integrating the entropy for determining the criteria's relative weights and VIKOR (VišeKriterijumska Optimizacija I Kompromisno Rešenje, Eng. Multi-Criteria Optimization and Compromise Solution) as ranking method. Respondent's subjective preferences were measured by 4-point Likert scale and for the purpose of the analysis the quantification of responses was made. The multi-criteria model provided in the paper includes 28 different criteria with approximately equal significance, grouped into six categories and from 73 up to 111 European cities per year depending of the sample size in each of the research cycles. The results of the ranking are visualised in order to determine urban areas in Europe where the inhabitants perceive is the highest overall level of smartness and sustainable urban development. The main finding of the paper implies that among the best ranked cities are mostly cities of Western Europe, mainly United Kingdom. It should also be noted that apart from Vienna, Luxembourg, Copenhagen and Stockholm, the other analysed capitals are not in the top 10 in each of the observed years.

4. Application of Multi-Criteria Decision Making for Patients Priority and Assignment to Operating Room

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Successful assignment and scheduling patients to the operating room are still problematic matters. To solve these issues, several methods were proposed such as Mathematical programming, heuristic, metaheuristic. Multicriteria decision-making (MCDM) tools could also be useful in finding solutions. MCDM proposes a set of techniques applied to certain criteria to help the decision-makers (DMs) identify, compare and estimate alternatives. The best alternative should answer the constraints of

the DMs and their preferences and priorities. The patient assignment problem can be assimilated as a multicriteria decision-making problem where many criteria should be considered in decision-making. This paper proposes a novel approach that is the application of MCDM for assigning patients to the operating rooms. Therefore, we address the problem of operating room planning and scheduling by using a multi-criteria approach. The production goal is to assign a list of patients on a limited number of operating room subject to a set of criteria. We propose an approach based on the use of C-TOPSIS with different weight methods. We will respectively use Entropy Method (EM), the standard deviation (SD), and Preference selection index (PSI) to determine the important scores of evaluation criteria. The objective of this procedure is to minimize the makespan of the operating room, taking into account the priority of the patient. Recall that the makespan denoted C_{max} is the maximum total processing time on any machine. The processing time is the operation duration; the machines are the operating rooms. The obtained results show that the best value of C_{max} is obtained by the PSI method. This result can be explained by the ability of the PSI to deal with different criteria by using the fuzzy logic to homogenize the different criteria functions. Our proposed technique has been applied to generate multiple schedules taking into account the different considered criteria. This evaluation method is used to select the best solution satisfying the preference of the decision-maker based not only on the importance of each criterion but also on the interactions between the criteria. We note the shortage of research considering the resolution of the scheduling problem by using TOPSIS technique, further work needs to focus on solving the proposed problem with other MCDM approaches in order to compare them with the presented approach.

TUE-3-B

Contributed Session: AHP/ANP Applications in Urban and Regional Development

Tuesday 13:50-15:30 - Room: Maiden's Tower

Chair: Sercan Cakir

1. A Multi-Criteria Decision Making Approach to Identify the Priority of Criteria Affect Sustainability of Eco-Villages in Turkey

**Gökçen Bayram, Marmara University, Turkey, gokcen_bayram@hotmail.com*

Recent economic, ecologic and social challenges lead to small and self-sufficient habitats, called eco-villages to deal with challenges and reduce the negative impact of pollution. We now see an increasing interest in the adoption of establishing and living in an eco-village all around the world. During 2000s there has been several attempts to establish eco-villages but now there are a few eco-village initiatives in Turkey. The term of wellbeing, which can be defined as all aspects involves the contribution of an individual's and the community's synergy and togetherness positively, is the key fact to provide sustainability of eco-villages. In this paper, a multi-criteria decision making model is proposed for identification of sorting according to priority of criteria that affect sustainability of eco-villages in Turkey. The study is structured on three major steps; criteria identification, questionnaire survey study and MCDM method implementation. In this study Analytic Hierarchy Process (AHP) is used as the methodological tool to evaluate and to identify the priority of the criteria. Literature review is utilized to determine criteria and the study is based on 5 criteria and 43 sub-criteria. In the extensive questionnaire survey the criteria and sub criteria are graded by using 1-9 Saaty scale in order to compare each criterion. Participants are selected from the experienced with eco-villages as inhabitant in an eco-village and experts in several ecology associations. The proposed evaluation criteria provide a reference for eco-village inhabitants and founders to provide sustainable eco-villages.

2. The Analytic Network Process as a Planning Tool for Sustainable Development

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1. Introduction This study conducts a systematic literature review on the Analytic Network Process's support for decision making processes for sustainable development. It focusses on the usefulness of the methodology and draws some conclusions on its potential and limitations. The research is frameworked in sustainable development planning. Several authors introduced the use of MCDM techniques for sustainability issues (Ginevičius and Podvezko 2009). Many of them focus on the use of the Analytic Hierarchy Process (AHP), which has been stood out as the most often used (Dos Santos et al. 2019) due to its ease of use for preferential information elicitation from expert. However, AHP does not allow considering the interdependences among criteria. For this reason, some authors recommend the use of the Analytic Network Process (ANP) because it allows better representing the complex interactions among the different components of a real system (Wu and Cui 2016) as is the case in the field of sustainability. As a result, several authors have introduced the use of ANP during the last decade. Regarding sustainability, many works in different areas have been proposed, e.g. engineering, environmental sciences ecology, science technology, business economics, operations research management science, computer science and energy fuels. This work gathers, maps, analyzes, and summarizes this academic literature by reviewing manuscripts in which ANP is applied for sustainability and which are indexed in the Web of Science and Scopus databases. The results, analysis, and discussion of the screened manuscripts show (a) a descriptive analysis, (b) bibliometric data, (c) a citation analysis, (d) an analysis of the most relevant literature and (e) an analysis of the most recent literature. Results also allow comparing the findings of this research with the work proposed by Dos Santos et al. (2019) regarding AHP.

2. Sustainable development in planning process The definition of sustainability implies a three-pillar concept: environmental, economic, and social. However, some recent publications in the field of sustainable planning also stress the importance of including participatory

processes. The achievement of an optimal solution for all of the stakeholders becomes difficult when the intervention of different agents, objectives and factors is considered, which involves the interaction of complex elements in complex context.

3. Hypotheses of the work This work is based on the next hypothesis: ANP is a useful tool to support planning processes for sustainable development.

4. Research Design/Methodology There are five steps that we propose to achieve the systematic literature review (Denyer & Tranfield 2009): 1. Question formulation 2. Locating studies: Identification 3. Study selection and evaluation: Screening 4. Analysis and synthesis 5. Reporting the results

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3. A Combined Simulation-Optimization and AHP Approach to Improve the Quality of Care in Healthcare Centers

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Quality of care is crucial for patients' satisfaction and safety in healthcare centers. The majority of hospitals attempt to implement facility-wide improvements to ensure high-quality care delivery. This study aims to propose a combined Simulation-Optimization and MCDM approach to accurately asses the impact of quality

improvement initiatives on different facets of healthcare systems. In this framework, first, the importance (weights) of the different healthcare criteria is determined by health providers' using an AHP approach. Then, the weights provided by AHP are applied in a simulation-optimization environment to determine the most efficient action with the most desirable quality of care. Simulation provides a platform to examine the effectiveness of different improvement efforts and calculate their impact on the system performance measures.

4. An MCDM Approach for Selecting Suitable Urban Green Spaces Based on a Desired Activity

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Publicly accessible urban green spaces play an essential role to ensure a high quality of life in cities by providing citizens with spaces for recreation and social interaction. Particularly in cities with high growth rates and the often associated densification, it is especially important for citizens to know where urban green spaces are, how they are equipped and how they can be accessed. With this information, the benefits of ecosystem services, e.g. cultural services such as recreational experiences, but also regulating services such as the cooling effect through vegetation, which citizens receive from urban green spaces, can be properly exploited. In this context, a service infrastructure and a web application for cities are being developed within the framework of an ongoing research project. One entry point of the app is to provide users with information on suitable urban green spaces within a city based on a desired activity such as jogging, walking or reading. This requires the development of a decision support system for the selection of urban green spaces for specific activities. How this can be developed is part of this conference

contribution, as we consider multiple criteria decision making (MCDM) methods as one potential solution in order to tackle the ambiguity in the selection of suitable urban green spaces. The study preliminarily focuses on comparing two prominent MCDM methods which are the Analytic Hierarchy Process (AHP) and Multi-Attribute Utility Theory (MAUT). We will discuss the suitability of both MCDM approaches in terms of acquisition and modelling of the user preferences and the computing of the weights. The a priori knowledge of user preferences for different activities will be collected through questionnaires. Both MCDM methods are then implemented for a specific use case scenario (jogging activity). In this scenario, each evaluation criterion, for instance, a) the size, b) the path network length, and c) the green volume of each urban green space related to activity "jogging" are associated with weights which are estimated based on the user's personal preferences. Afterwards, the scores of urban green spaces are calculated by aggregating the multiplication of indicators on the normalised values and estimated weights. Here we aim at providing a novel approach for applying MCDM to urban green space activity patterns. The results obtained from both techniques will be presented and discussed in terms of the strengths and limits.

TUE-3-C

Invited Session: MCDM/A Models with Flexible and Interactive Preference Modeling

Tuesday 13:50-15:30 - Room: Dolmabahçe Palace

Chairs: Suzana Daher, Rodrigo J P Ferreira

1. The MCDA as a Way to Avoid Political Polarization in Social Elections

**Pablo Manyoma, Universidad del Valle, Colombia, pablo.manyoma@correounivalle.edu.co*

Political polarization is a widely known phenomenon that has always attracted the attention of researchers throughout history. It has been believed that dialogue through different political lines is a key prerequisite for maintaining democratic citizenship. One

could even say that the debate is irreplaceable to form rational opinions that go beyond the limits of one's own subjectivity to incorporate the points of view of others. In addition to its importance in everyday life, political polarization has been the subject of debate and academic exploration due to its potentially negative consequences in democratic societies. These consequences range from simple discomfort among people to the use of this polarization as an element of retrospective economic evaluation, whether in recessions or recoveries in a particular country. The cases in which the supporters see the opposite party more negatively than theirs have increased in recent years in the Americas. The cases of the United States, Mexico, Costa Rica, Colombia and Brazil show that, many times, polarization is a problem of preferences. In this way, the extremes take on more importance and the midpoints are rarely seen. When this political scenario is configured, a complex series of phenomena begins to occur. Normally in these situations, the poles dominate the social conversation in all areas, they make their actions acquire more weight in public opinion, concentrating all available resources, increasingly, around these two poles. As the emotional burden of political confrontation becomes increasingly intense, the "available vote" in that society tends to move toward them as well, and the construction of alternatives different to the extremes becomes increasingly difficult. The democratic theory assumes that citizens have the ability to be informed, at least partially, and act based on such information, or at least act as if they are well informed. In different studies it has been observed that political polarization has determinants that usually respond to historical, socio-cultural, economic and geographical phenomena, among others. The electoral systems, for the most part, do not favor the median voter and favor political polarization, since they face the elector with a "large package" of elements that he has to decide, represented in a single candidate. The proposal of this research is to define an agreement on the fundamental problems of a society: violence, insecurity, lack of justice, poverty, employment, health, housing and education, among many others, and that function as decision criteria. This agreement is made through AHP to define the weight of each identified criterion. In addition to this, a

system of choice is proposed that allows ordering from highest to lowest the preference that citizens have for each candidate in each aspect declared as important. This is done through the Borda system of social choice. This methodology would reduce the polarization of candidates and would force the voter to be more aware of government programs proposed by the candidates themselves.

2. Understanding a Decision Policy: Using Fittradeoff as a Mirror for a Decision Maker

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The paper provides an evaluation of a decision policy, made by consensus among a group of high-level decision makers of the Brazilian Navy. There is not a unique set of alternatives, since the policy intends to guide future decisions, to be repeated from time to time. The policy establishes a rule to be used for future sets, concerning the same criteria. Each decision comprises ordering of alternatives (as a gamma problematic). The objective of the study was to provide for one decision maker a deeper understanding of the policy defined by the group and, furthermore, carry out a comparison between his own beliefs, regarding the criteria and the policy impacts. Those impacts were estimated using realistic simulated data, defined by the decision maker. The methodology used is the FITradeoff (Flexible and Interactive trade-off) because, as an aggregation model, it has proximity to the defined policy structure. Since there is a confidentiality issue, the focus is on the decision maker/facilitator interaction. The present work introduces the use of FITradeoff as a mirror to a decision maker, regarding his own decisions, the group consensus and its estimated impacts, so as to present confirmations of his expectations, but also depicting the lack of harmony in some aspects.

3. Evaluation of Energy Efficiency Services in Food Industries with Partial Information based on the FITradeoff Method

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A decision problem to select the most desired energy efficiency service in food industries in the south of Brazil was evaluated. The problem was structured through the Value Focused Brainstorming methodology and some criteria related to processes, management, knowledge, quality of energy and equipment were defined. The evaluated alternatives were consulting services in optimization, diagnostics, industrial automation, maintenance, regulatory consulting and education. For the preference modeling phase, the use of partial information becomes an attractive procedure because of the cognitive simplicity when compared to the use of complete information. In this sense, the FITradeoff method was analyzed. After structuring the problem together, decision-makers used the method individually to identify the priority service to be hired. This method proved effective in identifying the criteria weights each decision maker and indicate the best performing alternatives.

4. A Multicriteria Decision Model for Selecting an Integrated Security Area to Allocate a State Military Police Station based on FITradeoff Method

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Location problems consist of determining the proper placement of an infrastructure component in an area of interest while taking the preferences of decision makers (DMs) and existing constraints into account. Different methodologies have been used to support location problems, such as the maximal covering location problem (MCLP), Game Theory, Geographic Information Systems (GIS), Multiobjective Optimization and Multicriteria Decision-Making Methods (MCDM). In public security problems, selecting an appropriate location for a police station considering economic, social, criminal and political issues is still an open field of research. These issues may be represented by different (and somehow conflicting) criteria, depending on DMs' different operational and strategic points of view. This paper proposes the use of the FITradeoff elicitation procedure to support a DM in selecting a specific area/region to locate a new State Military Police Station (SMPS) in the State of Pernambuco, Brazil. The State of Pernambuco, located in the Northeast region of Brazil, has over 9 million inhabitants and a territorial area of 98,000 square kilometers. The State of Pernambuco's security system is organized into 26 Integrated Security Areas (ISA) that may incorporate one or more districts. This arrangement was proposed in 2007 when the then State Government implemented a security program called "Pact of Life". This program is associated with a public security policy, the main objective of which is to reduce intentional lethal violent crimes (ILVC), comprising murders and other crimes that could result in death such as bodily injury and robberies. The location problem behind this paper encompasses two decision-making steps to support the strategic objective (which is, to minimize crime rates) of the State of Pernambuco's Social Defense Department: (1) to define which ISA will receive a new SMPS; and (2) to define a specific geography location (site) within this ISA in which the new SMPS will be installed. This study focused on implementing a model to support the first decision-making step and on indicating some relevant concerns that should be considered for the second step. The contribution of this

study to existing literature is two-fold. First, to support DMs in determining which ISA should receive a new SMPS using a multicriteria approach based on an interactive and flexible tradeoff method, and secondly, to provide to public policy developers a well-structured model to support making decisions on these kinds of problems.

TUE-3-D

Contributed Session: Data Envelopment Analysis

Tuesday 13:50-15:30 - Room: Topkapı Palace

Chair: Özgür Kabak

1. Interval Scale Data in DEA: Efficiency and Robustness Analysis

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Conventional Data Envelopment Analysis (DEA) models are developed for the ratio scale data and they can not provide meaningful results for evaluating decision making units with interval scale data (Halme et al. (2002)). We considered an efficiency analysis to incorporate interval scale data and formulated a mixed-integer linear programming model to compute the minimum number of units that should be eliminated from the Production Possibility Set (PPS) in order to make the unit under assessment efficient. We defined the Interval Scale Efficiency Score (ISES) of the unit under evaluation as the number of the remaining units to the number of all units. We prove that the ISES is a well-defined efficiency measure according to Aparacio and Pastor's criteria (Aparacio and Pastor (2013)). This means that ISES is between 0 and 1, equal to one for only efficient units, strongly monotonic and unit and translation invariant. We also characterize how robust the ISEs are with respect to improvement and deterioration of each inputs/outputs variable. We formulate a general multi-

objective linear programming problems to compute the deterioration and improvement values of each input/output variable in order to keep the ISES unchanged. We apply our proposed models for a simple numerical example and compute changes for each inputs/outputs variable separately, by only solving a mixed-integer linear programming problem.

2. An Integrated MCDM Approach for Evaluating Performance of Airline Companies

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Strategic decisions about improving airline performance have become crucial due to increased aggressive competition in the airline industry. Evaluating airline efficiency is an extremely complex, multi-dimensional problem which requires the application of Multiple Criteria Decision Making (MCDM) methods. This study evaluates the performance of 45 airline companies via combining the balanced score card (BSC) approach and the network-based super-efficient data envelopment analysis (DEA). The proposed methodology incorporates finance, customers, internal processes, learning and growth dimensions of BSC into the analysis in order to conduct a comprehensive assessment of airline companies from financial and non-financial perspectives of performance. Moreover, the eigenvector centrality concept is employed to determine which airlines should act as a role model (peer) for efficiency in each dimension of BSC. Rankings of airline companies in each dimension are also presented using the eigenvector centrality values.

3. Efficiency of Childbirth Services in Turkey: A Jackknifing for Robustness Check of DEA Scores

**Songul Cinaroglu, Hacettepe University, Turkey, songulcinaroglu@gmail.com*

The motivation of this study is to analyze the geographic distribution of efficiency of childbirth services in Turkish provinces. Data was collected from official statistical records of the 2017 Public Hospitals Statistical Yearbook. A total of 81 provinces in Turkey, representing seven geographic regions, were included in the analysis. Charnes, Cooper, and Rhodes' input-oriented data envelopment analysis (DEA) was applied to determine provinces' efficiency scores, using childbirth-specific input and output indicators. Input variables of this study are as follows: total number of physicians', total number of nurses and midwives' and number of beds in neonatal intensive care units. Output variables are: number of normal delivery, C-section and operative delivery. A jackknifing was applied for a robustness check of DEA scores. This procedure is performed to test the robustness of DEA efficiency scores, obtained from input and output variables in 81 Turkish provinces. The iteration procedure generates four models. The first, called the "prior model," has 81 DMUs. According to this model, 22% of provinces are efficient. (In this model, 18 DMUS are efficient, and 63 are inefficient). The average efficiency score for the first model is 0.69.18 iterations were applied for prior model for every efficient DMU. During the prior model's jackknifing iteration procedure, efficiency scores from the first six iterations presented low correlations with the prior model. In other words, reestimated efficiency scores of provinces, after dropping the six most-efficient provinces one at a time from the analysis, indicate a low level of correlation with the prior model. Clearly, efficiency scores obtained without including the six most-efficient DMUs one at a time does not give results similar to the prior model's efficiency scores. Considering the six most-efficient provinces in the prior model affects the efficiency frontier. In this regard, to avoid extreme outliers that could affect the robustness of efficiency scores, the six most-efficient DMUs in the prior model are removed, and efficiency scores

are reestimated. After this iteration, 75 provinces remain for the second model. The same procedure applied for model two and three and finally, recalculated efficiency scores of the final (fourth) model for 72 provinces show that 13 provinces are efficient and 59 are inefficient. The iteration procedure for the final model shows that reestimated efficiency scores of the final (fourth) model have high correlations with 13 iterations. In other words, incorporating efficient DMUs into the final (fourth) model does not affect the efficiency frontier. The average efficiency score for the final model is 0.71. In this study, four different DEA models were constructed, and the final model's efficiency scores were recorded. Finally, a decision-tree procedure was integrated into the DEA results, and predictors of efficient and inefficient provinces were examined. The study's results showed that 18% of provinces were efficient in terms of childbirth services. Average efficiency scores were high (0.71) for provinces located in the Southeast Anatolia region of Turkey. Decision tree shows that Number of beds in neonatal intensive care units (Neo_int_n_b) is the most important predictor of efficiency for childbirth services. Geographic distribution of childbirth services' efficiency scores in provinces shows that Eastern Turkey has the highest score. Neo_int_n_b, one of the input indicators under the control of health professionals to better manage childbirth services, is the most important determinant of efficiency scores. Ensuring public health managers' awareness and continuous monitoring of childbirth services, while also focusing more on regional differences, are essential to improve the status of children's health in Turkey.

4. DEA with Window Analysis and Cluster Analysis Approach for Analyzing the Interaction of Human Development and Competitiveness

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Purpose – Countries utilize their competitiveness to achieve human development. On the other hand, when a country advances in their human development, it is likely their

competitiveness level also increases. This study aims to analyze this bilateral relation among human development and competitiveness at country level. Design/methodology/approach – United Nations Development Programme's (UNDP) Human Development Index (HDI) and World Economic Forum's (WEF) Global Competitiveness Index (GCI) is used to represent countries' human development and competitiveness respectively. Data Envelopment Analysis (DEA) with window analysis is employed to compute the countries' efficiencies on converting their human development to competitiveness and inversely, competitiveness to human development with 3-year time lag. Then, a stepwise cluster analysis for time periods are used to analyze the results of the DEA models. 56 countries that comprise the 90% of the globe's population or GDP are evaluated for the years 2010-2017 using the proposed methods. Findings – No drastic change is observed as according to the results 77% of countries remain in the same cluster in the investigated period. Input-GCI Output-HDI model is more reliable than Input-HDI Output-GCI model, since its results are consistent with the cluster analysis. Therefore, the direction of the relation between competitiveness and human development is from competitiveness to human development. The competitiveness level of a country in a certain year affects its human development with a time lag. The basic implication of this result is that the countries needing a development in human-well-being can focus on the improvements on their competitiveness. Originality/value – To the best of our knowledge, this is the first study to investigate the bilateral relationship between human development and competitiveness. To that end, we use DEA and cluster analysis. Additionally, longitudinal data is incorporated to observe the trends.

TUE-3-E

Invited Session: Continuous Multiobjective Optimization with Engineering Applications

Tuesday 13:50-15:30 - Room: Hagia Sophia

Chair: Michael Stiglmayr

1. Bi-Objective Optimization in Complex GAS and Liquefied Natural Gas Transport Network

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Naturel gas is expected to occupy a preponderate place in the global energy balance. As regards Algeria, a country that is a producer, an exporter and a consumer, this natural resource plays a key role in the country. The discovery and exploitation of the deposits, added to that already in operation, will increase the production of hydrocarbons. This growth of production will necessarily have direct consequences on the transport, storage and export capacity of liquid hydrocarbons, which will follow a growing trend in response to market demand to both national and international levels. The development of a global model integrating the gas pipeline from the liquefaction plants to the marine terminal does not exist. Hence, we will develop a multicriteria decision-making tool that will act as a standard of experimentation where we can see the impact of any decision that can be taken on the whole chain. In order to solve this problem, first, some hydraulic calculations are performed to transform this problem by writing it as a mathematical model (linear programming problem). In the second step, we pass through two stages: in the first stage, we prepare the parameters of the model using the excel solver then, in the second stage, the corresponding linear programming problem is solved using the IBM ILOG CPLEX 12.6 solver to obtain the optimal solution.

2. Decision Making in Pump Hydraulic Design

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In this study, we want to show the practical role of the decision making in the pump hydraulic design, and the challenges connected to it. This involves an iterative process combining computationally very expensive numerical simulations and analytical formulas with expertise and intuition. To obtain an optimal performance, a careful balancing of the trade-offs between various, conflicting objectives, is crucial. The real design problem considered is related to the development a diagonal pump with an axial diffuser. In our case, the pump was designed to replace an already existing but outdated pump. This setting imposed many limitations, and forced compromises in the design and its performance. To meet the requirements demanded by the customer, it took several rounds of discussions with the decision maker and corrections based on numerical simulations. Finally, to further improve the design, we created a parametric model of the diffuser and performed an optimization. In total, there were 22 geometric parameters and three objectives (efficiency at three different flow rates). The numerical simulations were performed in ANSYS CFX software, and one computation took ca. 20 hours - which limited the number of objective evaluations. Two different surrogate-assisted methods were used. First, a single-objective method called "Stochastic RBF". Scalarization of the objectives was necessary in this case, the weights were based on the discussion with the decision maker. Next, we decided to employ K-RVEA, an evolutionary surrogate-assisted, multiobjective optimization method which utilizes Kriging to shorten computing times. The K-RVEA displayed a superior performance to Stochastic RBF. Finally, one design was selected, and a model pump was produced and experimentally measured in a hydraulic laboratory. The outcome was satisfying, as all required performance indicators were met or exceeded.

3. Biobjective Shape Optimization Using Weighted Sums: Probability of Failure versus Costs

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We analyze the trade-off between the Probability of Failure of a ceramic component under tensile load and its material consumption using the weighted sum scalarization of a biobjective shape optimization problem. Numerical experiments indicate that even though the problem is non convex in general, weighted sum scalarization is a useful tool in this context due to its numerical robustness. With this approach we are able to overcome local minima of the biobjective shape optimization problem and control the trade-off between the two objectives while varying the weights. For solving the weighted sum scalarization we outline a steepest descent algorithm and apply it to two test cases based on a finite element discretization using B-splines as control variables. In the end we also address the drawbacks of the weighted sum scalarization and compare our results to an alternative approach, a gradient-based biobjective optimization algorithm.

4. Gradient-Based Biobjective Shape Optimization: Probability of Failure versus Cost.

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Shape optimization problems usually involve several conflicting optimization criteria like, for example, cost, reliability and efficiency of the shape. In most engineering applications, these optimization criteria are incorporated in one single-objective optimization problem by either using weighted sums scalarizations or by introducing constraints on, for example, the maximum allowable cost or weight of a component. In this study, we suggest a truly multiobjective optimization approach to shape optimization using the two optimization criteria reliability and cost, and present a numerical method to approximate the Pareto critical set for realistic test cases. Since the necessary discretization induces a high computational cost, we suggest to apply derivative-based methods and adapt a multiobjective descent algorithm introduced by Fliege and Svaiter in 2000. While this method was originally developed to compute one Pareto critical point, we suggest a combined scaling and reference point approach to obtain several meaningful solution alternatives that approximate a Pareto critical front. Besides the identification of an efficient multiobjective optimization tool, this involves the derivation of differentiable objective functions representing the reliability and the cost of a component. While sensitivities for cost and fluid dynamic objective functions have been used for a long time, this is not the case for objectives related to reliability since peak stress is not a differentiable function of the shape. This changes, if deterministic reliability criteria are replaced by a probabilistic criterion, namely the probability of failure (PoF), which has been introduced recently to the field of ceramic design and low cycle fatigue. Here we present a finite element based first discretize, then adjoin approach for the calculation of shape gradients (sensitivities) with regard to the PoF of ceramic designs. This is applied to the simultaneous minimization of the PoF and the volume of a 2D ceramic rod in a biobjective shape optimization problem. We show numerical results for two test cases and discuss the validity of the resulting shapes.

TUE-3-F

*Contributed Session: Data, Applications
and MCDM*

Tuesday 13:50-15:30 - Room: Basilica
Cistern

Chair: Seda Yanik

1. Implementation of an Enterprise-Level Open Source APM System and Comparisons with Alternatives Using the MCDM Methods

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Application Performance Monitoring (APM) systems are used for monitoring and management of performance and availability of software applications. APM systems strive to detect and diagnose complex application performance problems to maintain an expected level of service. The objective of this research is to find the best possible open source application or tool with various R&D techniques that can help achieve the goal of creating the most efficient and complete APM system by making comparisons with existing alternatives using the MCDM Methods. By putting together various APM tools, it is aimed to achieve a complete APM solution to address the needs of an organization for monitoring its applications on user-friendly dashboards. We show how we can efficiently combine the several open source tools such as Elastic Stack, Prometheus, Libbeat, Zabbix, and Grafana to implement an APM system. Elastic Stack, Prometheus, Libbeat, Zabbix, and Grafana are important open source tools that can be used to implement an APM (Application Performance Monitoring) system when put together. Built on an open source foundation, the Elastic Stack (formerly ELK Stack) lets you reliably and securely take data from any source, in any format, and search, analyze, and visualize it in real time. Prometheus collects metrics from monitored targets by scraping metrics HTTP endpoints on these targets. Grafana allows you to query, visualize, alert on and understand your metrics no matter where they are stored. Using Grafana or Kibana, you can create, explore, and share dashboards with your

team and foster a data driven culture. The Libbeat library written entirely in Go, offers an API that Beats can use to send data to Elasticsearch, while enabling gathering IIS logs, audit logs and many other properties. Finally, Zabbix provides a solution to gather various types of real-time monitoring data from tens of thousands of servers, virtual machines, and network devices for the purpose of alerting. We designed an APM system based on the above given tools using the publicly available plugins to integrate them. For this we used Prometheus to collect metrics, Elastic Stack to collect logs, Grafana and Kibana to create dashboards, Libbeat to send monitoring data to Elasticsearch, and Zabbix to gather real-time monitoring data from all the system devices. Finally, utilizing the MCDM Methods, we compared the designed APM system with other solutions in the open source world having the same purposes (e.g. OpenAPM).

2. Implementation of Spatial Data Warehouse and Multi-Criteria Decision Making in GIS

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GIS offers advanced functions for acquisition, storage, analysis and display of geographic information. However, their effectiveness for complex spatial analysis is questionable because of their determinism and decision-making rigor. The MCDM methods can make some solutions for a set of problems with various and multiple criteria. When the problem is so complex it is judicious to combine MCDM process with other approaches like Data mining. The OLAP technology which combines both bases multidimensional analysis and the concepts of the Data mining provides powerful tools allowing the highlighting inductions and information not obvious by the traditional tools. However, these OLAP tools become more complex in the presence of the spatial dimension. The integration of OLAP with a GIS is the future solution for geographic and spatial information. A precondition for the

implementation of any analysis or Data mining of spatial data requires the building and structuring of a Spatial Data Warehouse (SDW). This SDW must be readily usable by GIS and by tools proposed by an OLAP system. This work aims to develop MCDM and SDW methods which will be integrated into a GIS according to a "GIS-dominating" approach. The functioning tools of GIS will be operational to exploit the SDW.

3. A Data-Driven Multi-Criteria Optimization Framework for Bus Scheduling in Public Transportation

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As the vast majority of the world's population has started to live in cities, issues such as increased mobility needs, traffic congestion and carbon emissions are becoming important. In addition to all of these, the changing dynamics in the markets push the citizens into the expectation of transportation service in a comfortable and high quality manner. Thus, the companies providing mobility and the researchers are required to produce sustainable transportation solutions considering these issues. To provide efficient planning solutions for the transportation in cities, we deal with the scheduling problem of the buses in the public transportation. In large metropolitan cities, the bus network is very large. Thus, planning of services is difficult due to changing demand throughout the day, traffic congestions and the need to use the scarce resources optimally. In this study, we formulate an integer-programming for the optimization of a bus line. The problem seeks for the solution of optimal frequencies of a specific bus line's various short turn and complete trip alternatives that are used to balance the demand differences between the links of the line. We consider two objectives in our model formulation: (i) minimization of the difference between the provided service capacity and the demand; and (ii) passenger travel time. In order to reduce these two objectives into a single objective, we obtain the meaningful weights for each objective using the Analytical Hierarchy Process (AHP). The first objective,

namely difference between the provided service capacity and the demand, is evaluated in terms of the criteria of operating cost minimization from the operator perspective and comfort from the passenger perspective. The second objective, passenger travel time is evaluated in terms of the criteria of customer satisfaction from the operator perspective and utility from the passenger perspective. Moreover, we use a clustering approach to cluster the time of day based on the demand. Thus, we obtain the cutting hours of the morning peak, off-peak and evening-peak hours and find the optimal frequencies for these different clusters of the time-of-day separately. We present a case study in Istanbul which is one of the largest cities of the world with a population of 15 million. An extensive dataset is obtained from IETT that provides the bus public transportation service in Istanbul. The dataset that we use is related to one of the longest lines of Istanbul with the line number, 500T. The bus line, 500T has almost 70 stops and travels through highly congested links throughout the day. Moreover, the buses are commonly overcrowded. To overcome these problems, we use mathematical programming approach to specify optimal short-turn and complete trips and their frequencies. Using the real-life data, we implement our model and solve it using CPLEX. We specify the weights of the two objectives by AHP using expert opinion. We also present the pareto-optimal solutions.

4. A Data-Driven Optimization Model for the Urban Grocery Distribution Network

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Grocery distribution is commonly multi-layered starting from the farmer to the wholesaler, then to logistics service provider, to the retailer and finally to the end-customer. Thus, an effective and sustainable distribution network design considering the whole chain is quite complex and challenging. With the increasing use of internet and e-tailing, last-mile delivery has also become one of the challenges of grocery distribution. There exist many improvement

areas in the traditional grocery distribution such as reducing the carbon emissions by better routing, changing the transportation modes or eliminating the food spoil during the distribution. In this study, we propose a new urban distribution model for grocery goods particularly by integrating the railway mode in the distribution network and enhancing the last mile delivery via collaboration with the small independent grocery shops dispersed densely around the urban area. We assume that there are candidate grocery points within a given residential area and that the demand of the customers can be divided. The problem is defined as a multi-objective maximal covering hierarchical facility location problem. The hierarchical facility network considered in this problem consists of three levels, that are (i) railway stations, (ii) small grocery stores and (iii) end-customers. It is assumed that the railway is used to replenish the small grocery stores from a grocery warehouse which is close to the starting point of the railway line. The grocery goods are sent to from this warehouse to the specific railway stations to which grocery stores are assigned to and the grocery goods are picked up by the grocery stores. Contrary to the common practice of using trucks for the long-distance distribution process, using rail line as proposed in this study would contribute to cost-effectiveness and the carbon emission reduction even though, the latter is not explicitly added in the mathematical model. The network is also designed by incorporating the small grocery stores in order to maximize the coverage of the end-customers and to minimize the collecting cost of goods from the railway stations. The fulfilment of the end-customer orders is assumed to be either done by the grocery store on foot or by the end-customer and is not considered in the mathematical model. We formulate the problem as a three objective mixed integer programming model. The first objective is to maximize the fulfilment of the demand by ensuring that customers receive the service from the nearest grocery stores with the specified coverage parameter. The second is to minimize the distance between railway stations and grocery stores. The third is to equalize the income of all the grocery stores by determining which grocery store meets the demand of the customers. We propose a data-driven optimization approach for a case

study problem in Istanbul, Turkey. The urban railway to be used is a metro line named as "Marmaray". Marmaray line goes through the urban area from one end to the other and is assumed to be utilized for goods transportation before starting the daily scheduled earliest passenger transportation trip. To analyse the grocery demand in Istanbul with respect to the demographical and distance based variables, we use a credit card transaction data in the category of grocery from a large Turkish bank. Dataset includes the distance between the customer shopping location and the location of the customer base (i.e. either the home and work location) as well as the demographic variables together with the three-month customer grocery spending data. After the data analysis, we incorporate the obtained information from the dataset to the mathematical programming model and solve it using Cplex. We further analyse the effect of the coverage parameters and the number of grocery shops in the network by comparing the results of the numerical studies.

TUE-4-A

Contributed Session: Multiple Criteria Ranking and Sorting Methodology

Tuesday 16:00-17:40 - Room: Galata Tower

Chair: Marko Bohanec

1. A New Method for the Normalization of Multidimensional Data (IZ-Method) for MCDM Problems

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A review and critical analysis of currently methods for the normalization of multidimensional data in problems of multi-criteria decision making is presented. It is shown that within the framework of the existing methods of normalization the problems of scaling and converting scales, the asymmetry of normalized values, the conversion of cost criteria into the benefit criteria are not solved. There are no criteria for the effectiveness of linear and nonlinear normalization methods. The main part of the statements is given using formal mathematical proofs. The focus of the study is on the problems of normalization and the

effect of the method of normalization on the ranking of alternatives for MCDM rank methods. The rank model MCDM has the following form: $Q=f(A, C, DM, 'w', 'nm', 'dm')$, and includes the choice of the set of alternatives (A) and the set of criteria (C), the estimation of the values of the attributes of the alternatives (DM), the evaluation of the weight of the criteria ('w'), the choice of the normalization method ('nm') of the decision matrix, the choice of the metric to calculate the distances in n-dimensional space of criteria ('dm'), the choice of aggregation method (f) of attributes of alternatives. In accordance with the method of aggregating the attributes of alternatives, the assessment score Q of each alternative is formed and ranking is made. For different normalization methods ('nm'), the assessment score of alternatives Q can vary significantly. The difference consists not only in absolute values, but also in relative values, which changes the ranks of alternatives within the framework of the applied aggregation method. The author presents a new method for normalizing the decision matrix (IZ-method) for solving multi-criteria decision-making problems. Normalization of the elements of the decision matrix is performed in such a way that: I. To preserve the proportions of natural and normalized attribute values of alternatives for each criterion – the principle of "vertical" normalization. II. To equalized the largest and smallest values of the attributes of alternatives for all criteria – the principle of "horizontal" normalization. This ensures the equality of the contribution (on average) of each criterion to the assessment score and the absence of priority of individual criteria before assigning weights. IZ-method is a multi-step method. The first step is the normalization of the attributes of alternatives using the Max method. Next, the largest and smallest attribute values of the alternatives are aligned, the sorting of values of alternatives for cost criteria is performed, and then the normalized values are "stretched and compressed" in proportion to the natural values. As a result of such transformations, the normalized values retain the most complete information of the natural values of the attributes of the alternatives. The advantage of the IZ-method: – IZ-method allows scaling operation of natural values of attributes of alternatives based on linear transformations;

- IZ-method excludes the priority of the contributions of individual criteria to the assessment score of the alternative;
- IZ-method solves the problem of the asymmetry of normalized values;
- IZ-method solves the problem of conversion the cost criteria in the benefit criteria;
- using the nonlinear method at the first step of the IZ-algorithm gives better results of proportionality of the attributes of alternatives for each criterion, compared to the procedure of ordinary nonlinear normalization.

The report presents the full algorithm of the IZ-method and a computer program in the MatLab System. Numerous comparative numerical examples are performed for 8 basic normalization methods and 15 aggregating methods for the attributes of alternatives when calculating the assessment score of each alternative.

2. A Review of Using Convex Preference Cones in Multiple Criteria Decision Making

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Multiple Criteria Decision Making (MCDM) is a branch of operations research dealing with optimization problems concerning a number of conflicting objectives and criteria. Based on the orientation of different MCDM problems, several methods have been proposed to fulfill the underlying goals. One of the most well-known methods in the field of MCDM is based on using convex preference cones, originally developed by Korhonen et al (1984). The main assumption in implementing convex cones is that the DM's value function is increasing and quasi-concave, provided that all objectives are in the form of maximization. A simple approach developed by Korhonen et al. (1986) can be implemented for checking that whether there exist a quasi-concave value function consistent with the Decision Maker (DM)'s preferences. Their method is based on a simple a simple linear programming problem

which takes into account all the DM's preferences given in the form of pair-wise comparisons. The underlying theory of the convex cone based models is as follows. Assuming that the DM has presented his/her preferences in the form of pair-wise comparisons, some preference subsets are formed, consisting a subset of alternatives along with a single alternative which is indeed the worst one among those. Then associated with each preference subset, a convex preference cone and a preference polyhedron are defined. Finally, considering each preference subset and for each alternative does not belong to it a simple linear programming problem checks whether this alternative is dominated by the cone or not. In case it is cone-dominated, it is eliminated from further consideration. This simple and straightforward technique has led to several MCDM approaches for different goals, such as finding the most preferred solution, partial and total ranking of alternatives, evolutionary algorithms to find a part of Pareto optimal frontier, etc. In this paper, we provide a review on using convex preference cones in MCDM.

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3. Activity Based Project Risk Assessment Method Development via AHP-Stochastic TOPSISs Hybrid Algorithm

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In project planning, risk assessment method plays vital role. Poorly assessed project risks cause degeneration at project cost, project completion time, and project output quality and project scope. Each project activity risk influence these project success factors. Implementation performance of a project activity triggers or smooths of its successor's activity risks. Because of this; employing robust and detailed risk assessment methods is important to reach those project

goals. In project risk assessment literature, when it is investigated, it is noticed that risk assessment and evaluation methods are only developed at whole project level. Actually, they are not comprehensive enough to evaluate the project risks at activity level. Besides that traditional risk assessment methods such as risk matrix does not able analyse project risk quantitatively. With this motivation, main aim of this study is developing a multi-criteria based decision method which prioritizing project risks at activity level. AHP and TOPSIS method are combined to developed novel method. In this hybrid method, Constructing AHP model is to prioritize work packages with respect to relative importance of project time, project output quality and project cost. Broken down structure of these work packages are used as input for weighted criteria for TOPSIS method. In second layer of this decision method, TOPSIS model is used for prioritizing predetermined activity risks according weighted project work packages success criteria. In the application of this method, a case study approach is followed. In this sense, "Global Furniture Ltd." which is established in Istanbul, Turkey is chosen as a case to apply newly developed model. Results showed that application of AHP-Stochastic TOPSIS Hybrid Algorithm provides a platform that project risks could be analysed as quantitative and also at project activity level.

4. Improving Within-Class Ranking of Decision Rules in Qualitative Multi-Criteria Method DEX

**Marko Bohanec, Jožef Stefan Institute, Slovenia, marko.bohanec@ijs.si*

DEX is a qualitative multi-criteria method, in which all criteria are represented by qualitative (symbolic, verbal) attributes. The attributes are structured into a hierarchy, and the evaluation of alternatives is governed by decision rules, defined by the decision maker. DEX is particularly suitable for "sorting" decision alternatives into distinct preferentially ordered classes. The method DEX is implemented in the software DEXi

(<http://kt.ijs.si/MarkoBohanec/dexi.html>).

In DEX, all alternatives assigned to some class 'C' are mutually indifferent from each other. However, it is often desired to further rank alternatives within classes. This is

possible by employing the principle of dominance, which generally yields a partial ranking. This can be further extended by constructing an additional quantitative (numerical) evaluation model aimed at total ranking. Such model should be constructed automatically using only information that is already contained in the qualitative DEX model, without requesting any further information from the decision maker. The quantitative model has to fulfill several requirements: 1. Consistency of qualitative and quantitative evaluations: For each alternative assigned to class 'C', the corresponding numerical evaluation must lie in the interval $[c - 0.5, c + 0.5]$, where 'c' is the ordinal number of 'C'. The values $c + 0.5$ and $c - 0.5$ are interpreted as "ideal" and "anti-ideal" evaluations within 'C', respectively. 2. Compatibility of inputs and outputs: DEX models are hierarchical, therefore evaluations obtained as outputs at model subtrees enter as inputs to the higher levels of the hierarchy. Thus, the quantitative scales of input and output attributes must be compatible and should obey the " $c \pm 0.5$ " principle. 3. Quantitative evaluations must preserve the dominance between alternatives. So far, two such methods have been used in connection with DEX. They interpret decision rules as points in a multi-dimensional space and try to approximate them with some suitable numerical function. An older method, called QQ (Qualitative-Quantitative), constructs per-class hyperplanes, and a more recent method constructs per-class copula functions. Both methods have been successfully used in practice for ranking research projects, commutator motors and subject-predicate-object triplets in exploring literature domains. This work explores the idea to improve within-class discrimination of alternatives by formulating the construction of quantitative evaluation models as an optimization problem. In a nutshell, all decision rules that map an alternative to class 'C', should be distributed within the $[c - 0.5, c + 0.5]$ interval so as to maximize the distances between the dominating-dominated pairs of decision rules while trying to satisfy the above requirements. Following this idea, four new methods have been designed: two based on linear optimization, one on quadratic optimization and one that algorithmically explores the within-class dominance graphs. These methods were

experimentally assessed and compared with QQ on 3322 DEX real-life decision tables. All the new methods significantly outperform QQ in terms of within-class discrimination of decision rules. Among themselves, the new methods give very similar results, with no clear winner. Any of those methods will improve the within-class evaluation of alternatives in future versions of DEX.

TUE-4-B

Contributed Session: Practical Applications of AHP/ANP

Tuesday 16:00-17:40 - Room: Maiden's Tower

Chair: Sarbast Moslem

1. Performance Assessment of Transportation Options

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One of the crucial elements of human needs is energy. Our energy choices and decisions have a substantial impact on natural systems. As population, economic growth, and urbanization increases globally, energy demand increases even at a higher pace. By definition transportation is the movement of humans, animals and goods from one location to another thus intertwined with energy. Within the industries' demanding energy, transport plays a crucial role in exacerbated mobility. Transportation sector that induced by high population and industrialization emits a significant portion of total emissions. By all available modes for not only individual but also collective passenger transportation (subway, suburban train, bus, passenger cars, bicycles, etc.), meeting this steadily increasing travel demand and lowering its impact on the environment has been a hot research topic, as no standard solution has been found. As sustainable mobility planning consists of many dependencies and links among factors influencing the decision-making process, it has a perfect fit to use Multiple Criteria Decision Making (MCDM) methodologies, and this paper presents an assessment of environmental impact preferences of transport.

2. An ANP-based Methodology to Evaluate Energy Strategies in Turkey

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Planning of energy strategies is a complex decision-making process that encompasses a wide variety of interrelated sub-processes and related criteria where the ultimate goal is to meet the variant needs and wants of all stakeholders. Due to energy vulnerability at the global scale, its critical and sensitive nature, countries need to evaluate their energy policies comprehensively, rationally, and accurately. In order to adapt to the ever-changing energy market conditions, governments are in need of constantly re-planning their energy policies, taking into account their short-term and long-term strategic policies. Because of its multi-faceted nature, the determination of the right energy policy is deemed to be a complex yet crucial managerial problem. In this study, we employed an Analytic Network Process (ANP)-based methodology, which is one of the most promising and, as per the recent literature in this and similar application domains, most effective multi-criteria decision-making (MCDM) tools. ANP is capable of addressing the complexities imposed by this decision-making process because of its comprehensive working principle coupled with its network structure that can take into account the interaction from various elements at different levels. Since ANP can capture multi-dimensional relationships between alternatives and criteria, it helps in producing objective and comprehensive results. In this study, all factors and subfactors are determined according to the Strategic Plan of the Ministry of Energy and Natural Resources and evaluated using the Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis under the general theme of strengths/weakness and opportunities/threats of the energy market. In this context, four main criteria (i.e., themes), 24 sub-criteria, and nine alternatives are defined. The weights are

calculated and energy strategy priorities—to reveal the importance levels from high to low—are determined using the ANP-based MCDM methodology.

3. Ranking of Seismic Retrofit Strategies for Industrial Buildings: A Hierarchical Approach

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Recent destructive earthquakes in Northern and Central Italy resulted in considerable damages to real estate with respect to residential and industrial buildings and historic centers. Earthquakes occurred in May 2012 in Emilia-Romagna caused extent and serious damages to the economy of this area, due to the collapse of a large number of reinforced concrete (RC) precast industrial buildings, characterized by high seismic vulnerability. The estimated direct and indirect economic costs were about 1 and 5 billion Euros, respectively. In this context, the management of post-earthquake recovery operations and the adoption of preventive seismic risk mitigation strategies is of paramount importance. Effective strategies require the stabilization of severely damaged buildings and the preventive improvement of constructions structural response to seismic actions. Although the operation of emergency inspections are meant to classify buildings on the basis of building residual seismic capacity, decisions on prioritization of interventions depend on different criteria related to both buildings structural characteristics, materials and geometrical properties, and to peculiarities of manufacturing and production of goods and services made. In this paper, we investigate different seismic retrofit strategies and we propose an AHP model for multi-criteria prioritization of post-earthquake intervention on industrial buildings, damaged by earthquakes occurred in North-Central Italy in the last decade. We take into account multiple criteria grouped into technical (e.g., vulnerability, compatibility, reversibility), economic (e.g., construction costs, costs due to production downtime and disruption of

occupancy) and social (e.g., social reputation, workers' wellbeing) criteria.

4. Enumerating the Difference of Preferences Between an Emerging and Developed City Related to Public Transport by Using the Analytic Hierarchal Process

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Public transport improvement has always been a crucial issue to decision makers as well as to transport experts, especially in emerging and developed cities. The aim of this study is to evaluate public transport demand between an emerging city “Mersin” and a developed city “Budapest”. As a methodology, the analytic hierarchy process approach has been proposed to rate the most critical public transportation supply quality criteria from transportation experts point of view, the data has been collected by applying pairwise comparison questionnaire survey. AHP based on the dynamic analysis and sensitivity analysis gives the decision maker the confidence of the consistency and the robustness. Rating the criteria in the hierarchical structure is comprehensive, flexible and shows a great potential for supporting decision-makers with the transportation decision-making process. The two different groups showed the different views of development between decision makers and the public; this might be due to many factors like costs and political situation in the area that make public bus transportation development plans logical. The paper provides recommendations to enhance the operation for the general public transport system.

TUE-4-C

Contributed Session: Interactive Multiobjective Optimization

Tuesday 16:00-17:40 - Room: Dolmabahçe Palace

Chair: Kaisa Miettinen

1. Interactive Procedure for Multiobjective Dynamic Programming with the Mixed Ordered Structure

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Multiobjective, multistage decision problems are usually investigated as models of multiobjective dynamic programming, using the vector version of Bellman's principle of optimality non-dominated evaluations (in the criteria space) and efficient solutions (in the decision space). Deterministic, stochastic and fuzzy models are examples or this approach. Another method of generalization of single-criterion dynamic programming consists in regarding the evaluations as elements of a partially ordered space. A problem that appears in many decision models is that of the simultaneous occurrence of deterministic, stochastic, and fuzzy values in the set of multidimensional evaluations. A question arises: Can such mixed evaluations be used in optimal control of a multiobjective decision process according to a homogeneous scheme in ordered structures? The paper presents a multiobjective dynamic programming problem with the values of the criteria function in ordered structures. The first problem is a model with deterministic values; the second, one with triangular fuzzy numbers; and the third, one with discrete random variables with the k -th absolute moment finite. The fourth model is a product of the three models listed above. The aim of the paper is to present an interactive procedure which uses trade-offs and which allows to determine the final solution in the mixed ordered structure. The ordered structures and the proposed procedure are illustrated by numerical examples.

2. Focused NAUTILUS - An Interactive Method Parallelizing the Human and the Machine

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Many multiobjective optimization methods are interactive by nature. The solution process is divided into iterations, where in each iteration the DM provides some preference information to the method, then the method derives Pareto optimal solutions corresponding to these preferences and provides to the DM new information about the Pareto optimal set. Interactive methods have many applications in business and industry. One of their benefits is the efficient utilization of computational resources, since the method derives in each iteration only those Pareto optimal solutions, which correspond to the preference information. Solving real-life problems can involve heavy computations or simulations. Even deriving one Pareto optimal solution may result in an unacceptably long waiting time for the DM. One approach to overcoming this issue is using an approximate, finite representation of the Pareto optimal set constructed by means of a population-based heuristic algorithm prior to the interactive solution process. Then, in each iteration, instead of solving the original problem, the method selects an element from the representation best corresponding to DM's preferences. This approach allows eliminating waiting times at the expense of reducing the quality of information presented to the DM in each iteration. In the case of computationally complex problems, the quality of the Pareto optimal set representation may be unacceptable due to limited preparation time and available resources. In order to overcome this issue, we propose to hybridize an interactive method with a population-based heuristic in an intelligent way. Namely, after constructing the initial representation of the Pareto optimal set, the heuristic algorithm continues running in the background in parallel with the interactive solution process. The algorithm constantly improves the quality of representation

utilizing the additional running time. Moreover, the algorithm focuses on those areas of the objective space, which are currently interesting for the DM. The smaller are the areas, the higher is the quality of representation which can be achieved in them given the same resources. Our new hybrid method is called focused NAUTILUS (F-NAUTILUS). It is based on E-NAUTILUS, the method is designed to work with finite representations of the Pareto optimal set using the generic NAUTILUS concept. It starts from the worst possible objective vector and in each iteration, improves all the objective values, thus moving towards the Pareto optimal objective vectors. The direction of improvement is set by the DM via selecting one among several objective vectors provided by the method, which are calculated using elements of the representation. Then the method provides to the DM information about the achievable region (a box) in the objective space containing solutions in the representation dominating the selected objective vector. In the following iteration, only solutions from this box are used for selecting the direction of improvement. F-NAUTILUS utilizes the same idea but in addition to that, interacts with the heuristic algorithm running in parallel, by using intelligent agents. The closer is the current objective vector to the Pareto optimal points, the smaller is the achievable region. By setting the focus of the population-based heuristic to this box, the method increases the accuracy and density of the representation manifold. The quality of the Pareto optimal set representation significantly improves towards the end of the solution process seamlessly for the DM. We present the hybridization scheme in detail as well as an implementation of F-NAUTILUS combined with a multiobjective evolutionary algorithm, and show the results of experiments demonstrating the advantage of our method over E-NAUTILUS. This research is a part of developing an open source software framework DESDEO (desdeo.it.jyu.fi) for interactive multiobjective optimization methods.

3. Surrogate Assisted Interactive Multiobjective Optimization in Building Energy System Design

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Managers of larger buildings are confronted with complex investment decisions concerning possible extensions of the energy system, like photo voltaics, stationary batteries or heat storage. They have to consider a multitude of objectives, for example, investment and annual operation costs, CO₂ emissions and module lifetime. A computer-assisted optimization and decision making process promises substantial benefits in this complex problem. In this research, we provide decision support in building energy system management by applying interactive multiobjective optimization methods. We consider five objectives (initial investment cost, running cost, CO₂ emissions, resilience to power outages and battery lifetime) for a system upgrade with both hardware additions and modifications of system controllers. We use a building simulation software based on the Modelica standard to simulate energy flows in a facility with different investment options. For optimization, we apply evolutionary algorithms since, in the past, different evolutionary algorithms have been successfully tested to find viable investment plans for the problem considered. A major drawback of evolutionary algorithms is the long computing times (days to weeks) of a single optimization run, which stretches the patience of (high-level) decision makers (DMs) to the limit. In order to speed up the computation, we apply surrogate models. In particular, we focus on Kriging as surrogate models (also known as Gaussian processes) due to their ability to provide uncertainty information about the surrogates. With five

conflicting objectives, it is not easy to get a good representation of Pareto optimal solutions and, hence, we focus on applying interactive methods, which have not been applied to this problem before. The benefits of interactive approaches are threefold. First, the computation time is reduced because the algorithm will focus on those Pareto optimal solutions that reflect the preference information of the DM, not all Pareto optimal solutions. Second, the DM can direct the solution process to focus on those solutions that are interesting and does not need to spend time with uninteresting solutions. Finally, and most importantly, thanks to the iterative nature of the methods, the DM can learn about the nature of the problem and trade-offs involved as well as the feasibility of one's preferences. This will increase the confidence of the DM in the results of the optimization process and increase the chances of actually realizing the final solution identified. We demonstrate how the problem considered can be solved with an interactive multiobjective optimization method and discuss the findings. To be more specific, we apply variants of the reference vector guided evolutionary algorithm (RVEA), incorporate surrogates in the consideration, introduce a new surrogate-assisted interactive method and apply it in the building energy system design problem. Finally, we compare the quality of the solutions obtained to those of a non-interactive approach.

4. How to Compare Interactive Multiobjective Optimization Methods?

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Interactive methods have proven to be viable approaches to solve many kinds of multiobjective optimization problems. This is because they enable the decision maker to learn about the trade-offs involved, what kind of solutions are available and how feasible the preferences are. Furthermore, they can enhance computational efficiency since only such Pareto optimal solutions need to be

generated that reflect the preferences of the decision maker. Many interactive methods have been proposed in the literature and they differ from each other, for example, in the way the decision maker expresses preference information, how information is exchanged between the decision maker and the method, what kind of subproblems are formulated to get solutions based on the preference information available and what is the stopping criterion. We often say that we can stop the interactive solution process when the decision maker is satisfied and confident with the final solution but what does this mean? Besides, comparing interactive methods is not simple because the decision maker plays an important role and learns during the solution process. Thus, the order in which different methods are applied affects the results. To compensate this, one would need a large number of decision makers to use the methods in different orders. However, the decision maker must have appropriate domain expertise and be somehow responsible for the final solutions. In most real problems, it is not possible to have such a large number of decision makers. Naturally, students can act as decision makers but only if the problems to be solved have been formulated so that the students genuinely feel the responsibility for the final solution. If we consider non ad hoc methods, we can in principle replace the decision maker by a utility or value function in the comparison. However, this does not necessarily represent all properties relevant to human behaviour like anchoring, cognitive biases or the need to change the preferences thanks to learning. On the other hand, ad hoc methods cannot be compared even if a utility or value function was available. To avoid the need of having large numbers of decision makers, artificial or machine decision makers have been introduced recently for comparing interactive methods. However, they do not yet capture all relevant elements and we need to develop new performance metrics to be applied with them. In this research, we discuss how to quantify the performance of interactive methods. We consider learning and decision phases of interactive solution processes separately, since they have different objectives. In the learning phase, the decision maker should explore and then find a region of interest, and in the decision phase converge fast in the region of interest

identified. A fundamental question is how to characterize desirable features of interactive methods and solution processes. Once we have formulated this, we can formulate indicators to measure the performance and can use them in comparing methods. Aspects to be considered include how well are the preferences reflected in the solutions generated, how many iterations with the decision maker are needed, can we guarantee Pareto optimality, ability to consider different parts of the Pareto optimal set, confidence in the final solution, insight gained during the solution process etc. This research is a part of developing an open source software framework DESDEO (desdeo.it.jyu.fi) for interactive multiobjective optimization methods.

TUE-4-D

Tutorial: MOLP vs. DEA - Relatives or Friends

Tuesday 16:00-17:40 - Room: Topkapı Palace

Chair: Özgür Kabak

MOLP vs. DEA - Relatives or Friends

**Pekka Korhonen, Aalto University, Finland, pekka.korhonen@aalto.fi*

Abraham Charnes and William Cooper have had a significant impact on the development of Multiple Objective Linear Programming (MOLP) and Data Envelopment Analysis (DEA). The work of Cooper and Charnes on goal programming in the late 1950s can be regarded as pioneers of the MOLP-research area. Charnes et al.'s Management Science article from 1955 constituted the first goal programming model. The name "goal programming" was first introduced in Charnes and Cooper's book: Management Models and Industrial Applications of Linear Programming, in 1961. It was many years a dominating way to solve Multiple Objective Linear Programming (MOLP) problems. On the other hand, Charnes and Cooper are also the founders of the Data Envelopment Analysis. Together with Rhodes, they published the first article on Data Envelopment Analysis (DEA) in the European Journal of Operational Research 1978. DEA is characterized as a method for evaluating the relative efficiency of Decision Making Units (DMUs) performing essentially the

same task. It has become very popular in practice and it is a hot research topic as well. Although Charnes and Cooper have played a significant role in the development of DEA and MOLP, researchers in these two camps have generally not paid much attention to research performed in the other camp. Neither Charnes nor Cooper attempted to tie the two fields together. Even Cooper has said that MOLP and DEA are fully different analyses. Despite many apparent similarities, DEA and MOLP (MCDM) research has developed separately. It is a pity, because —despite differences in terminology—DEA and MOLP address similar problems and are structurally very close to each other. In both models, technically speaking, the purpose is to identify efficient points in a certain space and suggest projections of inefficient points on the basis of such information. DEA and MOLP should not be seen as substitutes, but rather as complements. In this tutorial, we show that the areas DEA and MOLP can cross-fertilize each other.

TUE-4-E

Contributed Session: Advanced Optimization Techniques and Multiple Objectives

Tuesday 16:00-17:40 - Room: Hagia Sophia

Chair: Ignacy Kaliszewski

1. Different Types of Solutions in Multiobjective Bilevel Programming: From Optimistic to Pessimistic Perspectives

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Bilevel optimization problems model hierarchical non-cooperative decision processes in which the upper level decision maker (the leader) and the lower level decision maker (the follower) control different sets of variables and have their own objective functions subject to interdependent constraints. The lower level problem is embedded in the constraints of the upper level problem. Decisions are made sequentially, as the leader makes his decisions first by selecting values for his variables. The follower then reacts by

optimizing his objective function(s) on the feasible choices restricted by the leader's decisions. Thus, the leader needs to consider the follower's reaction to the setting of his variables since this influences feasibility and the leader's objective function(s) value(s). Sequential decision-making processes that can be modeled by bilevel optimization problems arise in many aspects of resource planning, management and policy-making, namely the design of pricing policies. A multiobjective bilevel problem (MOBP) may have multiple objective functions at one or both levels. A special case of MOBP is the semivectorial bilevel problem (SVBP), in which there is a single objective function at the upper level and multiple objectives at the lower level. The existence of multiple objective functions at the lower level problem adds further challenges and difficulties to a bilevel problem because the leader has to deal with the uncertainty related to the follower's reaction. For each leader's decision, the follower has a set of efficient solutions. If the leader has no (or has little) knowledge about the follower's preferences, it may be very difficult for him to anticipate the follower's choice among his efficient set. Thus, the leader can adopt a more optimistic or more pessimistic attitude taking into account his anticipation of the follower's decision, which can be more or less favorable to the leader's interests. An optimistic attitude assumes that the follower's choice (among his efficient set restricted by the leader) is the "best" for the leader, while a pessimistic perspective assumes that the follower's choice is the "worst" for the leader. In SVBP the best (worst) solution for the leader is the one that presents the best (worst) value for the upper level objective function. In MOBP with multiple objective functions at both levels, the concept of pessimism has not been clearly defined in the literature. Actually, the works reported in the scientific literature devoted to SVBP and MOBP have mainly addressed the optimistic approach. However, it is seldom realistic to consider that the follower is indifferent to all efficient solutions resulting from a given leader's decision or that the follower chooses according to the leader's objectives. The combination of different leader's attitudes and follower's responses results in different types of solutions that should be exploited to provide useful information to the leader

about possible outcomes. For this purpose, new concepts of solutions are proposed to the SVBP and to the MOBP. Extreme solutions (optimistic, deceiving, pessimistic and rewarding solutions) and a moderate solution, resulting from the risk the leader is willing to accept, are defined for SVBP. Optimistic and pessimistic Pareto fronts are defined for MOBP. These novel concepts will be graphically illustrated emphasizing possible pitfalls associated with the computation of those solutions.

2. Geometry of the Domination Space of a Non-Convex Multicriteria Problem

**Andrzej Skulimowski, AGH University of Science and Technology, Poland, ams@agh.edu.pl*

By a dominating point in the multicriteria optimization problem $(F:U \rightarrow E) \rightarrow \min(Q)$, where Q is a closed, convex, and pointed cone in the criteria space E , we will mean any point x in E such that $x+Q$ intersects the set $FP(U,Q)$ - the set of nondominated elements in the above problem. The set of dominating points will be denoted $D(U,F,Q)$. While the geometry of $FP(U,Q)$ and of the Pareto set $P(U,Q)$ in U has been studied by many authors, the properties of $D(U,F,Q)$ are far less known and focus on some subsets of $D(U,F,Q)$ only. The best known subset of $D(U,F,Q)$ is the set of totally dominating points $T(U,F,Q)$, by definition x is an element of $TD(U,F,Q)$ iff $FP(U,Q)$ is contained in $x+Q$. When used in distance scalarization or compromise programming, under some well-known conditions imposed on the distance and Q , elements of $TD(U,F,Q)$ serving as reference points guarantee that the distance-minimizing solution is nondominated. The ideal points in E are defined (by most authors) as $(-Q)$ -optimal points of $TD(U,F,Q)$. It is far less known that so-defined ideal points need not be unique. The first part of the paper will be devoted to the presentation of the ideal point properties. We will also define the local ideal points, which constitute another important subclass of $D(U,F,Q)$ for non-convex $F(U)$ and provide the properties. We will also recall the uniqueness conditions for the ideal point and apply it to study the geometry of local ideal points. Furthermore, we provide new properties of generalized ideal points (GIP),

i.e. subsets of E defined as Cartesian products of nondominated sets with respect to a minimal covering of the set of criteria $\{F_1, \dots, F_n\}$, $G = \{G_1, \dots, G_m\}$, with $G_i = \{F_i(1), \dots, F_i(k(i))\}$. $F = (F_1, \dots, F_n)$ refers to the above formulated multicriteria problem, where E is assumed finite-dimensional. A special attention will be paid to the geometry of proper GIPs, i.e. GIPs such that the covering G is disjoint (or, in other terms, G is a partition of the set of criteria). We will provide the connectedness conditions for such GIPs and show visualizations of some characteristic proper GIPs in 4D. Then, in the second part of the paper, we will study the properties of other salient subsets of $D(U, F, Q)$, namely the sets of partly $(PD(U, F, Q) := D(U, F, Q) \setminus TD(U, F, Q))$ and strictly dominating points, $SD(U, F, Q)$. The latter is defined as follows: $SD(U, F, Q)$ is the set of elements x of E such that $(x+Q)$ intersected with $FP(U, Q)$ equals $P(FP(U, Q) \cap (x+Q))$. This set is important because any strictly dominating point yields a nondominated solution of a distance minimization procedure, under similar conditions concerning the distance in E and Q as in case of ideal points. Finally, we provide some properties concerning the mutual situation of GIPs and the strictly dominating points which allow us to derive Q -minimality conditions of distance minimization procedures with respect to proper GIPs. These results may also be applied to provide Pareto optimality conditions for the equilibria of mixed cooperative games, where several disjoint coalitions seek consensus solutions. Another application of GIPs is the detection of redundant criteria in a multicriteria problem, which can be related to the geometric properties of the domination space.

3. Cooperative Multiobjective Optimization with Bounds on Objective Functions

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An optimization problem is numerically not solvable if the optimal solution has not been derived because the budget (time, memory,

money) has run out. If this happens, in general (with exception for special cases for which primal-dual optimization schemes apply) no information is available how close is the best feasible solution derived thus far to the optimal solution. In multiobjective optimization the situation is the same – in general no information is available how close are the nondominated feasible solutions derived thus far to the efficient solution set. In this work, we show how to provide such information in the multiobjective context by exploiting the classic notion of relaxation. To this aim we make use the concept of lower shells and upper shells, developed in our earlier works. We show that a number of optimization problems, stemming from navigating over the Pareto front, can mutually "cooperate" in populating upper shells leading to progressively tightening bounds (lower and upper) on objective functions. No specific assumptions about the problem to be solved are made. We illustrate the proposed approach on multidimensional knapsack problems derived from singleobjective knapsack problems from the Beasley OR Library with sizes up to 30 constraints, 500 variables and 100% dense constraint matrices. We address cases when a top-class commercial mixed-integer linear solver fails to provide Pareto optimal solutions.

4. An Efficient Procedure Interior Point Method Based on a New Kernel Function for Linear Complementarity Problem

**El Amir Djeflal, University of Batna, Algeria, l.djeflal@univ-batna2.dz*

In this paper, we present an interior point algorithm for solving an optimization problem using the central path method. By an equivalent reformulation of the central path, we obtain a new search direction which targets at a small neighborhood of the central path. For a full-Newton step interior-point algorithm based on this search direction, the complexity bound of the algorithm is the best known for linear complementarity problem. For its numerical tests some strategies are used and indicate that the algorithm is efficient

TUE-4-F

Invited Session: Multiobjective Route Planning

Tuesday 16:00-17:40 - Room: Basilica Cistern

Chair: Diclehan T. Öztürk, Murat Köksalan

1. A Heuristic Approach to Multi-Objective Routing Problem for a Fleet of Unmanned Aerial Vehicles

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In this study, we aim to find routes for multiple Unmanned Aerial Vehicles (UAVs). The UAVs start from a common base, visit a number of targets and return to the base in a two-dimensional terrain. Each UAV can travel a limited distance since there is a fuel limit on UAVs. Nowadays, UAVs are used for several missions. At each mission, different objectives and problem structures should be considered. As an example, in military operations like espionage and reconnaissance, exposure of UAVs to enemy threats like radars are considered an important risk factor. Therefore, not only the number of visited targets should be optimized but also the duration of the threat exposure should be considered. In emergency aid operations, the most important objective is arriving at the targets as fast as possible. Especially in these missions, the UAVs should arrive at their final destination in the shortest time. Since in some operations the targets do not have the same importance, priority to the targets should be given. In our approach, we consider the following objectives; minimizing the total distance traveled by the UAVs, minimizing the radar detection threat of the UAVs, and maximizing the total reward collected from the targets visited. We first consider the two-objective version of this problem where we maximize the total reward collected from the targets while minimizing the total distance traveled. In the three-objective version, we additionally minimize

the total radar detection threat of the UAV fleet. In the two-objective version, there is a single efficient trajectory between target pairs. In the three-objective case, there are infinitely many trajectories connecting target pairs, each trajectory having a better distance or radar detection threat value compared to another. For the two-objective version, the aim is to find the visiting order. On the other hand, for the three-objective case, we need to determine both the visiting order of the targets and the trajectories to use between target pairs. For both problems, we aim to find all nondominated solutions. We employ an evolutionary algorithm, a modified version of NSGA-II, to find an approximation of the nondominated frontier. We develop specialized representation, crossover, and mutation operators in NSGA-II to address our problem. Each time a new solution is generated, we enhance it using a heuristic method. We develop a repair operator for solutions that violate the constraints. To handle the infinitely many trajectory options between target pairs, we develop some simplifications for the terrain representation. We also consider utilizing the preferences of the decision maker in the search process by modifying the crowding distance measure in NSGA-II with preference values of solutions.

2. Interactive Algorithms for Biobjective UAV Route Planning Problem in Continuous Terrain

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We study the unmanned air vehicle (UAV) route planning problem in the continuous terrain, where the UAV is allowed to move to any point in the terrain. We minimize the total distance traveled and the total radar detection threat. Two objectives and movement in continuous terrain leads to infinitely many trajectory options between target pairs. The overall problem has a continuous nondominated frontier. We develop interactive algorithms that find the

most preferred solutions of a decision maker (DM) for the cases of linear and quasiconvex underlying preference functions. In the underlying linear preference function case, we search for supported efficient solutions. The idea of the algorithm is to ask for pairwise comparisons and to update the weight space based on the DM's responses. We start with two weights that divide the weight range into three equal-length intervals and find the corresponding tours. We update the weight range based on the DM's choice between the tours and continue in a similar fashion. At the end, we present the solution corresponding to the weight that divides the final weight range into two equal-length intervals as the final solution. In the quasiconvex case, we conduct our search in two stages. In the first stage, we define weights dividing the initial weight range into $n-1$ equal length intervals and find the corresponding supported efficient solutions. Similar to the linear case, we ask for pairwise comparisons from the DM and we reduce the search region in the objective space into rectangular regions around at most three supported nondominated solutions. In the second stage, we search inside these rectangular regions. We use mathematical models that exclude the inferior regions to obtain new candidate nondominated solutions. We terminate both algorithms when the DM finds the two presented nondominated solutions too close to choose one of them. We demonstrate both approaches on different UAV route planning problems with 5 and 9 targets. The results show fast convergence to the preferred regions in few pairwise comparisons.

3. A Preference-based Multi-Objective Evolutionary Algorithm to Bi and Three-Objective UAV Route Planning Problems in Continuous Space

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We address a military-type UAV route planning problem where targets and radars

are located in a continuous terrain. A UAV starts its movement from a base, visits all targets and returns to the initial point. The terrain is monitored by radars. The aim in this problem is to determine both the visiting order of the targets and the specific trajectories to be used between consecutive target pairs under multiple objectives. We considered the bi-objective and the three-objective versions of the problem. In the bi-objective version, we minimize both the distance traveled and the radar detection threat. We included maximization of "satisfaction" as the third objective for the three-objective version. This objective indicates the satisfaction degree of a decision maker (DM) with the quality of information collected (e.g., visual images) from a target when it is visited. The quality of information collected from a target varies during a 24-hour time period depending on the weather and light conditions. Such a structure is referred as soft time windows in the literature. The continuous terrain where there are infinitely many trajectory options for each visiting order to the targets and conflicting objectives lead to infinitely many Pareto-optimal solutions. Generating all those solutions is neither computationally practical nor meaningful. We develop a preference-based multi-objective evolutionary algorithm (MOEA) that converge to the preferred regions of the Pareto-optimal frontier. Preferences of a DM are elicited through reference points in the objective space and the algorithm converges to regions of the Pareto-optimal frontier close to the reference point(s). Reference point-based MOEAs typically depend on the initial preferences of the DM, and are sensitive to the properties of the reference point (nondominated or dominated) and the structure of the Pareto-optimal frontier (continuous or discontinuous). Our algorithm provides flexibility in terms of reference point definition. The performance of the algorithm is robust to the type of the reference point and the structure of the Pareto-optimal frontier. Multiple reference points may be defined simultaneously and the algorithm finds close solutions to each reference point. The DM can also change his/her reference point during the algorithm and continue the search in different regions. Developed archive mechanism implicitly stores a representative set of nondominated solutions found throughout the algorithm.

This set can be presented to DM whenever he/she wishes. The information on the spread of the Pareto-optimal points provides insights to the DM for exploring different regions by changing the reference points. In addition to the preferred solutions of the DM, the algorithm is also able to present a set of solutions representing the whole Pareto-optimal frontier at the end. Addressing the UAV route planning in a continuous terrain also required the development of new mechanisms for solution representation and fitness assignment. To the best of our knowledge, this is the first study that adapts a preference-based MOEA to a UAV route planning problem with multiple targets in continuous terrain. We tested the algorithm on several hypothetical problems. Results show that our algorithm is able to approximate the true Pareto-optimal solutions independent of the shape of the Pareto-optimal frontier and regardless of whether the reference point is dominated or not. We also develop mechanisms specific to the UAV route planning problem and demonstrate the algorithm on several problems. Results show that our algorithm converges to preferred regions on the Pareto-optimal frontier and adapts to changes in the reference points quickly.

4. Real-Time Biobjective UAV Route Planning in Continuous Terrain

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We consider the route planning problem of an unmanned air vehicle (UAV) in the continuous terrain. In this problem, the UAV starts from a base, visits all targets, and returns to the base. During the mission period of the UAV, the locations of the targets change. We find the best route of a decision maker (DM) whose underlying preference function is linear, considering two objectives; minimizing distance traveled and minimizing radar detection threat. We develop a real-time algorithm that reconstructs the route of the UAV each time the UAV visits a target.

When the UAV is at the base, we solve a traveling salesperson problem to find a route. The problem then reduces to a shortest Hamiltonian path problem when the UAV is at one of the targets. The preparation phase before solving the new problem requires considerable computational effort. To obtain a good solution reducing the computational burden, we develop k-closest heuristic. We demonstrate the heuristic on two UAV route planning problems with 5 and 9 targets. We obtain good results in short durations.

WEDNESDAY

WED-1-A

Contributed Session: Outranking Methods

Wednesday 9:00-10:40 - Room: Galata Tower

Chair: Marc Pirlot

1. Some Considerations about the Legitimacy of Using Flow Scores to Compute PROMETHEE Rankings

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Multicriteria decision aid consists in helping decision makers to compare (rank, choose, sort, etc.) different alternatives which are evaluated on conflicting criteria. These last decades, numerous decision aid methods have been developed. They can be divided in three main different categories: aggregating, outranking and interactive procedures. One family of the well-known outranking procedures are Promethee methods. These work as follows. First, all pairs of alternatives are compared on each criterion leading to unicriterion preference values. These are then aggregated using a weighted sum to build a valued pairwise preference matrix. It is then exploited to assign a positive, a negative and a net flow score to each alternative. These scores are then used in order to get a partial (PROMETHEE I) or complete (PROMETHEE II) ranking. Despite the wide use of these methods in practical cases, there is a great lack of theoretical works about the nature of net flow scores. The aim of this work is to provide some new insights on the possible interpretations of these net flow scores. This will help the decision analyst and the decision maker to decide whether Promethee methods are well suited for the decision problem and the decision context at hand. In addition, we

point out new properties of the net flow scores which tend to legitimize or delegitimize the use of this method. Finally, a better interpretation of these flow scores will allow understanding better how to use the different preferential parameters used in Promethee as well as their influence on its final outcome.

2. Outranking Relation-Based Aggregation and Modelling of Time-Varying Preferences and Data for Multicriteria Decision Making

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A common assumption when addressing a multicriteria decision problem is to suppose that preferences and data is unchanging over time. This can be justified in some decision situations but not in general. Indeed, in several situations, the dynamic and evolving nature of real world is considered to have no effects on the outcomes of the decision-making process. In practice, however, the high equity of decisions and their long-term impacts on population, organizations, etc., impose, to some extent, an explicit incorporation of the dynamic nature of real world into problem formulation, modelling and resolution. Accordingly, we can distinguish two different perceptions of the decision-making environment: (i) a static perception in which the inherent dynamic nature of the decision problem are ignored (or not recognized) because they have no significant effects on the achievement of the decision-making process, or because their handling is expensive and/or complicate, or (ii) a dynamic perception in which the evolutionary nature of the decision environment is

explicitly integrated in the decision making process. Several researchers have been interested in the study of time effect on decision-making and different theories have been developed, including time preference, intergenerational time preference, intertemporal choice, time series analysis, dynamic/real time decision making, sequential decision-making and stochastic decision making. These researchers cover a large spectrum of domains, including economy, banking, finance, health, life saving, insurance, business, environment and climate change. Earliest investigations have been conducted in the economic context where attention is focused on the study of the effect of realisation of outcomes on the consumer preference. These initial works are based on the definition of a set of axioms that contribute to the construction of time-dependent utility functions. The basic concept of these studies is actualisation that postulates that the desirability of outcomes decreases over time. Later works concern the study of consumer behaviour in dynamic economic environment. The effect of time on consequences/preferences is also addressed in the context of intergenerational choice, where decision often needs a compromise between current and future generation. Most of the works in this domain are empirical and show that individuals give more importance to current generation than future ones. This paper addresses the problem of modelling time-varying preferences and data in the context of multicriteria decision making. In dealing with time-varying preferences and data, an important question arises: how can we represent the temporal preference semantics induced by the time dimension and how aggregate them coherently? In conventional preference modelling, we may distinguish three basic aggregation strategies: (i) the use of utility/value functions, (ii) the use of binary relations, or (iii) the use of if-then decision rules. In this paper, we propose a series of approaches to deal with time-varying data and preferences. These approaches are based on extended versions of the outranking relation and adopt different aggregation strategies: (i) criteria-oriented aggregation strategy where we proceed by an aggregation with respect to the time dimension followed by an aggregation with respect to the criteria dimension; (ii) time-oriented aggregation

strategy where we proceed by an aggregation with respect to the criteria dimension followed by an aggregation with respect to the time dimension; and (iii) mixed aggregation strategy where both dimensions are jointly considered. The proposed approaches are illustrated and validated using real world data. Results show that the proposed approaches permit to avoid the problems encountered by functional aggregation of time-varying preferences and data and handle most of temporal semantics.

3. Beyond Multicriteria Ranking Problems: The Case of PROMETHEE

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PROMETHEE is a well-known multicriteria outranking method that has been applied in hundreds of applications. Its success is due to its simplicity and the existence of user friendly software such as Visual PROMETHEE, Smart Picker or D-SIGHT. If it was primarily developed for (complete or partial) ranking purposes, recent extensions have been proposed in sorting and clustering contexts. Among them, the methods called PROMETHEE TRI and PROMETHEE CLUSTER were first presented in 2004. Unfortunately, these approaches suffered from some drawbacks that we highlight in this contribution. To overcome these problems, authors have developed other extensions such as FlowSort, PCLUS, etc. At first, the purpose of this presentation is to provide a summary of these contributions, to highlight their existing links and list several remaining research questions. Then, from a more general perspective, we will show how a ranking method can easily be adapted to be applied in a sorting or in a clustering context. In addition, we will illustrate how sorting methods can be used to compute complete or partial rankings. These concepts will be illustrated in the specific case of PROMETHEE (but are not limited to it). More globally, we will see that the boundaries between the three fundamental problem settings (ranking, choosing and sorting) are blurred. Finally, issues related to rank reversal problems will also be addressed from this new point of view.

4. Assigning Alternatives to the Good or Bad Category based on Several Limit Profiles

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Recently, Fernandez et al. (EJOR 2017) have proposed a method for sorting alternatives into ordered categories based on several criteria. This model known as ELECTRE Tri-nB is a variant of ELECTRE Tri. Instead of using a single limit profile to determine whether an alternative reaches at least a certain quality level, it uses several. In this work, we consider a simplified version of ELECTRE Tri-nB, which lends itself to an axiomatic characterization. Dropping some peculiarities of the underlying model, as originally presented, while keeping its essence permits to shed light on the main features of the model and to analyze its properties. More specifically, we characterize the assignments to ordered categories that can be described by the simplified model. This is done in the spirit of previous work by the present authors, in particular the characterization of outranking relations and the non-compensatory sorting (NCS) model (EJOR 2007). In this talk, we shall: - give a flavor of the axioms used to characterize the model; - analyze the model complexity in terms of the number of profiles needed to separate two ordered categories; - tackle algorithmic issues such as checking whether a given ordered partition can be represented in the model and, eventually, eliciting the model's parameters.

WED-1-B

Special Session: AHP/ANP Applications in Industry 4.0 - sponsored by ÇİMTAŞ

Wednesday 9:00-10:40 - Room: Maiden's Tower

Chair: Nenad Medic

1. Digital Transformation Roadmap in Manufacturing

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Digital technologies aimed at manufacturing processes are proliferating with the transformation of conventional business models. While multinational technology collaborations set the pace of the process, investments made in hardware infrastructure and human resources have become the new foundation for sustainable growth. For companies which determinedly press on with digital transformation in manufacturing, a correct road map and leadership are the keys to success, especially during these times which is the emergence of a new technologic revolution. Çimtaş operates in various sectors ranging from power, oil & gas to aviation. We strive to increase our efficiency and facilitate the lives of all our stakeholders by integrating digital technologies into all our processes. Last year we started our journey of digital transformation by initially evaluating previous success stories in various sectors and choosing our technology partners. We gathered a comprehensive team consisting of people from a wide range of disciplines in order to develop our digital road map and define our priorities. We have undergone a huge technologic transformation, initially about data gathering. In addition by putting the tailor-made MES and Condition Monitoring platforms into effect, which combine digitalization of customer processes and operations we have succeeded to reach out to our entire team. With the initiation of the second phase of our project around 2 months ago, we aim to interpret and convert various data collected from different sources into economic value by prioritizing them via multi-criteria decision-making approach and putting data science into the center of our focus. During this phase, in addition to our current partners we have included a couple of additional start-ups specializing in data science into our ecosystem, all the while increasing our international cooperation working with very valuable companies across the globe.

2. Strategic Comparison of Additive Manufacturing and Robotic Machining with Analytical Hierarchy Process under Different Competition and Production Scenarios

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This study provides a strategic comparison of additive manufacturing and robotic machining within the Industry 4.0 context under various competition and production scenarios. The comparison was carried out using the Analytical Hierarchy Process (AHP). The proposed AHP model helps to determine under what scenarios which production technology leads to a greater competitive advantage. The comparison results could be very helpful for companies that plan to use 3D printers and/or robotics as their production resources, since these resources require huge investments. Although there are studies in the literature comparing either robotic machining alternatives or different 3D technologies, there is no study comparing these two manufacturing technologies. Thus, to the best of our knowledge, this study is the first in this regard. In addition, the study offers an analytic modeling and measurement process to operationalize the contribution of these technologies and allows for a comprehensive comparison. In this respect, the criteria set and the comparison context is also novel. The proposed AHP model includes two main criteria, cost reduction and value creation, that are adopted from strategic management theory. Cost reduction consists of the following sub-criteria: material, labor force, energy, extra tooling and maintenance costs. Design, quality, support, image and delivery are the sub-criteria of value generation. The alternatives compared in the AHP model are robotic machining and additive manufacturing. No comparison was made between cost and value creation or between their sub-criteria by experts. Importance values of the main and sub-criteria was given as scenarios that are called competition scenarios, by the authors. All other

comparisons were made by experts who have experience in production as well as in robotics and 3D printers. Experts made comparisons for four different production scenarios regarding two different production volumes and two different product complexity levels. The study shows that different manufacturing technologies have strategic dominance under different scenario groups. Results of the AHP analysis indicate that additive manufacturing is clearly dominant in scenarios containing low production volume, regardless of how complex the part is, whereas robotic machining shows its dominance in high volume production of parts with simple designs. In the scenarios covering complex design parts and high volume production, there is no clear dominant manufacturing technology.

3. Applying Fuzzy MCDM Method to Select Internet of Things Platform for Iranian Companies

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With the advent of Internet of Things (IoT), many Industries have decided to utilize this technology in order to increase their efficiency and performance over the past years. Various applications of Internet of Things are used in different industries such as agriculture, transportation and health. IoT is made of three layers including sensor, communication network and platform. Sensors are responsible for accumulating data from environment and send it to platform through communication network. Platform is the closest layer to end-user which is responsible for data analysis and delivering services to different industries and users. One of the most important managerial task is selecting an appropriate platform based on the following criteria: "number of supported protocols", "security, maintenance and after sales services", "integration with other IoT platforms", "scalability" and "price" because there are numerous IoT platform vendors and astronomically high primary price of each one make the decision much more difficult. In this research, a multi

criteria decision-making method is applied to solve the problem in order to mitigate the complexity of decision-making. Additionally, due to the subjective proposed criteria, Fuzzy Set Theory and Grey Numbers are utilized for modeling qualitative comments of experts. The research has been conducted for one of Iranian Company called "Faraz" which intended to use one of top-leading IoT platforms to develop their own applications. The ultimate result of this research indicates that the most important criteria in IoT platform selection are "security", "price", "number of supported protocols", "ability of integration with other platforms", "scalability" and "maintenance and after the sales services" respectively and Microsoft platform was selected as the most suitable platform for Iran's Industry among top-leading IoT platform vendors in the world including "Oracle", "Microsoft" and "Amazon".

4. Determining Importance of Production Characteristics Using Fuzzy AHP: Industry 4.0 Perspective

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Industry 4.0 has gained a lot of interest in recent years. Most of the research related to this topic is oriented towards implementation and use of emerging technologies in manufacturing in order to make processes digitized and automated. Indeed, new technologies bring changes in manufacturing environment. However, it was determined by vast number of researchers that there are some prerequisites for appropriate implementation of advanced technologies in production processes. Organisational changes (i.e. use of innovative organisational concepts) have been recognized as an important factor for manufacturers to adopt to emerging trends of production. In constant struggle to maintain their competitiveness on the market, companies are focused on satisfying customers' needs. For this reason, companies engage in custom production

which often involves single units of complex products made according to customers' orders. Concept of Industry 4.0 is considered as an enabler of these trends in production. In order to adopt to these trends in most efficient and profitable way, companies should be able to recognize organisational and technological concepts that contribute the most to this kind of production. Also, this should be done in a way that does not disregard organisational and technological concepts that are not oriented towards aforementioned trends in production, as this is not the only possible way to meet customers' needs. The focus of this research is to develop a set of criteria that could be used for evaluation of organisational and technological concepts based on product and production characteristics. Those characteristics include product development strategy, manufacturing strategy, level of product complexity, and batch size. In this research, they are considered as 4 dimensions of the imposed problem. Subsequently, these dimensions are elaborated in more details in order to encompass all relevant criteria for evaluation of organisational and technological concepts. As a result, 12 criteria are identified, namely: product development according to customers' specification, product development as a standardized basic program into which customer specific options are implemented, product development for a standard program from which customer can select, manufacturing upon receipt of customer's order (i.e. made-to-order), assembly upon receipt of customers' order (i.e. assembly-to-order), manufacturing to stock, simple products, products with medium complexity, complex products, single batch, small batch, and large batch. Furthermore, this research aims to determine the importance of these criteria in the context of Industry 4.0. For this purpose, Analytic Hierarchy Process (AHP) was used. This method is considered as the most appropriate from the perspective of hierarchically structured problem, as it is the case in this research. Also, fuzzy logic was introduced in the evaluation process in order to reduce the vagueness and uncertainty of decision makers' judgment. In this research we used triangular fuzzy numbers, since they are the most utilized in fuzzy multiple attribute decision making studies, due to their computational simplicity and suitability

to the nature of experts' linguistic evaluations. Experts from manufacturing companies were involved in the evaluation process. The results indicate that in the context of Industry 4.0, criteria with highest complexity are considered as the most important. These results show that manufacturers are aware of the fact that new trends in production represent an important factor for achieving sustainability, development, and increased competitiveness of their companies. Results presented in this research are particularly important for strategic orientation of manufacturers. Moreover, these results could be used for further research that involves evaluation and analysis of the use of organisational and technological concepts in manufacturing companies.

WED-1-C

Contributed Session: MCDM for Environmental Decisions

Wednesday 9:00-10:40 - Room:
Dolmabahçe Palace

Chair: Pinar Darende

1. Sustainable E-Waste Recycling from Risk Assessment Perspective with TODIM

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Electronic waste is a growing problem due to shortening product life and increasing rates of consumption and technological development. Therefore, due to environmental concerns, recycling of electronic products is attracting more attention. E-waste contains many different hazardous materials and e-waste recycling activities have risks for human and environmental safety, and businesses. Aim of this study is to focus on sustainable e-waste recycling from risk assessment perspective by considering decision-makers' risk attitudes and irrationality under risk and uncertainty. Although there are different

methods for environmental risk evaluation, none of the methods considers human risk attitudes, and decision-making process of human is generally accepted as rational, such as the utility theory based perspective. Therefore, human decision-making process under risk and irrationality is not usually taken into account, and decisions are considered to depend only on the outcome. However, in real life, decisions are not always rational, and the decision makers can be risk-neutral, risk-averse or a risk-seeker. Therefore, to account for irrationality and risk attitudes of decision makers under risky and uncertain environment, Prospect Theory is proposed in this study, to create sustainable risk assessment. After theoretical explanations, appropriate methodology is needed to evaluate risks of e-waste recycling. For decision making under risk, prospect theory based multi criteria decision-making method (MCDM), TODIM, is recommended in this study. The word TODIM is an Portuguese acronym in for Interactive and Multi Criteria Decision Making. Unlike most of the multi criteria methods, which assume that decision makers seek the maximum global measure value for the corresponding solution, TODIM utilizes global measurement of value calculated by the application of Prospect Theory. TODIM gives the shape the value function similar to gains/losses function of Cumulative Prospect Theory, where gains and losses are always recognized concerning a reference point. Because it represents the limited rationality of the decision maker during the decision-making process, TODIM is a beneficial method for behavioural decision-making. The main approach of the TODIM is to define the relative degree of dominance for each alternative by using prospect theory based utility function. This study involved a numerical example, a computer disassembly problem. Aim of the problem is to find the optimal sequence of the disassembly tasks, which indicate parts of computer. In the numerical example there are 12 risks, which are named as criteria, and they are used to evaluate 9 tasks of computer disassembly processes, which are taken as alternatives. At the end of the implementation, tasks are prioritized by considering risk factors. To sum up, first novel point of, this study categorizes the risks of e-waste recycling as environment, human and business. The second novel point is to propose Prospect

Theory to consider irrationality, and risk attitudes of decision makers within the risky and uncertain nature of e-waste recycling. Related to the second novel point, Prospect Theory based TODIM method is proposed for risk evaluation in e-waste recycling. From the managerial implications point of view, e-waste recycling is an economically promising sector however, inherent potential risks should be considered by organizations in order to achieve sustainability by preventing environmental, human and business losses.

2. Application of Analytical Hierarchy Process for Management of Soil Erosion in Oman

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The level of soil degradation worldwide is alarming due to its potential for causing serious problems even to the extent of threatening food security. Sultanate of Oman also faces soil erosion which disturbs waterways, infrastructure, and agriculture. The problem of soil erosion has become increasingly apparent in Oman due to inappropriate land management, especially in the case of dams where sedimentation is a common issue. Currently, there are no appropriate practices followed to overcome the problem of soil erosion in Oman and no specific studies are available related to the suitable methods for soil protection in Oman. Hence, this study is an initiative to overcome the problem of soil erosion in Oman by proposing the best soil erosion protection method using Analytical Hierarchy Process (AHP). In order to achieve this goal, this study reviews different methods of preventing soil erosion and the factors governing their selection. The important and controlling factors were considered in an AHP model to rank the soil erosion protection methods. In the AHP method, a group of experts was formed to identify/modify the soil erosion protection methods and the criteria influencing their selection. After a thorough literature review, a consultation process was conducted with 15 experts from different sectors; including authorities responsible for

soil conservation in Oman, decision-making governmental departments and research institutes. The expert advisory group was formed based on the related knowledge background and experience in the field of study, which involved specialists from different organizations. The group comprises managers with duties of performance monitoring and measurement responsibilities, experts from operational levels such as engineers and technicians, academic staff, and consultants. The hierarchy is arranged in such a way that it has three levels. The top level consisted of the goals of the current study. The middle level comprised main criteria including the types and characteristics of soil in Oman (rocky and sandy), the climate of Oman (arid/semi-arid climate) and the cost of the soil protection methods. Meanwhile, the bottom level represents alternatives which involves stone gabions, land husbandry, windbreaks, hollows or pits, soil conditioning, field cropping practices, erosion control fences, treating footpaths, protection of the gully head, reshaping donga systems, revetments, compost blanket, masonry walls and brush layering and brush barrier. The results of AHP analysis indicated that the most suitable soil erosion protection method, based on the considered factors, is erosion control fences followed by protection of the gully head and revetment practice. The study also indicated that the AHP model is a suitable guiding framework for decision making because it involves a group of experts for the selection of soil protection methods based on the situation of Oman.

3. Developing Environmental Policy Instruments for Enhancing Females' Concerns based on the DANP-MV Method

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In the past decade, air pollution has become one of the most concerned risks, which has already impacted the life of most human beings from the aspects of environment, health, etc. During the past years, researchers have recognized the gender differences toward air pollution issues. Females are less concerned about the air pollution-related issues. However, females are more influenced by air pollutions. However, very limited works have tried to derive factors influencing females' attitude toward air pollution. Therefore, this research aims to derive the factors influencing females' attitudes toward air pollution. Further, appropriate environmental education policy tools will be defined to enhance female's attitude toward air pollution. A hybrid multi-criteria decision-making (MCDM) model, the DEMATEL Based Analytic Network Process integrated with the Modified Vikor (DANP-MV), is used to derive the influence relationships of factors by the DEMATEL. Then, the weights being associated with the factors will be derived by using the DANP. The Vise Kriterijumska Optimizacija Kompromisno Resenje (VIKOR) will be used to evaluate and select the most appropriate environmental policy tools for crossing the gender gap and enhance females' attitude toward air pollutions. An empirical study based on Taiwan will be used to verify the effectiveness of the proposed MCDM methods. The policy instruments will be defined to raise the level of the most dominant factors which can influence females' attitudes from the current status to the aspired level. These factors, influence relationships as well as policy instruments being defined will be used to inform policy for enhancing females' attitude toward air quality. The proposed policy instruments can be used by the governments.

4. Examination with an Intuitionistic Fuzzy Method by Region of Renewable Energy Investments in Turkey

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The need for energy resources increases rapidly depend on industrial developments, technological developments and population growth. In this context, the energy needs of Turkey especially electricity and heating will eventually increase in the next years since Turkey is one of the developing countries. The countries are enforced to prefer renewable energy resources over time since the decrease in fossil fuel resources and the negative effects of fossil fuels on human health and the environment. In this study, the selection of renewable energy types for seven different regions of Turkey will be discussed with considering the efficiency of the renewable resources of the regions. During the evaluation process; solar, geothermal, wind, biomass and hydroelectricity energy sources are considered with using Intuitionistic Fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method which is intended to determine whether will use of renewable energy in the related region. Investment priorities of selected plants according to the region are determined and sorted by using data, criteria and expert opinions.

WED-1-D

Contributed Session: Evolutionary Algorithms, Preferences and Applications

Wednesday 9:00-10:40 - Room: Topkapı Palace

Chair: Tomohiro Hayashida

1. Maintaining Diversity in Preference based Evolutionary Multiobjective Optimization

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The objectives of multiobjective optimization problems (MOPs) are often conflicting in nature and we have trade-offs among the objectives. Because of this, instead of having a single optimal solution, MOPs have a set of optimal solutions forming a Pareto optimal

set (in the decision space) or a Pareto front (in the objective space). Preference based techniques for solving multiobjective optimization problems have gained popularity over the years, where the preference information of a decision maker (DM) is used to find the most preferred Pareto optimal solution. Interaction during the optimization process allows the DM to gain insight about the problem and the trade-offs associated with it. Focusing on a desired region of interest rather than the entire objective space also significantly reduces the computational (and sometimes economic) cost of optimization. Hence, utilizing the preferences of the DM is preferable to using a posteriori techniques which try to approximate the entire Pareto front. Many decomposition based multiobjective evolutionary algorithms (MOEAs) have been created which find solutions of MOPs by decomposing the problems into single objective or comparatively simpler multiobjective optimization problems. This is usually done by using a set of uniformly distributed reference points or vectors which guide the solution process. Decomposition based EAs have proven to be capable of solving MOPs with up to 10-15 objectives and seem quite promising. One way to incorporate preference information into these algorithms is to redistribute the reference points in a non-uniform manner, in a way that reflects the DM's preferences. However, such techniques lead to a loss of diversity in the population. This is detrimental to the solution process, as MOEAs, which try to replicate the process of evolution via natural selection, require a diverse population to reach optimality. Additionally, drastic changes in the preferences of the DM, which may be expected if the DM is trying to navigate the objective space to learn about the trade-offs, may lead to a loss of the progress made by the MOEA. This happens because there are very few, if any, solutions near the new preferred location in the objective space, as the algorithm was focusing on the previous preferred location. Even smaller changes in the preferences of the DM may impair the progress of the MOEA. In this talk, we introduce new techniques of incorporating DM's preferences into decomposition based MOEAs, which alleviate the aforementioned problems. We compare the results of application of these techniques on well-

known evolutionary algorithms like RVEA and NSGA-III. This research as a part of developing open source framework DESDEO (desdeo.it.jyu.fi), will increase the appeal and applicability of decomposition based MOEAs so that the DM can better control the solution process and gain desired solutions.

2. Exact and Heuristic Methods to Solve a Bi-Objective Problem of Sustainable Cultivation

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In the current context of sustainability and a cultivation practice in agriculture that minimizes the environmental degradation, alternative ways that avoid the intensive use of chemical products in combating pests and the excessive use of the soil has been deeply studied. These measures proposed, if adopted, can stop an environmental crisis on the planet and make agriculture products healthier as well. In this sense, one of the central focuses in the crop production discussed lately is the use of measures that aim sustainable and ecological planning, considering the environmental degradation that has occurred in recent years. For this reason, the planning of agriculture activities, among them the Crop Rotation, has been gaining prominence in the studies aimed at sustainable cultivation, since it is one of the means of cultivation whose practical principles enable ecological and productive agriculture. This practice, once conducted by the rural farmers, brings several benefits since the control of pests, pathogens and weeds are performed biologically. This decrease the action of pesticides, which is harmful to the environment and bring measures of soil recovery, making it always fertile. In this study, a nonlinear (more specifically quadratic) bi-objective 0-1 optimization model is proposed. The aim is to minimize (i) the proliferation of pests among the planted crops and (ii) maximize the profit of the planting schedule in a certain planning horizon, respecting the constraints of non-overlapping planting, non-consecutive planting of varieties of the same family and of the planning time equal in all plots. To determine some Pareto optimal solutions to this problem, we attributed weights to the objective-functions involved, performing a weighted sum of the objectives. The scalar problems obtained with this approach were

solved, initially, by using a quadratic programming solver. In a second moment, a linearization strategy of the original model was applied and we also used integer linear programming in the resulting formulation. Difficulties arising with the algorithms that implement the exact methods were emerged in these two situations, due to the high number of integer variables in this problem and the high computational complexity of the model. This motivated the authors, in a third moment, to propose a genetic algorithm (GA) especially developed to solve the originated scalar problems. This GA contain two constructive heuristics unprecedentedly developed and aim to give an effective performance to the proposed metaheuristic. This study brings the following innovative aspects: 1) Development of a 0-1 objective mathematical programming model for sustainable cultivation; 2) A comparative computational study between the quadratic and linear formulations of the proposed model; 3) Development of a GA and two constructive heuristics to determine some approximations to the optimal Pareto solutions for the problem mentioned. Computational results have shown that GA is efficient, in the sense that it obtains feasible solutions to the problem in a CPU time inferior to the exact methods. In the case in which the exact methods end their running before obtaining the global optimum of the problem, the solutions from the GA proposed are, on average, better. This allows us to assume that the mathematical model, as well as the developed algorithm, are excellent tools in the decision making in this field. The mathematical model proposed, which aims to establish a way of sustainable vegetable production compromised with the profit of the agriculture producer, as well as the solution methods proposed, are applicable in real cases, helping decision-makers in choosing different alternatives of agricultural production on their farms and contributing to the advance of knowledge in the field of Multiobjective Optimization in a sustainable environment.

3. A NSGA-II and NSGA-III Comparison for Solving a Location-Allocation Problem

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Non-dominated sorting genetic algorithm II (NSGA-II) is a very well known and very widely used method for solving multi-objective optimization problems (MOOP). NSGA-II can easily handle constrained MOOPs and also was used for location allocation problems in literature. And more than a decade later, NSGA-III is introduced to researchers in the field and also being very widely used recently. The main difference between these two methods is how they deal with diversity in order to have more wide spread Pareto front solutions for covering wider ranges of alternatives. There are several studies on comparing the performances of these two methods on particular type of problems and within this study these two methods are going to be compared regarding their performances on a multi-objective multi constrained location allocation problem which was first presented as a disaster waste management model in the literature.

4. Interactive Multiobjective Reinforcement Learning for Multi-Step Optimization Problems

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In Robot that autonomously decides action based on surrounding environmental information such as disaster rescue robot and robot cleaner needs to optimize multiple objectives simultaneously, such as moving as fast as possible to the target location, increasing safety, reducing consumption of fuel and batteries, and so forth. However, in multi-criteria decision making, objectives often conflict with each other, and in such cases, there does not exist perfect optimal solutions that simultaneously minimize or maximize all the objectives. Instead of a

perfect optimal solution, a solution concept, called Pareto optimality, is introduced in multi-objective optimization, and many efforts are accumulated to find a set of Pareto optimal solutions (Zitzler and Thiele, 1998). To improve an objective function, one or more other objectives of Pareto optimal solutions are deteriorated. Moreover, when there exist multiple Pareto optimal solutions, a decision maker selects the most preferred solution. However, a complex procedure is required to identify the preference structure of the decision maker (Keeney, 1982). If each Pareto optimal solution is interpreted as a candidate and try to select one solution out of the Pareto optimal solution set, we do not necessarily need to identify the preference structure of the decision maker. Then, we can employ an interactive decision method that derives a so-called preference solution of the decision maker by using the local preference information obtained from an interactive process with the decision maker (Takagi, 2001; Sakawa and Yano, 1988). As a solution method for linear or convex optimization problems, it is possible to apply mathematical solution methods finding an exact optimal solution such as the simplex method, the successive quadratic programming, and the generalized reduced gradient method. However, for non-convex or discontinuous problems, approximation such as evolutionary computation is effective. (Higuchi et al., 2006; Sakanashi et al., 2004). However, it is difficult to apply these evolutionary computation methods to multi-step optimization problems. For multi-step problems, trial-and-error methods using multi-agent systems is effective and reinforcement learning with bootstrap type estimation is often employed (Sutton and Barto, 1989). This paper proposes an interactive multi-objective reinforcement learning method for choosing actions based on the preference of a decision maker. In previous studies, for applying reinforcement learning to a multi-objective optimization problem, after a multi-objective optimization problem is reformulated into a single-objective optimization problem by using a scalarization method with weighting coefficients, single-objective reinforcement learning is employed (Drugan, 2015; Natarajan and Tadepalli, 2005). However, it is difficult to determine the weight of the evaluation for each objective beforehand. Therefore, van Moffaert et al. proposed

hypervolume-based multi-objective Q-learning (HBQL) (van Moffaert et al., 2015) and Pareto Q-learning (PQL) (van Moffaert and Nowe, 2014) to evaluate Pareto optimal solution set with three indices of hypervolume, cardinality, and Pareto relation, and demonstrated effectiveness of these methods. The hypervolume (Bader and Zitzler, 2009) employed in HBQL is an index for evaluating a Pareto optimal solution set which means the size of a region dominated by obtained Pareto optimal solutions and limited by a certain reference point. In this paper, focusing on a property that a value of the hypervolume increases as the number of Pareto optimal solutions is small in the neighborhoods, we propose an interactive method reflecting the preference of the decision maker for multi-objective reinforcement learning in which the hypervolume is used for efficiently finding diverse Pareto optimal solutions, not for selecting the preferred solution from among Pareto optimal solution set.

WED-1-E

Contributed Session: Portfolio Optimization Models

Wednesday 9:00-10:40 - Room: Hagia Sophia

Chair: Michalis Doumpos

1. Portfolio Investments with Mean-Standard Deviation Model and Moving Pareto Fronts

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We study the decision making problem, where an investor looks for a portfolio of given assets aiming at optimizing two conflicting criteria: expected profit and risk of the investment. The criteria are modeled via two objective functions: mean of expected

return and standard deviation of the expected return. The considered problem is the well-known Markowitz portfolio selection problem. We present results of our investigations in the viability of financial investing solutions based on the mean-standard deviation model in the rolling time-window regime. For various investing scenarios representing different investor's risk profiles, we experimentally check, whether one can stable returns by investing consistently over some period of time as the mean-standard deviation model dictates. Most of the research in the modern portfolio theory concerns the static problem, i.e. the case where objective function coefficients are calculated once based on time series in a given time period. However, analyzing the behavior of the Pareto optimal set over time can also be important from the practical point of view. The lack of such analysis may be caused by the deficiency of large, preprocessed sets of data. We try to close this gap by creating such a dataset. We have collected a large set of stock price quotation data over a wide period of time, including most recent quotations. This allowed us to create a large number of instances of mean-standard deviation model rolling time windows over a wide time span. We experimented with the standard version of the model to remain within a scope of the quadratic programming framework, which offers efficient exact methods to derive Pareto optimal portfolios. For each time window, we created mean-standard deviation Pareto fronts and their approximations using, respectively, exact and inexact methods. In this manner, we have built statistics about Pareto front composition and its dynamics over time. In particular, we have shown that a specific heuristic, based on pairwise asset/portfolio combination yields surprisingly good approximations of Pareto fronts with portfolios of low asset cardinalities. Besides that, we have calculated return from investments according to different investor's risk profiles. The research is a stepping stone towards extended mean-standard deviation models accommodating various side constraints. As such constraints break down the quadratic programming framework, approximate Pareto front building methods of verifiable approximation, like the ones we developed, became of importance.

2. Asset Elimination in Linear-Quadratic Problems of Financial Portfolio Management

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The bi-objective mean-variance problem of portfolio selection formulated and solved by Harry Markowitz gave rise to a new direction of research connecting financial investing with multiobjective optimization. The feasible solution set of this problem is a simple, continuous set of n -dimensional vectors representing shares of n given assets in the portfolio. The linear and quadratic objective functions represent mean and variance estimates of the portfolio return, respectively. Several efficient algorithms have been proposed for analytic derivation of the set of Pareto optimal solutions of the original problem. However, the modern practice of finance dictates the need for extending the mean-variance model, bringing to life more complex multiobjective optimization problems. One type of extensions is adding more objective functions describing additional aspects of investment. Another type of extension relates to controlling the number of assets selected for investment. The modern financial markets include many thousands of assets making the problem dimension high. On the other hand, the number of assets to be invested in can be restricted in each particular case due to various reasons, such as limited cognitive capacities of decision makers or limited operational capacities of financial institutions. Under such settings, the decision maker may need to introduce an upper bound on the number of non-zero asset shares or other types of constraints related to selecting individual assets into the portfolio. Introducing such constraints into the model gives rise to mixed-integer formulations posing computational

challenges in the case of large n . In order to address such challenges, we develop techniques for limiting the number of selected assets and controlling the selection process. In addition to several mechanisms of limiting the number of assets known from the literature, we propose two new approaches which are applicable to multiobjective portfolio problems with any combinations of linear and quadratic objectives. One approach relates to introducing a parametric pairwise comparison relation between assets for eliminating ones which are in a way dominated by others. Another approach is a simple iterative heuristic of approximating the Pareto front with a small subset of assets. We propose several strategies of combining different approaches in order to control the number of assets in the portfolio. We present results of computational experiments demonstrating strength and weaknesses of those strategies.

3. On Convex Multiobjective Programs with Application to Portfolio Optimization

**Margaret Wiecek, Clemson University, United States, wmalgor@clemson.edu*

Among multiobjective programs (MOPs) convex problems play a specific role due to their elegant mathematical properties, easier solvability, and relevance to real-life applications. A major class within convex MOPs is made up by multiobjective quadratic programs (MOQPs) that have come as an extension of well-established and useful single objective quadratic programs (QPs). MOQPs have a special structure that is amenable to analytical derivations and algorithmic developments, but more importantly, to mathematical and real-life applications. They model decision making problems in science, business, and engineering such as regression analysis, finance, predictive control, and others. In finance, biobjective portfolio optimization was initiated by Markowitz (1952) who proposed to minimize the predicted variance of portfolio return as a measure of risk and to maximize the expected value of the portfolio return. Since then many researchers have been studying portfolio optimization in a multiobjective setting but in all those studies, the portfolio problems typically include one quadratic function

modeling the risk variance. Qi (2017) is perhaps the first to present an analytical study addressing the multiobjective portfolio optimization problem (MOPOP) with more than one quadratic objective function. This goes along with Boyd et al. (2016) who recognize the need to model different types of risk measures naturally leading to several quadratic functions in the MOPOP model. However, the authors are not aware of any study addressing the computation of the efficient set for MOPOPs with more than one quadratic objective function. Recognizing the importance of convex MOPs, we collect their theoretical properties from the perspective of parametric convex optimization since scalarized MOPs naturally result in parametric single objective programs (par-SOPs). Parametric optimization involves two groups of unknowns: the optimization variables for which the SOP is solved and the parameters that represent unknown problem data. An optimal solution and the optimal objective value to a par-SOP come in the form of functions of the parameters, and the solution to a par-SOP also includes a partition of the parameter space into invariance regions for which a specific optimal solution function and the optimal objective value function are valid. In the context of multiobjective optimization, the obtained optimal solutions to the par-SOP become (weakly) efficient solutions to the MOP and come as functions of the scalarizing parameters, while the partition of the parameter space provides a full range of the (weakly) efficient solutions for a full range of potential values of the scalarizing parameters. We review three well-established scalarization techniques treating them as parametric optimization problems and emphasize their applicability to (strictly) convex MOPs. For a specially structured class of convex MOPs, we propose a modified hybrid scalarization that combines the weighted-sum method with the epsilon-constraint method with the distinction that only some objectives are put into the weighted-sum while the remaining objectives create additional constraints. The modified hybrid problem is useful when the objective functions of the original MOP come in two groups with different real-life meanings. The scalarization allows the decision maker for an independent analysis of tradeoffs among the criteria within each group. Recognizing also the wide applicability of convex MOQPs,

we review four state-of-the-art exact algorithms for computing their efficient solutions and choose one of them that suits our needs best. The two lines of investigation, the modified hybrid scalarization with the accompanying tradeoff analysis and the best solver for MOQPs, are merged to solve the MOPOP with three or more quadratic objective functions, a class of problems that have not been solved before. Numerical examples are included.

4. The Robustness of Multi-Objective Portfolio Optimization Models: An Empirical Comparative Analysis

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The selection of investment portfolios is a major topic in financial decision making, with many portfolio optimization models available in the literature. These models extend the traditional mean-variance framework using a variety of other risk-return measures. Existing comparative studies of such models have adopted a rather restrictive approach focusing solely on the minimum risk portfolio without considering the whole set of efficient portfolios, which are also relevant for investors. This paper, tries to move a step forward, focusing on the performance of the whole efficient set, rather of a single portfolio. To this end, we examine the out-of-sample robustness of efficient portfolios derived by popular optimization models, namely the traditional mean-variance model, mean-absolute deviation, and conditional value at risk. Moreover, several multi-objective formulations are considered, which combine different risk criteria through a weighted Chebyshev scalarization approach. Tests are conducted using data for S&P 500 stocks over the period 2005-2016. The results are analyzed through multiple performance indicators from portfolio and multi-objective optimization theory to assess the risk-adjusted performance of the portfolios and compare the efficient frontiers derived from the models under

consideration. Moreover, we analyze the deviations between historical (estimated) efficient frontiers, actual out-of-sample efficient frontiers, and realized out-of-sample portfolio results. The results provide insights into the effectiveness and performance of multi-objective portfolio optimization models, as well as the synergies derived from combining different risk criteria for portfolio management.

WED-1-F

Contributed Session: Practical Applications of MCDM in an Interconnected World

Wednesday 9:00-10:40 - Room: Basilica Cistern

Chair: Sule Onsel Ekici

1. Evaluation of Potential Fiber Infrastructure Regions for Turk Telekom Company

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Increased use of internet forces internet service companies to provide innovative solutions. In order to meet 'faster internet' demand of customers, Turk Telekom, the first integrated telecommunications operator in Turkey, is planning to expand fiber optic infrastructure in Istanbul, Turkey. The purpose of this study is to evaluate the alternatives and select the best potential fiber infrastructure region in Istanbul. Here, eight region alternatives in Istanbul are evaluated based on four criteria which are cost efficiency, service quality, estimated number of customers and infrastructure convenience. To evaluate and rank the alternatives, as the MCDM method, fuzzy AHP is integrated with fuzzy PROMETHEE. Fuzzy AHP is applied to determine the importance weights of criteria and Fuzzy

PROMETHEE is implemented to rank the region alternatives based on the determined weights. Utilizing the integrated Fuzzy AHP-PROMETHEE approach, the best location alternative is found as Eyup and the complete order from best to worst alternative is determined as Eyup, Umraniye, Basaksehir, Beylikduzu, Sancaktepe, Esenyurt, Kucukcekmece and Arnavutkoy.

2. Analytical Hierarchy Method For Decision Making In Turkey's Telecommunications Sector

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In recent years, one of the sectors that gained the most momentum with the rapid development of technology has been the Telecommunication Sector. Customer preferences are also very important for companies in the telecommunications sector. Companies attach great importance to the opinions of customers and they want to respond to their needs in the fastest way because competition is high, alternative operators are rare and innovation is quickly copied in the sector. One step that can put operators at the forefront of this competitive market is to anticipate the criteria by which customers can give importance to certain characteristics for a telecom operator selection. Hence, with this information operator can direct the customer to the relevant product with a dominant marketing power at the decision stage. The main purpose is to understand how demographic characteristics and specific criteria that affect a customer's choice in an operator selection process. In the first phase of the project, the decision making methods and the criteria affecting the selection of people which are Communication Quality, Price, Extra Benefits, Service Quality, Brand Value and Environmental Impact in the literature were investigated. The result of the study was decided to use Analytical Hierarchy Method. Thus, the main criteria that affect the operator selection of persons and which will be at the bottom of the hierarchical structure of AHP are determined. With the alternative operators in Turkey, namely Turkcell, Turkish Telecom and Vodafone, the

hierarchical structure of the considered aside the AHP, have created. In an AH process, the comparison can be made either by collecting one-to-one customer opinions via the questionnaire or by contacting relevant experts. In order for the study to be fair, it was targeted to meet with two experts Turkcell and Türk Telekom's Marketing department. The interviewers filled the matrices together fairly. The results matrix was obtained by bringing together the matrices filled by the experts and it was revealed to what extent certain groups of professions were influenced by the criteria in the selection of operators. The results of the study showed that the gender and educational status criteria, which were set as a demographic criteria, did not have a distinctive effect on people's choices. Age affects especially the students and non-business owners; gender affects the non-business and public employees. Private Sector is respectively affected by Communication Quality, Extra Benefits, Quality of Service, Brand Value, Price and Environmental Impact. In general, public employees are affected by Communication Quality, Extra Benefits, Quality of Service, Price, Brand Value and Environmental Impact respectively. Self-Employed is respectively influenced by Communication Quality, Service Quality, Extra Benefits, Price, Brand Value and Environmental Impact. Although the general characteristics of these three occupational groups are similar to each other, it has been observed that the value of the brand is high due to the fact that the price criterion is insignificant and the environmental value is high. The fact that the Quality of Service criteria is of high importance in the freelance employee is interpreted as the fact that each problem is based on the importance of the customer's categories and the continuous contact with the customer service. Non-Business people do not have a decent income structure, price for themselves is an important criterion. For the students, it was observed that the price was of high importance due to the problems in the income structure but because of the fact that it was one-to-one adaptation to youth trends (Cinema tickets, innovative DSS services), the most important criterion was Extra Benefits.

3. Prioritization of Public Services for Digitalization

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Digitalization is one of the main focused strategies in organizations with the impact of Industry 4.0 revolution. The expectations and the habits of the customers are rapidly changing as they gain more accessibility to technology in their daily lives. This leads a big transformation on the customer service systems. By the utilization of IoT technologies in service systems, people are getting used to reach information easily. As well as the organizations, public sector should also focus on digital transformation due to this change in the expectations of the citizens. Public services could utilize from digitalization to analyze consumption of resources, decrease wastes and increase efficiency on the service time for different activities. Additionally, digitalization will provide a more detailed and larger data on citizens' changing behaviors and their new expectations from the managers. On the other hand, citizens need to have accessibility to the information they need using IoT tools and if it is possible, get the service online. From that driving point, the main objective of this study is determined as prioritization of the public services to decide which one should be digitalized earlier. To do this, first public services that could be digitalized are listed, and then the alternative tools, applications are discussed to determine alternative technologies, which will be compared in the study. Public services that have high interaction with citizens and have problematic processes are the ones, which could utilize more from the digital transformation. Therefore, health care services, waste disposal department, public transportation, information services, social care services, and citizen complaints resolution centers are selected for initial digitalization. It is believed that the digitalization of these services will decrease the idle times and increase efficiency, by this way, service processes will be improved. For each of the department available platforms, applications are examined and their main

functions are determined. At the same time, the utilities of the digitalization that will be the criteria for the comparison are determined from the literature review. Reduced cost, fast response, ease of accessibility, reduced service times, increase in the available information and increased quality are determined as the criteria. For the determination of the criteria weights and comparison of the alternatives, Analytical Hierarchy Process is used. After determination of weights for these different utilities gained by digitalization, departments and their services are evaluated according to the effects of their digitalization on the utilities. Health care services department is selected first for the digitalization as it has the highest priority from the results. The digitalization of health care services involves online consultation for the controls, online initial diagnosis in emergencies, planning scheduled visits and health consultations, ease of access to the information on the preventive health care and previous data share for agreed citizens.

4. A Decision Support Methodology for Increasing the Efficiency of the Largest Border Crossing between Europe and Turkey

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Turkey is at the crossroads of the new Silk Road connecting China to Europe. This silk road would be redeveloped as the Belt and Road Initiative, one of the most significant infrastructure project of the new era. After the completion of this project, the current heavy traffic flow through Turkey will be extremely heavier due to international trade. This is why, the efficiency of border crossings between Turkey and Europe is of primary importance. Turkish authorities, being aware of this new challenge, made important efforts to improve the efficiency of border crossing operations, especially at Kapıkule Border Crossing operations. Kapıkule Border

Crossing is the busiest land border crossing point in Turkey and also in Europe. This crossing is the second busiest in the world. It has become inadequate to process the increasing number of trucks transporting goods between Europe and Turkey. To address this issue, in a previous study, a detailed process analysis was conducted, a simulation model was developed, and several action plans representing improvement strategies were analyzed and ranked in terms of the daily average number of trucks waiting in the queue to enter and leave the border crossing. However, to increase the efficiency of Kapikule Border Crossing, the selection of the action plans should not be solely based on the average number of trucks but should also be evaluated from a much broader perspective taking into account several objectives that are generally in conflict with each other. Therefore, in this study, we propose a multi-criteria decision support methodology that evaluates these action plans by considering additional attributes; such as investment cost, operations cost, sustainability, border security, and the satisfaction of the beneficiaries, establishing a preference ranking of action plans to improve the capacity of the Border Crossing. Our results have implications for policymakers not only in Turkey but also in the EU. In accordance with the multi-attribute decision-making framework, in this study, three main stages, namely, problem structuring, decision modeling, and decision analysis, are conducted. In the problem structuring stage, we identify the alternatives which are improvement action plans and the attributes which will be used for evaluation. In the decision modeling stage, based on the judgments of the stakeholders, the importance of attributes is revealed. Additionally, we ask the stakeholders to evaluate the performance of alternatives with respect to the attributes identified in the first stage. Finally, in the decision analysis stage, we prioritize the alternatives, using a well-known and widely implemented multi-attribute decision making method: PROMETHEE using the Visual PROMETHEE software. The prioritization of the alternatives is then presented to the authorities

WED-2-P

Plenary Session 3

Wednesday 11:10-12:10 - Room: Mustafa Kemal Amfisi

Chair: Murat Köksalan

New Results for Solving Imperfect-Information Games

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Most real-world settings are imperfect-information games. They present challenges beyond those in perfect-information games. In 2017, our AI Libratus beat top humans in the main benchmark, heads-up no-limit Texas hold'em. In this talk I will discuss some of our more recent work on imperfect-information games. Topics include a unified framework for abstracting games with bounds on solution quality [Kroer & Sandholm, NeurIPS-18], a sound depth-limited search framework [Brown & Sandholm, NeurIPS-18], the fastest equilibrium-finding algorithms [Brown & Sandholm, AAAI-19], deep learning as an alternative to abstraction [Brown & Sandholm, Deep RL Workshop-18], a general framework for online convex optimization for sequential decision processes and extensive-form games [Farina et al., AAAI-19], the first scalable algorithm for trembling-hand equilibrium refinements [Farina et al., NeurIPS-18], and trembling-hand refinement of Stackelberg equilibria [Farina et al., IJCAI-18; Marchesi et al. AAAI-19].

WED-3-P

Doctoral Dissertation Awards

Wednesday 13:10-14:25 - Room: Mustafa Kemal Amfisi

Chair: Jose Rui Figueira

1. Output-Sensitive Complexity of Multiobjective Combinatorial Optimization Problems with an Application to the Multiobjective Shortest Path Problem

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In computational complexity of multiobjective combinatorial optimization (MOCO) problems, it is long known that even the easiest problems in terms of single objective optimization do not admit a polynomial time algorithm in their multiobjective versions, because the number of Pareto-optimal outcome vectors may grow exponentially in the size of the input. Thus, from the standpoint of classical complexity theory, most MOCO problems are indistinguishable. In my thesis, I establish the use of output-sensitive complexity theory--a concept well-known in theoretical computer science--in multiobjective optimization. The basic assumption is that we want to compute the Pareto-optimal outcome vectors and thus accept the fact that the number of outcomes can be exponential in the input size. But we still want an efficient algorithm to be fast if the outcome is small and not too slow if the outcome is large. Hence, we look at the running time as a function of the input and the output size. An algorithm is thus called efficient, if we can bound its running time by a polynomial in the input and the output size. An efficient algorithm in this regard is also called output-sensitive. To justify this new complexity theory, I give easy and hard examples of multiobjective combinatorial optimization problems: I prove that the multiobjective global minimum cut problem is an easy problem in this regard, as well as--under mild assumptions--multiobjective linear programming (MOLP) and finding extreme nondominated points of MOCO problems. I investigate the latter approach in an experimental study and show that the use of a theoretical analysis framework can lead us to selecting and improving algorithms that are also very usable in practice. This also solves a central open question in multiobjective combinatorial optimization, since a (practically) efficient computation of the extreme nondominated points was only known for the case of two and three objectives. To further justify output-sensitive complexity, I also provide non-trivial hard examples: I develop a methodology adopted from the theory of output-sensitive complexity and apply it to multiobjective optimization. I prove that the general multiobjective single pair shortest path (MOSP) problem is hard in this regard and cannot be solved in an output-sensitive way unless $P = NP$. In a second part of my thesis,

I investigate the practical effectiveness of approximation algorithms for the MOSP problem. It is a well-studied problem and practically useful algorithms exist to some extent. Still, if the number of objectives is larger than just a few, exact methods turn out to be prohibitive. There are several known approximation approaches, but they all share one downside: The running time can still be exponential in the number of objectives. Moreover, while the worst-case is well controlled in these algorithms, the best-case usually is not good. Especially in the case of the state-of-the-art algorithm, the worst-case matches the best-case. In contrast, in exact label-setting algorithms, the best-case running-time matches the running time of a simple Dijkstra-Algorithm. So, in my thesis, I design a new approximation algorithm based on labeling algorithms to use the decades of knowledge we have on labeling algorithms. The goal is to construct it in a way so it is usable in practice and still gives the same quality guarantees. While it turns out that its worst-case running-time guarantee is not as good as the state-of-the-art, I conduct extensive computational experiments that show the practicability of my implementation of the new approximation algorithm in contrast to the existing approximations. It turns out, that the approximation algorithms from the literature can only solve very small instances, while my new approximation algorithm is much more usable in practice and is capable of solving real-world instances of meaningful size.

2. Preference Disaggregation: Towards an Integrated Framework

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Preference disaggregation aims at capturing preference models by decomposing indirect preference information. The preference model reflects on the conflicting points of view that collectively form a basis for the judgments. This topic is addressed by several disciplines, including behavioral science (decision analysis), artificial intelligence (preference learning), economics and marketing (choice modeling). These streams, although originated from different philosophies, are converging to a comprehensive understanding of human preferences as the main ingredient of

decisions. This dissertation sheds light on this phenomenon by introducing an integrated analytical framework that allows capturing preferences of a complex form based on preference information of the simplest form. The research contributes to preference disaggregation paradigm in Multiple Criteria Decision Aiding (MCDA) by adding several methodological flexibilities that are built on Linear Programming (LP) techniques. In the first part of my thesis, I introduce a motivating example based on the case of nonmonotonic preferences in the brand color context, addressing how brand color can influence customers perception of a brand. To this aim, an iterative approach based on LP technique is developed and applied to a real data set of major beauty & care brands (published in the Pattern Recognition Letters journal). The next part of the thesis introduces a comprehensive analytical framework for capturing preferences of complex form by processing indirect preference information in form of holistic comparisons. The methodological framework is designed also to be computationally efficient so that can be employed in decision problems with large number of alternatives or numerous evaluation criteria, or even discretized continuous decision problems. The analytical framework is developed based on LP and enables capturing complex preferences by exploiting preference structure, while maintaining the balance between complexity and expressiveness of the constructed preference model. The effectiveness of the methodology is demonstrated through comparison with the benchmark models and a large simulation analysis (published in the European Journal of Operational Research). The third part of the thesis follows an extensive experimental analysis based on simulation to study the impact of decision problem settings and parametrisation procedures on the outcome quality of the preference disaggregation analysis. The study examines existing parametrisation procedures in various problem settings, and discovers conditions under which the existing procedures fail to provide robust and expressive results. Based on these findings, a new supervised parametrisation strategy is introduced, which demonstrates a "good" performance across heterogeneous sets of simulated settings (published in the Computers and Operations Research

journal). The dissertation, as a compendium of publications, takes a constructive view of preferences and contributes to MCDA literature by addressing three fundamental components in three main aspects of preference disaggregation paradigm. First, great potentials of MCDA frameworks for formulating and exploring complex business problems, especially those without sufficient prior knowledge of the context, are demonstrated. Second, an efficient analytical framework for elicitation of preferences and construction of value functions in presence of non-monotonicities is introduced. Third, importance of decision problem settings in preference disaggregation to derive robust recommendations and construct expressive models is studied.

3. Portfolio Selection in Evolutionary Algorithms

**Andreia P. Guerreiro, University of Coimbra, Portugal, apg@dei.uc.pt*

Evolutionary Algorithms (EAs) are algorithms inspired in the process of natural selection, and are among the most popular methods in multiobjective optimization. As objectives are typically conflicting with one another, instead of a single optimal solution, there is usually a set of optimal solutions which, together, form a trade-off surface. The choice of the best solution depends on the preferences of a Decision Maker (DM), which arise from subjective information not contained in the multiobjective optimization problem formulation itself. In the absence of such preference information, an optimization algorithm should be able to cover the optimal tradeoff surface as well as possible, in order to increase the chance that at least one satisfactory solution is presented to the (unknown) DM. One of the main steps of an EA is selection, which is aimed at focusing on the best solutions, but must also maintain a sufficient level of diversity in the population. A very successful selection approach consists in optimizing a measure of the quality of the population as a whole, accounting simultaneously for individual quality and population diversity. Such EAs are called indicator-based EAs, as they rely on set-quality indicators to perform selection. Indicator-based EAs are currently state-of-the-art algorithms in Evolutionary Multiobjective Optimization (EMO). More

recently, the notion of selection in EAs has been linked to the Portfolio Selection Problem (PSP), which is well known in Finance. In this analogy, individuals are seen as assets whose returns are random variables that are characterized by their expected values and covariance matrix. Balancing between good and diverse solutions in a population becomes analogous to balancing expected return and risk, respectively, in financial portfolios. In particular, it has been empirically shown that such a balance in EMO selection can be achieved using the risk-adjusted performance index known as Sharpe ratio, without modification, as a new quality indicator in the context of a particular formulation of random individual return related to the concept of dominated hypervolume. The focus of this work is the subset selection problem at the core of selection in EMO algorithms, but from the more general point of view of Portfolio Selection. Two lines of work are followed. The first one consists in improving those state-of-the-art algorithms that are based on the hypervolume indicator, which is a well known and theoretically supported, but computationally expensive, quality indicator. The second line of work goes beyond subset selection: a new type of indicators based on the Sharpe ratio is studied, both theoretically and experimentally, shedding new light on selection, fitness assignment and preference integration in EMO algorithms.

THURSDAY

THU-1-A

Contributed Session: Multiple Criteria Ranking or Sorting

Thursday 9:00-10:40 - Room: Galata Tower

Chair: Jean Rosenfeld

1. Comparison of Unsupervised Methods to Reduce Multi-Objective Models to Single-Objective Models

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Two main approaches to solve multi-objective optimization problems are (i) generating Pareto efficient solution alternatives and (ii) reducing the multi-objective optimization problem to a single-objective one. The former approach returns alternative solutions, among which the decision maker needs to select one to implement. Therefore, even if this approach is used, the later approach would be utilized in the final selection. On the other hand, in the later approach, a multi-objective optimization problem is reformulated as a single-objective optimization problem, and then the corresponding single-objective model is solved to generate a single solution. Especially for problems with many (more than three) objectives, reduction to single objective is needed even if Pareto efficient solutions are generated because the number of Pareto efficient solutions significantly increases with the number of objectives considered. There are different methods for reducing a multi-objective optimization problem to a single-objective one. For instance, weighting (ranking) different objectives and formulating a single objective function as the weighted sum of the individual objective functions is one such method. However, in most weighting methods, the decision maker's preferences are sought, i.e., such methods are supervised by the decision makers. The single-objective reduction methods can be classified into two categories: supervised

and unsupervised methods. In supervised methods, the decision maker inputs information to the optimization process. This intervention by the decision maker can be problematic in several scenarios. For instance, if the objectives are exogenously imposed by regulatory parties as in the case of safety related issues, the decision maker can be liable for the weights defined when the weighting method is used. Therefore, in such scenarios, reduction to single-objective should be unsupervised to avoid bias towards the decision maker's preferences. There are several unsupervised methods for reducing a multi-objective optimization problem to a single-objective one. In this study, we discuss three unsupervised methods and compare them. Particularly, equal-weighting, min-max-deviation, and distance-to-ideal-point are the three unsupervised methods considered. Under equal-weighting, the objective functions are equally weighted; under the min-max deviation method, the maximum deviation from the individual objectives' optimal values is minimized; and under the distance-to-ideal-point method, the single objective is to minimize the distance to the ideal point (a point which has the optimal objective function values of the individual objectives). We first compare these three methods using a set of randomly generated alternatives with different number of objectives (this comparison is motivated from hazardous materials routing on rail with many safety criteria that are suggested to be considered by federal authorities). After that, our focus is on multi-objective binary knapsack problem. We analyze a set of problem classes (with different sizes and numbers of objectives) and compare these three different methods. Our comparison focuses on robustness of each method as measured by how well each method performs based on the other methods' single-objective function definition.

2. Financial Rating with Ordinal Classification based on the Hierarchical SMAA Choquet Integral Approach

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We consider financial rating proposing a robust ordinal regression and a stochastic ordinal regression model taking into account interaction in a hierarchy of criteria corresponding to financial and economic indicators underlying the rating. Formally we apply Robust Ordinal Regression (ROR) and Stochastic Multiattribute Acceptability Analysis (SMAA) to a sorting model based on the Choquet integral taking into account a hierarchy of criteria. The advantages of our approach are shown by means of an application to financial rating of European Countries. Economic and financial data used in the analysis are provided by Standard & Poor's Global Inc.

3. A Temporal Sorting Multi-Criteria Approach under Stochastic Uncertainty

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In recent years, Quebec government has highlighted the importance of making sustainable decisions that take into account the sustainable development principles. Furthermore, climate change and the associated uncertainties has been added as a major concern in the last few years. Consequently, decisions need to be both sustainable and robust under climate change uncertainties. In this context, the need for new multi-criteria decision-making methods, which are able to take into account immediate and future impacts in a long-term perspective and which model the uncertainty related to climate change vulnerabilities, has emerged. Such methods will support decision-making in all government departments and agencies and in different domains such as water management, electricity generation, spatial planning, healthcare, transportation, manufacturing, energy, forest management, etc. Several questions arise in this context and deserve to be answered. How to evaluate the sustainability of decisions? Can we sort decisions into categories according to their

degree of sustainability achievement while evaluations are uncertain and temporal? Are existing sorting multi-criteria methods could be of used ? This paper aims to answer these questions. It proposes a generalization of SMAA-Tri to temporal context (multi-period evaluation of alternatives). The proposed method will allow the sorting of each decision depending on its temporal and stochastic impacts. The results will assign each decision to a category according to their sustainability level under climate change uncertainties. Temporal evaluations are represented by immediate and future impacts of decisions on a finite horizon. Stochastic uncertainty is modelled with Monte-Carlo simulations as in SMAA Tri (Tervonen et al., 2009). The proposed method consists of two phases i) a multi-criteria aggregation and ii) a multi-period acceptability index aggregation. Multi-criteria aggregation consists of applying SMAA Tri at each period. As a result, acceptability index is computed for each period and for each category. The second phase will consist in an aggregation of the acceptability indices obtained over the multi-period horizon. We will make an analogy considering each category as an alternative, each period as a criterion, and each relative importance of periods as the criteria weights and apply TOPSIS. TOPSIS will provide us with a score for each category representing the closeness to the ideal solution. The ideal solution is a category for which the acceptability index is equal to 1 at each period. This research work demonstrates how the paradigm behind outranking sorting methods and specifically SMAA-Tri, can be generalized to the context of temporal evaluations of decisions. The proposed approach is then applied in sustainable forest management context. The objective of the illustration is to sort each forest management option according to its sustainability achievement and climate change uncertainties. First, we will need to balance several standpoints, such as biodiversity conservation, soil and water conservation, maintenance of forest ecosystem productivity, maintenance of multiple socio-economic benefits and consideration of the population's values and needs. Second, the option is evaluated in the short, medium and long term (150 years which corresponds to forest regeneration period). Third, evaluations and criteria weights will be considered stochastic and

Monte-Carlo simulation will be done in order to provide a robust sorting of the decision.

References: Tervonen T., Figueira J.R., Lahdelma R., Almeida Dias J., Salminen P., (2009) "A stochastic method for robustness analysis in sorting problems", European Journal of Operational Research, vol 192, pp. 236-242.

4. An Alternative to L1 K-Means Algorithm to Obtain Partially Ordered Clustering

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Clustering problems are well known in data mining. Methods, such as k-means or hierarchical algorithms, are widely used in practice. These approaches generally use a distance metric to form groups that are as homogeneous as possible and as heterogeneous as possible between themselves. In our opinion, traditional clustering techniques cannot be directly applied in a multicriteria context. Indeed, since criteria have to be optimized, the comparison between two alternatives usually leads to asymmetric relations (in opposition to the symmetric relation provided by a distance metric). This distinctive feature opens new perspectives for clustering such as the establishment of preferential relations between clusters. Totally ordered multicriteria clustering consists in detecting a partition where a complete and transitive relation exists between each pair of clusters. This means that the first cluster is considered better than the second, which is better than the third one, etc. Several multicriteria clustering models have been developed over the past ten years, including partially ordered multicriteria clustering where some cluster pairs cannot be ordered. In this contribution, we investigate a minimal extension of the well-known k-means algorithm to address multicriteria problems. This will allow us to build partial relations between the clusters. A quality indicator is also adapted from the standard Dunn index

to assess the quality of a partition. This indicator is based on the asymmetric preference relation that we use in the multicriteria k-means extension. Experiments on an artificial dataset, consisting of clusters designed to present a partial order based on two criteria, illustrate the results provided by the proposed method and compare them with the standard k-means ones. We then consider the World Happiness Report 2018 dataset and show that the proposed method gives better results for the quality indicator based on the preference relation, while the standard k-means method is better for the Dunn index. The main objective of this work is to present a common framework to stimulate discussions between experts in data mining and multicriteria decision aid.

THU-1-B

Contributed Session: AHP/ANP Applications in Aviation

Thursday 9:00-10:40 - Room: Maiden's Tower

Chair: Raimo Hämmäläinen

1. Multicriteria Decision Making Based on Sustainability in The Selection of UAV Applications for Smart Cities

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Smart city is defined as an advanced modern city that utilizes information communication technology and other technologies. The smart city applications can improve both quality of life, operational efficacy of urban services and ensuring the resource availability for present and future generations in terms of social, economic, and environmental aspects. The smart city emerged as a solution to address the challenges arise due to exponential growth of urbanization and population and its popularity is increasing day by day. Smart cities can elevating the level of comfort of residents with activity such as optimize resources utilization and enhance operations in health, transportation, energy, and environment. One of smart city technologies is the

unmanned aerial vehicles (UAVs), which can provide many applications for smart cities and create a positive impact on the society. There are various UAV applications such as traffic monitoring and management, security and crowd monitorings, UAV-based infrastructure inspections, health emergency services and UAV taxi. This paper include decision making process for selection of smart applications in smart cities. This decision process is applicated for Istanbul metropolitan municipality and the best selection/ranking is made and ranking of preference are made for the most practicable UAV applications. In this decision making process, we use multicriteria decision making methods namely fuzzy analytic network process (ANP) based on sustainability criteria using fuzzy numbers.

2. Unmanned Aerial Vehicle Selection Using Fuzzy AHP and TOPSIS Methods

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The military usage of unmanned aerial vehicles (UAVs) has risen as a direct need of the armed forces. The UAVs provide ease of operation to the armed forces, particularly in the border regions, providing intelligence, surveillance and reconnaissance (ISR) as well as a strike capability to understand and defeat the threat. The UAVs offer a significant advantage by avoiding operator damage while providing the same and in some cases superior capabilities as a manned aircraft. For example, some UAVs can stay aloft for longer durations than expected on crewed aircraft. UAVs play a vital role in present day operations due to their asset capabilities, low operating costs and their ability to reduce the risk of life of pilots. In this paper, by using fuzzy analytical hierarchy process (FAHP) and the technique for order performance by similarity to ideal solution (TOPSIS) technique we propose a new method for UAV selection problem. The problem of UAV selection is a strategic and significant issue, especially in the military sector. Moreover, selecting the optimal UAV among many alternatives is a multi criteria decision making problem. This paper presents an

evaluation model based on the FAHP and the TOPSIS to help the actors in the military sector for the selection of optimal UAV. In order to illustrate the use of the model for the UAV selection problem, an application is made with UAVs used by the air forces of some countries. In this methodology by utilizing improved AHP by fuzzy set theory, first we try to calculate weight of each criterion. Then by implementing TOPSIS algorithm, assessment of UAVs has been done to obtain final ranking. To determine the most appropriate UAV to help the actors in defense authorities, first, evaluation criteria affecting operator preferences are identified based on a detailed literature review and expert opinions. The authors come up with a set of main criteria that includes maximum payload, operational radius of action, cruise speed, maximum speed, service ceiling, takeoff weight, powerplant, wingspan, endurance, and length. After constructing the hierarchy, the authors ask the operators of UAV pairwise comparison questions to assess the relative priorities of evaluation criteria. UAV operators are taken as the target group of the survey. Twenty UAV operators participate the survey. As a further study, survey results can be generalized by expanding the participant group and interacting with other staff involved in the operation of the UAV system.

3. Application of Analytic Network Process to the Interview Examination in an Air Traffic Control Department

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In the aviation sector, air traffic controllers (ATCOs) and pilots are the staffs who have the high responsibilities in flight operations, and they undertake critical tasks where even a small error may cause serious consequences. ATCOs are responsible for ensuring the safe, regular and rapid flow of aircraft traffic in airspace and at airports. They consistently carry out their duties in co-ordination and co-operation with pilots, technical personnel, management and other supervisors. Pilots provide take off, landing,

descent and other maneuvers of aircraft in accordance with the instructions received from ATCOs. Someone who is not appropriate for this profession is more likely to make mistakes when they are on duty. At this point, the capabilities of the ATCOs become crucial. The selection of ATCOs and the training quality given after selection should be focused so that skilled and qualified people can do this job. Failure to select a suitable candidate is a major obstacle to training a qualified ATCO, no matter how good the quality of the training is. In the study, firstly, the process of admission of candidates to an air traffic control department was examined. In the current process, students should take a series of examinations including mathematics, aptitude, interview and simulation. These examinations, except the interview, are more convenient for measurable and objective evaluation. However, in the interview stage, candidates are subjected to a more qualitative evaluation by an interview committee. A certain number of the candidates listed according to the interview scores are entitled to proceed to the final stage. To improve the evaluation process, we consider this phase as a multicriteria decision making problem with tangible and intangible criteria and propose an Analytic Network Process (ANP) model. ANP is able to determine criteria weights considering dependency and feedbacks among them. Multi-criteria decision-making methods for personnel selection in the air traffic control is a new area, and only few studies are available in the literature. Five main criteria are determined, through a survey, as communication skills, stress control, attention level, job interest and self-reliance. The evaluation of the candidates for each criterion is made using rating method due to large number of alternatives. Finally, the ranking obtained by ANP and rating method is compared with the current system.

4. Team Situational Awareness and Systems Intelligence in Fast Group Decision Making

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In the early decision making literature intuitive and fast decision making was studied under the theme naturalistic decision making but the related questions seem to have been forgotten today. Situational awareness (SA) and team situational awareness also relate to fast decisions and were studied early in connection with pilot decision making. These topics have increasing practical relevance today. In many areas decision making is done in teams and also in a rapidly changing environments with multiple criteria. It is characteristic that there is not time for extensive analyses and model development at the time decisions have to be made. Such areas include, e.g., emergency situations, fire rescue, acute medical operations as well as rapid prototyping in project development. We demonstrate the challenges in rapid team decision making by describing a military example of decision making in air combat by a team of fighter pilots. In these decision situations behavioral issues become most important. The way the team interacts and shares the situational awareness and the mental models of the overall team becomes essential. Originally the literature on SA mainly considered military decision making and the focus was on the related cognitive factors. However, in teams emotions and social dynamics as well as the creation of trust can also be important. It is well known that emotions play a crucial role in decision making. Thus, it is natural to suggest that socio-emotional factors should also be taken into account when evaluating the situational conditions in team decision making. We propose that the concept of Systems Intelligence (SI) can be a way to bring these missing human elements into the generalized definition of SA. SI emphasizes the importance of systems thinking and the attunement among the team members. Our suggestion is that including SI as a topic in the training of the members in the decision making team will help in generating trust and shared SA which again are a prerequisites for good decisions. Rapid decision making relates to intuitive and heuristic processes which reflect System 1 thinking in the dual processing theories of human cognitive behavior. The evaluation processes carried out e.g. in traditional multi-criteria analysis rely on System 2 thinking. So one could say that the challenge in supporting rapid decision

making is to develop procedures which would enable the decision maker to use System 1 processes to intuitively or heuristically generate solutions in different contexts with a multi-criteria perspective. A natural first idea to reach this goal is to train intuition by practicing multi-criteria evaluations beforehand in different situations related to the context at hand. One way of approaching this is to develop prototype practices which is typical, e.g. in fire emergencies. In fighter plane pilot training the practices refer to tactics, techniques and procedures. In these practices the multi-criteria dimensions of the decision remain implicitly embedded in the good practices. There is no time for explicit analysis. In multi-criteria decision making one can practice decision in different situations with generic pre-structured value tree models. This is also applicable for groups. The group can jointly develop the value trees for different situations and practice the approach beforehand. This has already been considered in nuclear emergency preparedness exercises. The current literature on multi-criteria group decision support has, as far as the authors are aware of, not considered rapid decision making nor the concept of shared SA. When the emotional elements are included in SA, the new perspective can help to understand the systemic nature of participatory group decision making in different domains ranging from life threatening situations to value laden contexts such as environmental decisions.

THU-1-C

Contributed Session: Contemporary Approaches in MCDM

Thursday 9:00-10:40 - Room: Dolmabahçe Palace

Chair: Umut Asan

1. Cognitive Biases in MCDM Methods: An Embedded Filter Proposal

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The backbone of the Multi Criteria Decision Making (MCDM) techniques is the specialist assessment. The specialist make pairwise

comparisons between criteria or alternatives. The mainstream research focus on the ambiguity in this process. Fuzzy logic is used to overcome this problem. On the other hand, there is another challenge to cope with to make accurate decisions: Cognitive biases. Thanks to pioneer study of Nobel winner researchers Tversky and Kahneman (1974), bias in human judgement and decision making is discussed. It was shown that people rely on a limited number of heuristic principles which reduce the complex tasks to simpler judgmental operations. But these heuristics lead to severe and systematic errors by the way they are quite useful. The first three heuristics described in the first article are representativeness, availability of instances and adjustment from an anchor. Gains and losses are evaluated differently due to the shape of the value function, which is concave for gains and convex for losses according to the Prospect Theory (Kahneman & Tversky, 1979). Tversky and Kahneman (1981) also demonstrated choices can be influenced by the framing (i.e. wording) of decision alternatives. Two decision-making processes (System 1 and System 2) in the brain is explained in "Thinking Fast and Slow" book written by Daniel Kahneman. System 1 thought is rapid, instinctual and emotional, often on impulse and is part of the fight or flight response. Contrary to System 1, System 2 thought is slower, more deliberate and logical. According to the research on cognitive biases, it is taught to research of the effect of cognitive biases on MCDM. It was found in the literature that anchoring effect in interactive MCDM is studied by Buchanan (1997). However, the second study found in the literature is published after twenty years in 2017 by Borrero and Hanao. The sentence of "The relationship between cognitive biases and these decision-making tools has not been amply investigated." shows the need of research on this issue. Two motivational biases, respectively known as confirmation and desirability of choice are studied in that research. The efforts to diminish the effects of biases is called "debiasing" (Cheng and Wu, 2010). It is aimed to propose a filter to counteract the accurate decisions about cognitive biases as a debiasing strategy in this study. The first filter is restructuring the questions not to cause biases. Einstein's "If I were given an hour in which to do a problem

upon which my life depended, I would spend 40 min studying it, 15 min reviewing it and 5 min solving it” quote shows that the difficult part of decision making is often not about the right answer, but rather asking the right question (Ryan, 2018). The other filter is manipulating the weights according to the degree of expected cognitive biases. For example it is proved that women decisions affected more than men decisions from cognitive bias. There will be produced a debiasing factor to multiply the weights. Also from the point of view that deciding faster will increase the bias risk, the response time will be measured and will be used to manipulate the weights (Guo, 2017). Expertise level is also will be quantified to manipulate the weights. The other thing need to be handled is to look at the objective of the criteria (minimizing/maximizing) to detect loss aversion affect. This issue is very important because it is proved that clinician’s decisions are affected from cognitive biases (loss aversion bias, numeracy bias toward frequencies omission bias, confirmation bias and availability bias) (Braverman and Barby, 2012). Pandey and Jessica (2018) also measured behavioral biases affecting real estate investment decisions in India. Shu (2018) studied in her PhD thesis about hiring a personnel bias effect. These application areas show the importance of this issue.

2. A Behavioral Approach to MCDM Problems

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Multi-criteria decision making (MCDM) is primarily concerned with modeling and analysis of judgments about alternatives with respect to multiple criteria. MCDM often involves dealing with uncertain information as well as highly subjective judgments of a group of individuals. Judgments are affected not only by factors related to the problem but also by the context within which the judgment is made and by individuals’ past experience, beliefs, preferences and expectations. In spite of this fact, MCDM techniques unrealistically assume that decision makers are completely rational; in other words, they ignore the fact that humans’ cognitive abilities are limited and that their decisions are influenced by their

attitudes towards risk and psychological biases. Behavioral experiments have proven that such approaches represent the real decision making process only poorly and reduces the accuracy and reliability of the decisions. A review of the literature shows that different theories have been developed to address a particular set of these issues. The most common ones are fuzzy set theory and prospect theory. Although fuzzy set theory has been successfully integrated with various MCDM techniques, the same is not necessarily true for prospect theory. In recent years, there has been a growing interest in these theories, especially in prospect theory, which is a well-established descriptive theory concerned with how humans actually make decisions and how they behave under risk. Reference dependence, loss aversion and nonlinear weighting of probabilities are key features introduced by this theory to explain the judgmental principles that govern the evaluation of alternatives and the weighting of uncertain outcomes. The theory departs from the classical assumption that decision makers are completely rational and provides a better understanding of the factors influencing the decision process. Thus, integrating prospect theory into MCDM would yield more accurate and reliable decision making models. However, this requires addressing some issues related to data collection and evaluation as well as group decision making. A number of studies have been suggested to handle these issues, but none of them are sufficient. In this study, an approach is introduced that extends the application of prospect theory to MCDM problems under uncertainty. A decision maker’s risk attitude (subject to a certain reference point) is determined and integrated into a multi-criteria group decision framework to select the best alternative. The proposed approach aims to improve the accuracy of decisions by studying additional dimensions of the decision-making process. It introduces methods for data collection and aggregation of individual judgments. In order to demonstrate the effectiveness and applicability of the proposed approach, an MCDM application involving non-dominating alternatives and conflicting criteria is presented. Comparison with the results of expected utility theory demonstrates that the proposed approach provides a better modeling of MCDM under uncertainty.

3. Combining Health Technology Assessment (HTA) & Multi-Criteria Decision Making (MCDM) Analysis to Evaluate Kidney Stone Treatment Alternatives

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Increasing prevalence of kidney stone disease during the last decade has pioneered the development of health technologies that provide new treatment approaches to healthcare providers and patients. In this regard, applying a convenient, highly accurate and low-cost treatment approach became an important concern. In today's healthcare, Extracorporeal Shock Wave Lithotripsy (ESWL) and Laser Lithotripsy (LL) are accepted as effective and minimally invasive procedures for fragmentation of kidney stones. Pros and cons of these treatment methods are still being questioned by healthcare experts, which lead to the necessity of a comparative analysis. At this point, MCDM is a powerful and convenient tool for such kind of a comparative study. This study aims to compare ESWL and LL as kidney stone treatment alternatives by hierarchical fuzzy TOPSIS which can handle crisp and fuzzy data expressed in linguistic terms. A hierarchical evaluation structure consisting of 5 main criteria, namely, "Technical & Technological", "Organizational", "Economic", "Ethical, Legal & Social" and "Clinical" and 24 sub-criteria is constructed to determine the most suitable treatment alternative in an integrated manner. A group of experts, consisting of medical doctors (nephrologists and urologists) and researchers evaluate the importance of each criteria and sub-criteria and also the ratings of alternatives with respect to sub-criteria. A case study will be carried out at one of the biggest private hospital complex in Istanbul to apply the

proposed decision-making model. Results of the proposed evaluation framework will be utilized by healthcare providers in the field to improve the quality of healthcare service and may give insights to all interested stakeholders in the healthcare delivery system.

4. A Multi-Criteria, Multi-Stakeholder Decision Aid Tool for the Assessment of Real-Estate Investment Alternatives under Financial Performance Uncertainty

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Investment decisions in private real-estate demand the consideration of several qualitative and quantitative criteria, as well as the different or even conflicting interests of the participating stakeholders. Meanwhile, certain indicators are subject to severe uncertainties, which will eventually alter the expected outcome of the investment decision. Even though multi-criteria decision making (MCDM) techniques have been extensively used in real-estate investment appraisals, there is limited evidence from the private rented sector, which constitutes a large part of the existing real estate assets. Existing approaches are not designed to capture the inherent variability of the decision environment while at the same time, they do not always achieve a consensus among the participating actors. In this work, through a rigorous literature review, we are able to identify an exhaustive list of assessment criteria, which is further validated through an iterative Delphi-based consensus-making process. The selected criteria are then used to construct an Analytical Hierarchy Process (AHP) model evaluating four real-world, real-estate investment alternatives from the UK private rented market. The volatility of the financial performance indicators is grasped through several Monte Carlo simulation runs. We test the described solution approach with preference data obtained by seven senior real-estate decision-makers. Our computational results suggest that financial

performance is the main group of selection criteria. However, the sensitivity of the outcome indicates that location and property characteristics may greatly affect real-estate investment decisions.

THU-1-E

Contributed Session: Bringing Multiobjective Optimization to Applications

Thursday 9:00-10:40 - Room: Hagia Sophia

Chair: Nader Azad

1. Visualizations to Support Scenario-based Multiobjective Optimization

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Uncertainty is present in almost all real applications, which further increases the complexity of multiobjective optimization problems. In the absence of reliable probability distributions that model this uncertainty, scenarios represent plausible future states in which the same solution or decision may present different objective values. In scenario-based multiobjective optimization problems, the performance of a decision should be evaluated according to all objectives under the conditions of each plausible scenario. Thus, scenarios introduce an additional dimension to the solution process and complicate the task of the decision maker (DM). Visualizations can help a DM to understand and compare not only trade-offs between different objective functions but also trade-offs under different scenarios. In traditional multiobjective optimization, visualizations are typically used for representing Pareto optimal solutions in the objective space, helping DMs to observe, learn and evaluate trade-offs between objectives and eventually choose the most preferred solution. In the presence of multiple scenarios, those traditional visualizations fail to capture the trade-offs

between scenarios. In this work, we start from the perspective of a DM facing a scenario-based multiobjective optimization problem and consider some fundamental questions that a DM may expect to be answered by a suitable visualization. Examples of such questions are “which objective values can be reached in a predefined percentage of scenarios?” and “how to compare trade-offs between objectives under conditions of different scenarios?” We also classify problems into several cases based on the number of objectives, scenarios and solutions (e.g. a bi-objective problem with few scenarios and few solutions to compare, or a problem with many solutions and/or many scenarios). Then, we propose different visualizations that are well suited for each case and help the DM answer the questions identified above. For example, we extend the empirical attainment function for bi-objective problems and heatmap visualization for decision making in higher dimensions. Moreover, the pros and cons of utilizing the proposed visualizations are discussed and illustrated with several examples. To the best of our knowledge, this is the first study in which visualization methods are particularly proposed for scenario-based multiobjective optimization, which is quickly becoming an attractive area of research both in theory and real-world applications. This research is a part of developing an open source software framework DESDEO (desdeo.it.jyu.fi) for interactive multiobjective optimization methods.

2. A New Approach for Solving Multiple Objective University Course Timetabling Problem

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Abstract Many scenarios, especially those that interest multiple decision-makers (DMs), include multiple and conflicting objectives. In such cases, the DMs generally provide a set of preference information to sort and scale the satisfactory levels for the multiple objectives. A broad range of conventional

multiple objective decision making (MODM) approaches take only cardinal preference information (weights) into account by employing them in the objective function as a weighted sum of the multiple objectives. The weighted sum may not sort/scale the satisfactory levels with respect to the weights as well as being a radical function, that is the satisfactory levels may be unresponsive to small changes in the weight vector. In this study, a new fuzzy multiple objective linear programming (FMOLP) formulation is presented that address the aforementioned issues and, that is able to process ordinal and cardinal preference information simultaneously. The presented formulation is applied to a real-life university course timetabling problem to reveal its advantages over the conventional approaches.

3. Generating a Partial Approximate Pareto Set for Makespan and Flow Time Minimization: Case of an External Sterilization Service

**Onur Ozturk, University of Ottawa, Canada, oozturk@uottawa.ca*

A sterilization service is intended to sterilize any medical device used in a surgical procedure. Once sterile, these devices can be reused in other surgeries. They are therefore called "reusable medical devices (or shortly RMDs)". In the case of an external service, RMDs used in different surgeries are sent to sterilization altogether at the same time. The steps of the sterilization process are the following: rinsing and washing, verification, conditioning, and finally, autoclaving. After all these steps, RMDs are ready for reuse. Among these steps, the washing is usually a bottleneck for the whole process. Washers are capable of treating many RMD sets (RDMs used in different surgeries) at the same time. Thus, we model the washing step as a batch scheduling problem where RMDs are treated as jobs having different sizes. We focus on the minimization of total time of daily washing operations and work-in process levels. The importance of the first objective is due to operational hours of sterilization services which can be typically open ten hours a day. The second objective aims to minimize the waiting time of RMDs just before being washed. In the scheduling literature, those objectives are called makespan and flow

time. First, we propose a (2, 2)-approximation algorithm for the simultaneous minimization of makespan and flow time. The idea of the algorithm is the following: -maximize the number of jobs put in a batch by initially sorting jobs in non-decreasing order of sizes, - if a job does not fit in an existing batch, job is split and its first part entirely fills the open batch, - then a new batch is opened and the second split part is placed in that batch, - afterwards, all split jobs are removed from batches and, if necessary, new batches are generated for those jobs. Then, we develop a procedure to generate an approximate Pareto set following the initial solution given by the approximation algorithm. The Pareto set approximation procedure generates additional batches to the detriment of maksepan and rearranges the assignment of jobs to have a better flow time value. Each time a new batch is generated, the procedure looks up the job having the largest size and places that job in the new batch. Then, the space emptied with the displacement of that job is filled with other jobs which are initially scheduled at a greater instant. This process continues until the used capacity of the additional batch is maximized. We ran several numerical tests to test the performance of the approximation algorithm and the Pareto set approximation procedure. We also benchmarked the approximation algorithm to a genetic algorithm from the literature, before and after implementing the Pareto set approximation procedure. Numerical results showed that the approximation algorithm dominates the genetic algorithm for small and medium size instances containing up to 20 jobs. On the other hand, implementation of the Pareto set approximation procedure improves the initial solutions given by the approximation algorithm and the benchmarked method by around 10%.

4. A Bi-Objective Optimization Model for Planning Rail Hazmat Shipments in the Presence of Random Disruptions

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Hazardous materials (hazmat), though harmful to humans and the environment, are integral to industrial lifestyle and thus need to be transported in significant volumes. Railroad is one of the safest modes for transporting hazmat, in large part because of the implementation of a comprehensive safety plan and a host of industrywide initiatives, however, the possibility of spectacular events resulting from multi-railcar incidents do exist. The derailment and explosion of several crude oil rail tank cars causing irreparable destruction and loss of human life in Lac-Mégantic (Quebec, Canada), in July 2013, is an example of the possible catastrophe associated with rail hazmat shipments. Disruptions, induced by nature such as hurricane Katrina in 2005 or man-made threats such as the 9/11 terrorist attacks in the United States, could either threaten the transportation networks or render a single transportation mode such as railways unavailable. Unfortunately, the existing risk management techniques have limited efficacy in the event of disruptions, and the resulting unavailability of rail-links. Thus, there is a need to study disruption to railroad operations, especially since such events are not infrequent. It should be evident that the resulting risk management methods and optimization techniques should not only incorporate disruptions but also prescribe contingency plans for rail hazmat shipments. However, implementing such techniques so that the transport risk and the transport cost are within reasonable bounds under both normal and disruption situations is challenging because of two reasons: first, both the risk and the cost elements would tend to increase during disruptions since safe and economic routes might not be available; and second, it is difficult to evaluate the effectiveness of contingency plans because of the inherent trade-off between upfront cost to the railroad operator versus the possible mitigation (of risk and cost) resulting from the disruption. We make the first effort to fill the gap by developing a bi-objective two-stage stochastic program that considers random disruptions in the tactical planning of rail hazmat shipments. A new measure of hazmat risk that combines expected risk with the variability in risk, and whose goal is to

ensure that the risk measure remains within tolerable limits, is developed. The complexity of the resulting optimization program, and the inherent structure, motivated deploying an augmented ϵ -constraint technique to generate a formulation involving single objective. The proposed analytical approach was used to study the transportation system of a Class I railroad operator in North America, and the resulting analyses led to the following conclusions. First, rail hazmat risk can be reduced by using proactively adding extra capacity to the safer links, and/or reactive strategies of re-routing and using third party logistics. Second, the new risk measure that combines expected risk and variability in risk could be a very valuable tool for both the railroad industry and the regulators who deal with low probability – high consequence hazmat events. Third, any given railroad network can be preprocessed to ascertain the critical and near-critical service legs for adding extra capacity to be commensurate with the risk attitude of the decision maker. Fourth, cost savings is higher from adding extra capacity vis-à-vis re-routing railcars. Fifth, safer service legs are chosen for capacity addition even in the absence of disruptions, because that would help cope with disruptions and also reduce hazmat risk under normal operating conditions.

THU-1-F

Contributed Session: Practical Applications of MCDM

Thursday 9:00-10:40 - Room: Basilica
Cistern

Chair: Matthias Ehrgott

1. MRP-WES: Multiple Reference Point based Weak and Strong Synthetic Indicators

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In this paper, a novel methodology based on the multicriteria reference point scheme (the

Multiple Reference Point Weak-Strong Synthetic Indicator, MRP-WES) is proposed. The decision maker can establish any number of reference levels for each indicator, and the final outcome can be interpreted in terms of the position with respect to these levels. In order to illustrate the behaviour of the scheme proposed, we apply it to the construction of the EU-Regional Social Progress Index, taking into account the three dimensions considered: "Basic Human Need" (BN), "Foundations of Wellbeing" (FW) and "Opportunity" (O). Besides, two different aggregations are proposed: the weak indicator (WSI), allowing for full compensation among the single indicators, and the strong indicator (SSI), not allowing for any compensation. If we wish to propose a ranking, partially compensatory synthetic indicators (MSI) can be built for different compensation degrees, ranging from 0 to 1. From the practical point of view, the main advantage of MRP-WES is twofold. First, the MRP-WES indicators can be easily interpreted as the global position of the corresponding unit with respect to hypothetical global reference levels, resulting in a meaningful measure. Second, apart from providing an overall measure, the MRP-WES method provides warning signals which let the decision maker detect bad performances in certain indicators that may remain unnoticed otherwise. Finally, we show that the MRP-WES indicators satisfy a series of properties which are regarded in the scientific literature as highly desirable for a Synthetic indicators.

2. Accelerating Pareto Local Search Algorithms using Epsilon Dominance for the Beam Angle Optimisation Problem

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The problem of finding the beam angles configuration (BAO) that leads to the best treatment plan in radiation therapy is a very challenging optimisation problem. Further, as we aim to deliver radiation to a tumour according to some medical prescription and, at the same time, minimise the damage on surrounding organs/tissues, the problem is inherently a multi-objective one. To solve this problem, several strategies have been proposed in the literature. Among them, multi-objective local search algorithms (MOLS) have been shown to be a very simple and effective strategy to solve the BAO problem. However, MOLS algorithms have several problems we need to address to think of applying this kind of strategies in clinical practice. One main problem is their slow convergence. As mentioned previously in the literature (Cabrera-Guerrero, 2018), MOLS can take many hours (or even days) before to converge to a set of locally efficient treatment plans. Further, most of these plans tend to concentrate on the same part of the objective space, leading to a lack of diversity among the locally efficient solutions found by the algorithm. In this study, we propose to use the epsilon-dominance concept to reduce the number of non-dominated points the MOLS keeps in its archive at each iteration, so the algorithm can converge faster. Also, we implement some rules to improve the diversity of the efficient treatment plans in the archive at each iteration. We apply these ideas to a Pareto Local Search (PLS) algorithm previously proposed in the literature (Cabrera-Guerrero, 2018). We consider two different neighbourhood definitions. The algorithm is tested on two clinical prostate cases. While the tumour is located on the prostate, organs at risk considered in this study are the bladder and the rectum. Preliminary results show that using the epsilon-dominance rule allows us to reduce the number of solutions to be explored by the PLS algorithm at each iteration, leading to a faster convergence with a minimum impairment on the final treatment plans found by our approach.

References Guillermo Cabrera-Guerrero, Andrew J. Mason, Andrea Raith, Matthias Ehrhott, 2018. "Pareto local search algorithms for the multi-objective beam angle optimisation problem," Journal of

Heuristics, Springer, vol. 24(2), pages 205-238, April.

3. Dimensionality Reduction for Multiobjective Optimization via Thermal Maps – The Case of Intensity Modulated Radiotherapy

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Large-scale multiobjective nonlinear optimization problems can be intractable by any methods, either exact or evolutionary. In such cases, two major approaches are available: decomposition and dimension (size) reduction. In multiobjective optimization problems arising in Intensity Modulated Radiotherapy (IMRT), problem sizes quickly explode when discretization grids become fine. By necessity, radiation plans are Pareto optimized on coarse grids which can lower the quality of radiation plans. We present an approach in which an IMRT case is defined on a fine grid and the resulting large-scale multiobjective optimization problem is run for a number of iterations to find a good feasible solution. Then, variables are aggregated on the base of some heuristic which uses for the input thermal maps intensities, as defined by the feasible solution, of rays emanating from the radiation source. Finally, the aggregated problem is run to optimality. Our approach allows to account for the specificity of individual patient organ-tumor structures which are reflected, roughly, in the feasible solution to the large-scale multiobjective optimization problem. We experimented with real data provided by one of the Polish

oncological clinics. We made use of evolutionary singleobjective and multiobjective optimization methods. Our results are comparable to those obtained from a commercial radiotherapy planning system. The choice of evolutionary optimization was motivated by our want to easily incorporate into the treatment planning information about various radiobiological effects modelled as nonlinear objective functions (e.g., tumor control probability). As yet, commercial treatment planning systems do not account for such effects.

4. Evaluating the Quality of Radiotherapy Treatment Plans for Prostate Cancer

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External beam radiation therapy is a common treatment method for cancer. Radiotherapy is planned with the aim to achieve conflicting goals: while a sufficiently high dose of radiation is necessary for tumour control, a low dose of radiation is desirable to avoid complications in normal, healthy, tissue. These goals are encoded in clinical protocols and a plan that does not meet the criteria set out in the protocol may have to be re-optimised using a trial and error process. To support the planning process, it is therefore important to evaluate the quality of treatment plans in order to recognise plans that will benefit from such re-optimisation and distinguish them from those for which this is unlikely to be the case. In this talk we present a case study of evaluating the quality of prostate cancer treatment plans based on data collected from Rosemere Cancer Centre at the Royal Preston Hospital in the UK. We use Principal Component Analysis to select the most relevant data. We then apply Data Envelopment Analysis to assess the quality

of individual plans. Each plan is compared against the entire set of plans to identify those that could realistically be improved. We further enhance this procedure with simulation techniques to account for uncertainties in the data for treatment plans. The proposed approach to plan evaluation provides a tool to support radiotherapy treatment planners in their task to determine the best possible radiotherapy treatment for cancer patients.

THU-2-P

Plenary Session 4

Thursday 11:10-12:10 - Room: Mustafa Kemal Amfisi

Chair: Ilker Topcu

Voting with Intensity of Preferences

**Luis Vargas, University of Pittsburgh, United States, lgvargas@pitt.edu*

In this paper we develop a method based on the idea of pairwise voting to rank projects or candidates and incorporate in the ranking process how strongly the referees/voters feel about the comparisons they make. Voting is a modified form of ranking and all the votes are equally important. However, there are situations like voting in which the votes are not just ordinal, but each voter expresses an intensity of preference for the different candidates, e.g., ranking projects for funding. We show that our method yields the same results as ordinal voting in large populations when the intensity of preferences becomes extreme. Voting with intensity of preferences does not violate democracy but softens the stand of voters and allows for consideration of the diversity of issues involved in voting.

THU-3-U

Business Meeting

Thursday 13:10-14:10 - Room: Mustafa Kemal Amfisi

Chair: Murat Köksalan

THU-4-A

Invited Session: Hybrid Approaches in MCDM

Thursday 14:20-16:00 - Room: Galata Tower

Chairs: Esra Karasakal, Orhan Karasakal

1. Convex Cones and Column Generation, Part I: Perfect Information

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We work on the multiple criteria selection problem that aims to find the most preferred alternative among a set of known alternatives evaluated on multiple criteria. We assume the decision maker (DM) has a quasi-concave value function that represents his/her preferences. The DM provides pairwise comparisons of alternatives and this information is used to generate convex cones (Korhonen et al., 1984). The generated cones eliminate inferior alternatives and the most preferred alternative is identified after enough pairwise comparison information is gathered. Generally, an interactive approach is used to obtain the preference information of the DM (Köksalan et al., 1984; Köksalan, 1989; Taner and Köksalan, 1991; Köksalan and Taner, 1992; Özpeynirci et al., 2017). The aim of interactive algorithms is to detect the most preferred alternative by performing as few pairwise comparisons as possible. In this study, we aim to compute the minimum number of pairwise comparisons required to identify the most preferred alternative. For this purpose, we assume that the value function of the DM is known. If all convex cones are generated, then it is possible to find optimal pairwise questions and convex cones to eliminate all alternatives but the most preferred one. Özpeynirci et al. (2017) generate all single and double cones (cones that require two pairwise comparisons) and find an upper bound for the objective function value. It is not practical to generate all cones since Köksalan et al. (1984) show that the number of convex cones grows exponentially with the number of alternatives. We develop an approach that utilizes column generation for generating cones under the perfect information assumption. We then, embed this approach in a branch and bound framework to guarantee the optimality. We conduct computational experiments on different problem instances and report the results.

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2. A Mathematical Programming Evaluation Approach for Multiple Criteria Sorting Problems

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Multiple criteria sorting problem is to assign alternatives, evaluated according to multiple criteria, into predefined preference ordered classes. In this study, a new distance metric based sorting method is developed to solve multiple criteria sorting problems. The aim of the proposed method is to assign each alternative to one class or a set of possible adjacent classes. In the proposed method, centroids of the classes are estimated using sample preference set provided by the decision maker. Distance to the centroids are used as a criteria aggregation function. A mathematical model is formulated to determine the weights of the distance metric. Assignment is performed according to the weighted distance of each alternative to each class' centroids. The proposed method is applied to different data sets and its performance is compared with other methods in literature.

3. Convex Cones and Column Generation, Part II: Interactive Algorithm

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Multiple criteria selection problem aims to find the most preferred alternative among a set of known alternatives evaluated on multiple criteria. We assume the decision maker (DM) has a quasi-concave value function that represents his/her preferences. The DM provides pairwise comparisons of alternatives and we use this information to generate convex cones (Korhonen et al., 1984). We eliminate the alternatives that are dominated by these cones and identify the most preferred alternative after certain number of iterations. In the literature, there are several studies that consider convex cones and use interactive approaches to obtain the preference information of the DM (Köksalan et al., 1984; Köksalan, 1989; Taner and Köksalan, 1991; Köksalan and Taner, 1992; Özpeynirci et al., 2017). The aim of interactive algorithms is to detect the most preferred alternative by performing as few pairwise comparisons as possible. In this study, we develop an interactive algorithm that uses convex cones and column generation. We get some initial information from the DM and estimate the value function. Throughout the iterations, the interactive algorithm seeks for the cones that can be generated with the currently available information including transitivity using the column generation approach. After the alternatives dominated by the generated cones are eliminated, the algorithm estimates the benefit of asking a specific pairwise comparison to the DM. This benefit is calculated based on the dual prices provided by the mathematical model that aims to minimize the total number of questions with the currently available information. The pair of alternatives that is estimated to eliminate the largest number of alternatives is presented to the DM. Necessary updates on the mathematical model and the remaining alternative set are done. The procedure continues until there is

only one alternative left. We conduct computational tests and compare the results with the minimum number of questions found by convex cones and column generation under perfect information. References Korhonen P., Wallenius J., Zionts S., Solving the discrete multiple criteria problem using convex cones. *Management Science*, 1984, 30, 1336–1345. Köksalan M., Identifying and ranking a most preferred subset of alternatives in the presence of multiple criteria. *Naval Research Logistics* 1989;36:359-372. Köksalan M., Karwan M., Zionts S., An improved method for solving multiple criteria problems involving discrete alternatives. *IEEE Transactions Systems Man Cybernetics*, 1984;14:24–34. Köksalan M., Taner O., An approach for finding the most preferred alternative in the presence of multiple criteria. *European Journal of Operational Research* 1992;60:52–60. Taner O., Köksalan M., Experiments and an improved method for solving the discrete alternative multiple-criteria problem. *Journal of the Operational Research Society* 1991;42:383–91. Özpeynirci Ö., Özpeynirci S., Kaya A., An interactive approach for multiple criteria selection problem. *Computers and Operations Research* 2017; 78: 154-162.

4. Multiple Criteria Target Classification Using Heterogeneous Sensor Data

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Radar systems have important roles in both military and civilian applications. As the capabilities increase in terms of range, sensitivity and the number of tracks to be handled, the requirement for automatic target recognition (ATR) increase. ATR systems are used as decision support systems to classify the potential targets in military applications. These systems are composed of four phases, which are selection of sensors, preprocessing of the radar data, feature extraction and selection, and processing of features to classify the potential target. In this study, we focus on the

classification phase of ATR and develop a novel multiple criteria classification method based on modified Dempster Shafer data fusion algorithm. Ensemble of classifiers are used as a classification algorithm. They are treated as the state of the art technology for classification in which each single classifier is trained separately, and then the results of them are combined through several fusion algorithms. Support vector machine and neural network are employed as probabilistic classifiers in ensemble. Each non-imaginary dataset coming from multiple heterogeneous sensors is classified by both of the classifiers in the ensemble, and the classification result that has higher accuracy ratio is chosen for each of the sensor dataset. After getting probabilistic classification of targets by different sensors, modified Dempster Shafer data fusion algorithm is used to combine the sensors' results to reach the final classification of the targets. In this talk, a number of classification algorithms are compared with the proposed algorithm and the results will be discussed.

THU-4-B

Contributed Session: Business Applications of AHP/ANP

Thursday 14:20-16:00 - Room: Maiden's Tower

Chair: Ilker Topcu

1. A Geometric Standard Deviation Based Soft Consensus Model in Analytic Hierarchy Process

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Sophisticated real world problems can be successfully solved by group multi-criteria decision-making approaches that are recognized as reliable and effective. To efficiently tackle such problems a group of decision makers with different opinions, knowledge and experiences should be included in the decision-making process. Analytic hierarchy process (AHP) is one of the well-known approaches for handling group multi-criteria decision making problems. Aggregating individual judgments into group

judgments is a challenging topic in AHP and needs to be researched more in depth. The best known aggregating method is the weighted geometric mean method, but the decision makers are usually not satisfied with this technical solution. A certain level of agreement among decision makers increases the effectiveness of the decisions. Of course, consensus which would represent a unanimous agreement of all decision makers is an ideal solution; however it is difficult to achieve such ideal solution in heterogeneous groups included in decision-making process of real world problems. It is already known that consensus and soft consensus reaching models can lead to more unified and effective decisions and more satisfied decision makers. A consensus process involves several consensus rounds and in each round the degree of consensus is measured. The level of agreement in a group of decision makers can be measured by the distance between the priority vectors, by compatibility index or any other consensus measure. We propose a new soft consensus model based on a geometric standard deviation as a measure of closeness of group opinions. Geometric standard deviation describes the variability of a set of numbers around their geometric mean. One of the important aspects of the consensus reaching process is that decision makers can decide whether they are willing to adapt their judgments. In AHP consensus reaching models which are found in literature it is assumed that once a decision maker rejects to adapt his judgments, he cannot change his mind in the future iterations. We found this fact to be a deficiency and in our proposed model the decision maker can change his mind. At the end, we apply the model to an environmental problem about the development of a mountainous area. Several stakeholders are included in the decision making process with economic, environmental and social criteria and objectives. The purpose of the application is to compare the new proposed consensus model with other existing models.

2. Strategic Pricing Decision using Analytic Hierarchy Process

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Price is the only “P” of marketing mix that generates revenue and therefore how firms should set and adjust their prices in order to maximize profitability is very important. During last few decades, many quantitative techniques were developed to dynamically adjust prices so that the right prices are in the right place at the right time, through the right channel and to the right customer. However, most of these quantitative techniques are based upon various inherent assumptions and use limited number of parameters and variables. In addition, these quantitative techniques often use precise historical data but provide little scope to incorporate the preferences of the decision maker (DM) in the process of making pricing related decisions. Studies have shown that the judgments are always inferior to forecasting models because forecasting models use precise historical data. However, the quantitative model lack in capturing all the relevant realities of the environment. In certain situations, the judgments of the decision maker can give superior results. Further, quantitative models are well suited to estimate an exact price offering but judgments based models can very well be used to estimate price brackets and positioning. Setting an exact price offering often depends upon the price brackets and positioning. This is because the ultimate price figure should always align with the marketing/pricing strategy of the firm. Deciding marketing/pricing strategy of the firm require processing various quantitative and qualitative indicators of the market as well as of the firm. This requires understanding of the market through the expertise, knowledge, and preference of the pricing expert or the decision maker. However, there is no decision framework available in the literature to take a decision on the pricing strategy of a firm using the preference or the judgment of the pricing expert or the marketing manager. Using the findings of Rao and Kartono (2009), this research work proposes a decision hierarchy that can be used to take a decision on the pricing strategy of a firm. The decision hierarchy begins with the overall objective of setting or selecting a best pricing strategy for the new/existing product or services of the

firm. Down further, the decision hierarchy contains two criteria, six sub-criteria, and three possible strategic alternatives as shown in the figure 1. The two broad criteria considered here are the objectives of the firm and the market determinants. To select a best pricing strategy for the firm, the decision maker will define the relative importance between the objectives of the firm and the market determinants. Each of these two criteria is measured with the help of three sub-criteria. The decision maker will then define the relative importance of these three sub-criteria with respect to the criteria under which they are placed in the decision hierarchy. This is required because a firm may have several objectives to achieve but all will have different priorities with respect to the overall objective of the firm. Similarly, several market determinants are required to be assessed and their relative priorities are to be defined in terms of their importance in shaping the pricing strategy of the firm. Leaves of the decision hierarchy are the three possible alternatives. The decision maker will then define the relative importance of the three alternatives separately and independently with respect to each of the sub-criteria placed immediately above the alternatives in the decision hierarchy. Since the assumptions of the problem structure closely match with the axiomatic assumptions of the Analytic Hierarchy Process (AHP), a popular multi-criteria decision making method, this research also demonstrates how the AHP method can be used to solve the strategic pricing decision problem.

3. Skills of A Management Science Consultant: AHP Model through the Perspective of Senior Managers in a Developing Country

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In order for companies to survive and develop in this dynamic and complex world, it is necessary for them to adapt to changes and to invest in employee education. Efficient management is not only about achieving results, but also gaining the trust and respect of employees. The management of companies with the decisions it makes

should bring the company closer to achieving the set goals. Besides the knowledge, skills and experience it possesses, the management should also emphasize the quantitative analysis. Good measurement enables results to be obtained, which should serve as a recommendation for the management's decision-making process. The aim of the research in this article is to examine how much the Management Science (MS) models and methods are applied in companies in a certain developing country, i.e. the Republic of North Macedonia, what effects have been achieved by their application, and which skills MS consultants should have in regards to being engaged in solving the problems that companies face. The survey was conducted via a questionnaire given to senior managers of state and private companies in the Republic of North Macedonia. The total number of received questionnaires is 236; out of which 17 are incomplete, so 219 have been analyzed. Out of these 219 questionnaires, 68 were filled out by senior managers of state companies, while 151 of them came from private companies. Most of the companies (154) are located in the capital of the country, Skopje. In terms of the industry, most state-owned companies (13 of each) fall under public administration and defense: compulsory social security and health and social care activities, while most of the private companies (40) are from the manufacturing industry. Considering gender, 113 are males and 106 are females, while the average age is 43. Regarding the level of education, the majority of the respondents (143) have gained a University education. Most of the respondents (151) answered that there is a need for MS support, and that in the future they plan to hire an MS consultant, while 68 respondents said that they do not need such support nor engagement from an MS consultant. The skills that an MS consultant should have are grouped into two categories: fundamental and ancillary practical skills. On the basis of the estimated average grade of importance of the fundamental skills, the MS consultant able to view the problem was given the highest average, followed by: being able to connect the results to the real situation, structure a problem, analyze the model, relate to the client, model the problem, identify opportunities for analysis in a creative manner, and comprehend the

social geography of the client body. Ancillary practical skills are divided into five fields: marketing, sales, formal communication and reporting, skills in interacting with the client and facilitating, and computing; while the average grade of importance for each skill in these fields is estimated and analyzed. The emphasis in this article is to develop a structure of a multi-criteria decision model (AHP) for managerial decision-making regarding hiring an MS consultant based on their fundamental and ancillary practical skills from the point of view of the senior managers in both private and state companies in the Republic of North Macedonia. Only the skills with an average grade of importance that is not below four will serve as input in the AHP model. The constructed multi-criteria decision model is presented and it will be tested in both state and private companies in the country. With this kind of research we want to introduce the management in our country with the benefits of using MCDM methods and models in their companies, especially for the purpose of making better decisions that will lead to successful operating and growth in future. Key words: MCDM, AHP model, developing country, MS consultant, skills

4. An Integrated Multi Criteria Decision Making Method for R&D Project Selection

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Research and development activities can be considered as putting forward and creating new products or services as well as improving existing products or services by using technology, knowledge and experience. Research and development activities serve significant roles for the countries and societies as these activities may lead inventions, innovations, technological developments, economic growth, and better living conditions. Although there are several possible research and development projects, those can be executed by an institution, an agency or a

company; some of them should be selected because of time, workforce, and monetary constraints. This study proposes an integrated multi criteria decision making aid for the executives of the companies in private sector in their selection decisions of research and development projects. After defining evaluation criteria through literature survey and experts' opinion, the relations among them were revealed using cognitive mapping approach. Cognitive maps are cause-effect networks, with nodes representing concepts articulated by individuals, and directional linkages capturing causal dependencies. Then, analytic network process (ANP) method was utilized to determine the importance of criteria. ANP is a methodology that allows groups or individuals to deal with the interconnections (dependence and feedback) between factors of complex structure in decision making process. As a further step, in a case study, the global scores of candidate projects were computed using simple additive weighting (SAW) method. A global score in the SAW is obtained by adding normalized contributions of alternatives with respect to each attribute. Finally, goal programming was used to select best combination of candidate projects under various constraints regarding to company strategies and decision maker preferences. Objective function of the optimization model is minimizing deviations of conflicting goals. Goals of the model consist of (i) expected net present value of projects, (ii) global scores of candidate projects and (iii) funding potential of each project. Constraints include dependencies between projects, limits related to expected contributions of projects and source constraints like time, budget and human resource.

THU-4-C

Invited Session: MCDM in Solving Urban Problems using Big Data

Thursday 14:20-16:00 - Room: Dolmabahçe Palace

Chairs: Sehnaz Cenani

1. Anchoring in Two-Criteria Trade-Offs between Carbon Dioxide Emission and Travel Time

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Anchoring is one of the most common cognitive biases people may be influenced by when making decisions, estimates, and predictions. Here we will present the effects of anchoring and framing in a two-criteria trade-off setting. The context is a personal decision on reducing carbon dioxide emission from air travel, which is currently a hot topic in Sweden. Participants in a between-subjects experiment were asked to make a trade-off, matching a reduction in CO₂ emission from 99 kg to 22 kg to an increase in travel time from 1 hour to a value they chose themselves. However, the participants were anchored by first having to consider if they would be willing to increase the travel time to more than 2 hours (low anchor condition) or 6 hours (high anchor condition). Robust data analysis methods were used for hypothesis testing. As expected, the answers from participants in the group with a high anchor were significantly higher than answers from the group with a low anchor. Since reducing private air travel is often proposed as a component of reducing one's carbon footprint, we supposed that many participants in the study should be willing to extend the travel time in order to reduce the CO₂ emission. However, it may be difficult to realize how much this reduction from 99 to 22 kg CO₂ is worth. In order to put this amount in context, two other groups of participants in the study received an additional piece of information in the context description: "The Swedish Environmental Protection Agency recommends that each of us should not use more than two tons of greenhouse gases per person and year, which amounts to a maximum of 38 kg CO₂ per week on average." This additional information thus puts the emissions of 99 and 22 kg CO₂ in context, being in the same order of magnitude as a maximum weekly recommended use. Further, this additional information conveys a normative message. It may also be seen as a case of issue framing, where we have emphasized the issue of a personal responsibility for reducing greenhouse gases. With the additional

information, the anchoring effect is even more pronounced. Although the experiment shows no significant main effect of the additional normative message, there is an interaction between anchoring and the given information. The results of our experiments are important in multiple criteria decision-making since similar kinds of trade-offs and matching procedures are common in practical elicitation procedures. E.g., the situation corresponds to making trade-offs in the even swap method.

2. Understanding Divisions of a City by Evaluating Location-Based Social Media Data

**Kutay Yunculer, Istanbul Technical University, Turkey, yunculery@itu.edu.tr*

For municipalities, urban designers, and architects, defining the divisions of a metropolis is an essential part of developing urban strategies. However, only using city districts' provincial borders is not illustrating the whole picture because of the two main deficiencies. First, in most of metropolises, a single district contains multiple partitions with different specialties and mostly these partitions are not defined by borders of the district which they belong. For instance, if the urban-scale network of Istanbul is explored by the method which is explained in the second paragraph, one can see that historical areas of Istanbul named Eminönü and Sultanahmet which are actually in Fatih district are in the same cluster with another district named Beyoğlu instead of Fatih. Secondly, in rapidly changing cities such as Istanbul, characteristics of these districts are changing continuously. At this phase, research projects such as Livehoods [1] are remarkable by showing us, how promising it can be to use data gained by location-based social media networks' APIs. Despite missing some necessary information due to limitations and constraints (i.e. limited sample of check-ins, not implementing centrality algorithms to the study), Livehoods emphasised the possibility of picturing urban divisions by using location-based social media data and clustering algorithms. This research is aiming to adapt approaches of previous research such as Livehoods to current versions of location-based social media networks' APIs. More importantly combining these approaches with some more recent research, which were mainly

focusing on analysing and determining significancies of venues in a city by using centrality algorithms such as PageRank. With this methodological motivation, this study targets contributing urban decision making processes in two different ways. First and most important goal is developing and publishing a Python library which collects urban-scale data from location-based social media networks' APIs such as Foursquare's Places API then converts this data into a GEXF graph file which is proposed by developers of Gephi. Second goal is directly related with the first one by aiming to be a proof-of-concept of it. To achieve this goal, an urban-scale graph of Istanbul and Stuttgart will be produced and stored as GEXF files by using the Python library which is developed as part of this study, then these graphs will be evaluated by analysis tools such as PageRank and Modularity algorithms which are implemented to Gephi, an open-source data visualization and exploration software. Main motivation while choosing these two cities was their networks' distinct characteristics from other cities and from each other. To be more precise, when Istanbul's network is explored in Gephi, an urban-scale graph which consists of 28 interwoven clusters will be seen. On the contrary, when a researcher analyses Stuttgart's urban-scale network by the same technique will see discrete clusters. Furthermore Stuttgart has a strong connections with neighbor cities especially with Ludwigsburg, conversely intercity connections cannot be noticed in the case of Istanbul. Last but not least, the result of the evaluation process will be published as an interactive website which will let researchers, professionals and citizens to create their own reports about Istanbul and Stuttgart. Thus, this website aims to bring processed information such as clusters in these cities, distribution of venue types in these clusters, average centrality of venues in different clusters, and average centrality of venue types in the whole city as well as in different clusters, together with the essence of exploratory data-visualization concept. [1]

<http://livehoods.org/>

3. A Decision Support System to Provide Real-Time Alternatives for Placement of E-Scooters in a Smart City: A Case Study of Istanbul

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A smart and sustainable city should be an innovative city that uses information and communication technologies (ICT) to improve the quality of life via its operations. They need to be planned, managed and regulated by open data collected through different data sources to provide efficient services. It can be said that one of the essential services of a city is transportation. In smart cities, intelligent transportation systems help to solve problems such as traffic congestion or the amount of fuel spent in traffic by providing communication between vehicles and devices that build the whole transportation network. In order to achieve the success of intelligent transportation systems, transportation methods should be planned dynamically according to the collected data and the requirements of the city's transportation network. Then the necessary decisions should be made with the help of all the data and information to improve the transportation system. Today in 2019 as we move from the information age to the digital age, the possibilities of data usage may reshape the decision support systems. Social media is one of the new tools that collects valuable information like geolocation data to be used in various decision support systems for different industries. The location tags that are used in location-based social networks like Instagram and Twitter can have an impact on the studies related to urban design and planning. In this study, we present an electric scooter deployment model to reduce traffic congestion and travel time with the use of real-time data from social media in urban areas with heavy pedestrian and vehicle traffic. According to the Turkish Statistical Institute, in 2018 more than 15 million people live in Istanbul and the number of motor vehicles is more than 4 million. Therefore, Istanbul is chosen as the case study for the proposed model, since transportation is one of the most critical problems of the city. Sustainable urban mobility is a feasible solution for

transportation-based problems. Electric vehicles are cost-effective and sustainable transportation methods. Among them, e-scooters can easily fit into small and narrow streets and reduce parking problems in cities. It is also an exciting transportation method especially preferred by young people. In the scope of this study, a survey is conducted to estimate the e-scooter potential usage in Istanbul. The main criteria for the locations of e-scooters are collected through online questionnaires and information available from the e-scooter companies around the world. Following that, collected criteria are processed in multi-criteria decision analysis. We use the Analytic Hierarchy Process (AHP) method to weight and rank these criteria for sharing location selection. This paper proposes the use of the AHP method for application in the smart and sustainable city context. Thus, a decision hierarchy is built for setting the priorities for e-scooter mobility in an urban environment. The Super Decisions, which is an open-source decision support software that implements the AHP and ANP, is used to evaluate decision processes in this study. Then, the methodology is used to develop a prototype for an application that collects pedestrian and vehicle traffic information from different districts and location tags from social networks in real time. All traffic information is collected through transactions of Google Maps users and cross-checked with the survey results. The short-distance routes with the high pedestrian and vehicle traffic in the city are categorized in the decision process. In that way, the location alternatives to place e-scooters will be changing according to data coming from traffic information applications and social media. We assume that this system will offer the best locations for e-scooter placement and use. Additionally, the proposed approach can reduce commuting time, while contributing to the reduction of environmental footprint.

4. Selection of Temporary Shelter Sites and Optimising Evacuation Routes as a Disaster Management Strategy: A Case Study for the Expected Istanbul Earthquake

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Disasters have devastating effects on socioeconomic, built environment and infrastructure; also create a volatile, uncertain, complex and ambiguous processes which are hard to manage. Therefore, developing a proper disaster management strategy is a crucial need, especially for the governments. Also, disasters need excessive efforts on logistical and organizational aspects of the affected country. So, using traditional methods while developing this strategy may not be efficient; therefore, it is crucial that the implementers of disaster management should adopt contemporary, rapid, precise and effective methods in the process of successful humanitarian aid and disaster relief. In general, there are three basic phases of disaster management, which are: (1) preparedness: which consists the activities of pre-disaster period, (2) response: which consists the activities of disaster period and (3) recovery: which consists the activities of post-disaster period. In pre-disaster period mitigation and preparedness activities are held in a strategic planning approach. In disaster period, response activities take place, so agile principles should be taken into account in this period as short term project management, flexibility and nimbleness are the most important subjects. In after-disaster period, recovery activities replace the premises. Preparedness phase needs proactive approaches, as the other ones need reactive approaches. One of the hardest things in disaster management is the trade-off between cost and responsiveness; also, it's a hard and fragile process that needs quick actions. To achieve effective, efficient and timely responses during and right after disasters; strategic planning should be done long before the happening. Selecting appropriate shelter area and routing for the safest evacuation is the key to this planning process, especially for the densely populated cities. This paper mainly focuses on the preparedness phase of the disaster management as offering a decision-making tool to support the government for selection of temporary shelter sites and optimizing evacuation

routes of disaster victims. This selection and optimization process needs multi-disciplinary approach involving many different knowledge areas including management, seismology, environment, sociology, planning, architecture, law, transportation, engineering and so on. As a case study, the expected Istanbul earthquake is chosen in terms of what-if scenario of a very disastrous earthquake to demonstrate the implementation of the proposed model. In this paper, we analyze the principles of site selection of temporary shelters from the relevant literature and prioritize the important criteria and sub-criteria. The analytic hierarchy process (AHP) is used to find criteria weights. As a multi-criteria decision problem, we formulate the selection of the most appropriate shelter sites in terms of location, capacity, resources, allocation of victims and evacuation route principles. Then, we compare them with the current areas defined by the local government. As a result, improvements were achieved on comprehensiveness among population, averaged evacuation distance traveled by the victims and reaching times of the affected victims to the temporary shelter sites when compared to the current ones. This study offers a tool for policy-makers in terms of effective decision-making support on shelter location planning. The aim of this study is to better understand the criteria related to the post-disaster shelter location planning and to design a decision support system for policy-makers in the smart city framework. For the further studies, it is proposed to analyze the described methodology and use the proposed system on previous and future disaster situations occurred in different places of the globe to observe whether it is performing well in different real-life scenarios.

THU-4-E

Contributed Session: Practical Approaches to Challenging Problems in Multiobjective Optimization

Thursday 14:20-16:00 - Room: Hagia Sophia

Chair: Ralph Steuer

1. A Set Covering Trade-Off to Solve the Complete Vertex p-Center Problem

**F. Antonio Medrano, Texas A&M University-Corpus Christi, United States, antonio.medrano@tamucc.edu*

The vertex p-Center problem consists of locating p facilities that cover all n demands in order to minimize the maximum distance between a demand and the facility that covers it. In other words, it is equivalent to finding the minimum coverage radius r and locations of p facilities capable of covering all demands. Originally formulated by Hakimi (1965), this problem is NP-Hard, and the standard formulation has proven to be particularly challenging for IP solvers on large problems. Thus, most solution approaches use heuristics or relaxations (Minieka 1970, Tansel et al. 1983, Mladenović et al. 2003, Elloumi et al. 2004). The complete p-Center problem extends the formulation to solve the for all p-values from 1 to N, where N is the number of nodes to cover. This provides a complete coverage trade-off curve between number of facilities and coverage radius. This talk proposes an approach for solving the Complete Vertex p-Center Problem using an iterative location set covering approach with selecting only r-values that have the potential to be exact solutions. Experiments on a variety of data sets demonstrate that this new covering trade-off method is faster than approaches using traditional p-Center formulations, and in certain instances can be further sped up with brute force combinatorics.

2. Multi-Objective Combinatorial Optimization of Coupled Systems

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We take interest in the optimal functioning of systems which can usefully be seen as composed of distinct subsystems. This may be the case because most constraints defining the global problem are local to particular subsystems, while these subsystems still are linked together by other constraints. Such systems have been called

coupled, complex or even interwoven. They can model multi-site production problems, resource allocation problems, multi-agent task planning and other such coordination problems. The problems we consider are both globally multi-objective, and such that each objective function is additively separable along the subsets of variables characterizing the subsystems: it is the sum of terms which relate to subsystem problems. Thus, each restriction of the problem to variables characterizing a subsystem defines a local multi-objective problem for the same number of objectives as the global problem. Such a definition suggests a decomposition of the problem into subproblems, and a coordinated resolution of the subproblems. The weaker the coupling between the subsystems, the more relevant decomposition proves to be, for example relaxing the coupling constraints. Such strategies have been extensively studied in the single-objective case and with continuous variables. It should also be noted that the multi-objective versions of problems with "block angular" structures are a particular case of the class of problems under consideration. Our work differs from two main other approaches to the optimization of coupled systems. One is multidisciplinary optimization, in which, although global problems may be formulated as multi-objective, each subsystem problem is single-objective. Multidisciplinary problems are also endowed with a hierarchical structure of the subsystems, and thus benefit from natural coordination schemes. In our case, the absence of such properties is an obstacle to the decomposition of the global problem into a collection of parameterized subproblems, such that the optimal solution for a subproblem and a parameter value would provide a useful information for the pursuit of resolution - if only because a subproblem has not one but many incomparable optima. In addition, theoretical results suggest that combining local optimal solutions in order to get optimal solutions to the global problem cannot be done as straightforwardly in the case of Pareto efficiency as it can be done in the case of single-objective optimality. The second approach we differ from, stems from recent work by Dietz & al. (2018), who proposed a framework for complex systems multi-objective optimization in which subproblems are themselves multi-objective.

However these authors do not consider the global vector-valued objective function as an objective-wise aggregation of local objective functions along subsystems, rather they project the objective space of each subproblem into a subspace of the global problem's objective space. Finally, there is, to our knowledge, no literature dedicated to coupled systems with integer variables, in which subproblems can themselves be NP-hard. After having defined notions which are key to the study of the multi-objective combinatorial optimization of coupled systems, we will present a reference problem, which is of particular interest to us because both the global problem and its subproblems can be solved using multi-objective dynamic programming, which generalizes easily beyond two criteria. We will also propose a multi-objective Branch & Bound approach to the resolution of coupled problems, which uses decomposition to quickly obtain lower and upper bounds, and a branching scheme specifically designed to progressively decouple the problem and reduce it to a significantly easier version of itself. In particular, from a certain depth of the search tree, the problem will be fully decoupled and decomposition will be available to speed up the resolution using, once more, dynamic programming.

3. Rationalizable Strategies for Competing TSP with Multiple-Criteria

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The presented study concerns a novel method for solving Multi-Objective Games (MOGs), which are also known as vector-payoff games, multi-payoff games and multi-criteria games. The considered MOGs are non-cooperative, two-persons, zero-sum games with pure strategies, in which each player has self-conflicting objectives and none of the players has a-priori objective preferences. Yet, each player knows all the available strategies of the opponent and all the payoff vectors that result from all possible interactions between their own and their opponent's strategies. The main assumption is that not only that each player is rational but also that each player knows it.

Namely, common knowledge of rationality is assumed. The considered MOGs involve incomplete information that induces partial order to the outcomes of the game. Traditionally, such MOGs have been solved either by an equilibrium solution concept or by a MiniMax solution concept. Yet, existing studies suffer from not considering performance trade-offs. Namely, they assume that the players have no preference of objectives when selecting a strategy. In contrast, this study is based on the assertion that in general decision-makers should take into account performance trade-offs when making a decision. In view of the aforementioned assertion and the state-of-the-art, a novel solution concept to MOGs has been recently suggested by the authors. In contrast, following the solution concept of rationalizability, here the solution concept is revised into mutual-rationalizability that involves the assumption of common knowledge of rationality. The proposed approach, for solving MOGs, involves two-stages. In the first stage, a Set of Rationalizable Strategies (SRS) and their associated payoff vectors are sought for each of the players. This is done using Pareto-based best replies of the opponent, with an iterative search technique that accounts for mutual-rationalizability. The proposed mutual-rationalizability approach results with trade-off information at the end of the first stage. In the second stage, Multi-Criteria Decision Analysis (MCDA) techniques are used to select a strategy out of the obtained SRSs based on the trade-off information that is revealed in the first stage. To demonstrate the proposed solution concept a MOG version of the Traveling Salesperson Problem (TSP) is employed. The latter game type (TSP MOG) amalgamates two known versions of the TSP including the competing TSP and the selective TSP. The demonstrations include several case studies with a relative small network of cities, which allows full sorting that results in the exact SRSs. The main conclusion from this study is that the proposed solution concept, as amalgamated with the suggested MCDA techniques, provides players of MOGs with a novel approach to support justified strategy selection based on trade-off information.

4. Reducing Times for All Efficient Extreme Point Computation in MOLPs with Larger Numbers of Objectives

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The paper addresses unresolved issues with regard to the problem of partitioning the criterion cone of a multiple objective linear program (MOLP) into sub-cones for the purpose of solving a MOLP in parallel to achieve dramatically reduced times in all efficient extreme point computation. One of the issues discussed is the declining effectiveness of the approach as the number of objectives increases. Another is the task of balancing the size of the sub-cones in accordance with the size of their spherical caps. Numerous graphs are shown and some interesting computational experience is reported in connection with this paper.

THU-4-F

Contributed Session: MCDM for Strategic, Tactical and Operational Decisions

Thursday 14:20-16:00 - Room: Basilica Cistern

Chair: Alexander Engau

1. World Mega Trends and Their Implications for MCDM Research

Hannele Wallenius, Aalto University, Finland, hannele.wallenius@aalto.fi

**Jyrki Wallenius, Aalto University, Finland, jyrki.wallenius@aalto.fi*

We overview several of the technology mega trends and other trends, which are of interest from the MCDM perspective. We discuss, what role MCDM could play in this revolutionary development. We also discuss how the mega trends change the field of MCDM. Digital technology is making rapid advances. The implications for people, companies, and societies are pervasive. The envisioned changes will bring about: (1) digital connectivity, independent of time and place, and (2) tools for quickly analyzing vast amounts of digital data. In the World Economic Forum's recent report, the

changes are grouped into six “mega-trends”. We will focus on the following three. 1. The Internet – world’s access to the Internet will continue improving; people’s interaction with it will become more ubiquitous 2. Big data and Artificial Intelligence – the ability to access and analyze huge amounts of data 3. The sharing (or platform) economy These trends will greatly impact our lives, businesses, and governments - even universities - all around the world. As the World Economic Forum’s Report astutely observes, our lives are increasingly being driven and enabled by software. The potential of the digital technology is huge, both in enhancing traditional industrial processes (robotics), and even more importantly in generating novel digital services. Many aspects of healthcare are also benefiting tremendously from new technologies. The digital revolution has begun. Besides technology mega trends, there are other highly important mega trends. These mega trends, unlike technology mega trends, are generally perceived as challenges or threats to humankind. Some of them are discussed in PwCForesight#megatrends and by the World Economic Forum, for example: climate change, concern for environment. We discuss the above mentioned technology mega trends and the non-technology mega trend related to climate change from the above World Economic Forum’s list. What role can MCDM play in them? How can MCDM help? What MCDM concepts will be useful? The ubiquitous nature of internet will present new opportunities for MCDM scholars. We need new kind of decision support for billions of users who shop online. The support in an online environment must, however, be simpler than traditional MCDM tools. Search engines used to find desired products or services, but (price-only) search engines are not necessarily good enough in differentiating among offers. There is a need for multi-attribute search engines. Moreover, popular recommender systems should better capture people’s preferences. Big Data needs optimization tools to help DMs, data alone is not sufficient. Do we want to delegate important decisions to robots? The MCDM spirit has been to highlight the importance of the human decision maker. We feel that it is important that technology is seen as augmenting human capabilities, not replacing them. How do we make sure that

the learning robots have ‘emotions’ and empathy? New opportunities for our field are offered by platform economies, where supply and demand meet. The preferences of those who demand services and who offer services must be matched. We can envision several novel application areas for MCDM, such as online auctions, voting advice applications, ride-sharing apps, accommodation-sharing sites. The environment is one of the most popular application areas for MCDM tools. These problems require DMs to consider multiple criteria and complex tradeoffs. An important area for MCDM is helping design environmental and energy policy. Moreover, a novel application area is investment decisions to be based not only on expected returns and volatility, but a third dimension: sustainability, ethics. We conclude our presentation by describing our views on how we see MCDM changing as a result of these trends.

2. Using FICO Xpress for Solving Large-Scale Multi Objective Combinatorial Optimization Problems in Finance

**Sebastien Lannez, FICO Xpress Optimization, United Kingdom, SebastienLannez@FICO.COM*

With the FICO Decision Optimizer software, powered by FICO Xpress solvers, a strategy analyst can define and optimize complex decision problems using an intuitive graphical workflow. In this talk, we will show how an analyst user without prior experience of optimization can create a loan amount pricing optimization application and solve complex multi objective optimization problems. The presented example business problem aims at determining the best loan amount and price to be offered to the customers in a lender’s portfolio. In order to comply with regulatory constraints and company policy the solution must satisfy certain budget and loss limits. These calculations are defined by various artefacts, like PMML probability models or equation components, and then combined and linked together to form the Decision Impact Model, a graphical model representing the full decision making process that leads to the offering, which can also be considered as a Bayesian Networks of causal probabilities which calculate the expected decision

outcome values. This Decision Impact Model is automatically transformed into optimization problems, simulation routines or scoring algorithms, without any intervention from the end user. Solutions generated by the software can then be compared using the built-in dashboards making it simple to benchmark business-as-usual or challenger solutions from a simulated decision process against optimized solutions generated by the solver. The optimization problem that is automatically produced by Decision Optimizer is a Generalized Assignment Problem. Each account in the portfolio is assigned a treatment which corresponds to a set of predefined actions. The global constraints of the GAP are used to model resource limits like budget or available offers. A typical instance of this application has 150 treatments, 1M accounts and between 5 to 20 global constraints. The two functionalities we will present during this talk allow the user to explore the objective function value space and discover the relationships between various objectives by solving multiple objective combinatorial optimization problems:

- In the first approach, the user specifies what are the objectives or constraints to explore, defines ranges and the exploration step size and lets the optimizer search for optimal solutions in the partitioned feasible space. This approach can be seen as a simplified version of the epsilon constraint method described by Haimes, Ladson and Wismer [1] in which the epsilons are uniformly sampled over a distribution defined by the end user. The optimization problem is solved for every partition and the optimal solutions are displayed on a two-dimensional efficient frontier graph for which the two axes are taken from the set of objectives. We show that this predefined partitioning of the feasible space is a tractable approach for large optimization problems.
- With the second method the user can choose to apply a more dynamic approach based on an implicit enumeration of all possible epsilon values as proposed by Kirlik and Sayin [2]. This latter approach ensures that all non-dominated solutions will be found but is computationally more demanding. We will give preliminary results comparing the time and memory requirements of the two approaches.

- [1] Haimes, YY, Ladson, LS & Wismer DA, "Bicriterion formulation of problems of integrated system identification and system optimization." IEEE Transactions on Systems Man and Cybernetics, vol. 3, pp. 296, 1971
- [2] Kirlik G, Sayin S, "A New Algorithm for Generating All Non-dominated Solutions for Multiobjective Discrete Optimization Problems." European Journal of Operational Research, Vol. 232, pp. 479–488, 2014

3. On Combining Explainable Artificial Intelligence and Interactive Multiobjective Optimization in Data-Driven Decision Support

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Nowadays, many decision making processes are driven by data and, thus, the term data-driven optimization has been widely used. Data can be coming, e.g., from different sensors due to rapid rise of Internet of Things, experimental measurements or social networks. The amount of available data is often huge and it poses challenges for decision making in i) how to find and apply relevant data for the problem at hand and ii) how to use that in supporting decision making. On top of that, the problems often have multiple conflicting criteria that need to be optimized simultaneously, thus, requiring multiple criteria decision making (MCDM) techniques in finding a most preferred solution. Machine learning (ML) tools are often essential in building the optimization problem from the data. In addition, ML can be used to learn decision maker's (DM's) preferences in order to propose promising solution candidates during the solution process. If the DM does not understand why certain solutions are proposed, it may hinder the DM in trusting those recommendations resulting in not considering them at all. Therefore, the ML tools used should also give an explanation why the solutions are proposed to the DM. These methods belong to explainable artificial intelligence which is an emerging research field due to high popularity of applications of artificial

intelligence. So far, explainable ML methods have been used to explain performance of ML algorithms but they have not been used much as a decision support for MCDM (i.e. in a prescriptive analytics context). By explaining their reasoning to the DM, the ML-based decision support tools become more easily trusted and accepted by them. This means that when the DMs understand better the reasons behind the decision support, they are equipped to make more transparent and trustworthy decisions. This is especially the case when dealing with multiple conflicting objectives, where understanding the trade-offs between the objectives is crucial. In this paper, we discuss the challenges of combining explainable ML with interactive multiobjective optimization in a data-driven context. By using an example case study, we show how these two distinct approaches can be combined and what kind of issues must be considered in order the combination to be effective. To our knowledge, this has not been done before. Typical to interactive methods is that the human DM actively participates in the solution process and provides preference information when the most preferred solution is searched. The challenges include 1) which way to utilize ML within the optimization process, 2) what kind of explanations to provide for the DM, and 3) how to present the explanations to the DM. The first challenge deals with identifying the role of ML as a part of the whole solution process and what kind of ML tools to use. It is commonly known that there exists a trade-off between the performance and explainability of ML models. For example, deep learning with neural networks has recently become popular ML approach for complex data. While those models have a good performance, their explainability is very low. On the other hand, decision trees have high explainability but may not perform so well with complex data. Secondly, the type of explanations depends on the ML models used as well as the application considered and they can be, e.g., visual or descriptive. Finally, how to communicate the explanations to the DM is also important and requires a graphical user interface (that is also an important element in interactive multiobjective optimization methods) utilizing, e.g., techniques from visual analytics to communicate the message.

4. Multicriteria Project Prioritization in Transportation Asset Management

**Alexander Engau, Dalhousie University, Canada,
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Transportation systems all over the world continue to grow rapidly and to become increasingly complex. To better program and respond to the many resulting challenges, Transportation Asset Management (TAM) deals with the planning, building, operating, maintaining, upgrading or expanding of the underlying transportation infrastructure and its physical assets including roads, bridges and any other transportation facilities. Hence, in their most general form, TAM goals are to optimize overall system performance including cost effectiveness and efficiency, resource allocation and utilization as well as the general satisfaction of all users and system stakeholders. It follows that TAM is inherently multi-criterion in nature so that its decisions and any related decision-making procedures should ideally follow best business and engineering practices and be conducted based on quality, relevant and credible information with well-defined objectives for a meaningful tradeoff and decision analysis. Following a general discussion of transportation asset management in practice, this presentation then will focus specifically on one “real-world” situation based on a recent collaboration with a major transportation agency in the United States. In agreement with the mission, vision and general goals of its recent strategic management plan, we will begin to briefly outline the underlying objectives hierarchy which includes system performance and general organizational excellence, safety and health, stewardship and efficiency as well as sustainability, livability and economy. In particular, having been invited to review and further propose associated multi-objective decision analysis (MODA) approaches for its optimal resource allocation and project prioritization, we will highlight a few specific lessons we have learned. First, we will shortly revisit the original suggestion to merely use a standard cumulative benefit for a classical benefit-cost knapsack heuristic and comment on its well-known drawbacks and perceived disadvantages in comparison to some of its other more positive benefits. Second, we will

continue in more detail to also describe two closely related, alternative but actual MODA approaches that are based on multi-objective goal programming and data envelopment analysis, respectively. Third, we will compute and compare their final compositions of several optimal project portfolios using an experimental but realistic data set of 40 candidate projects with a total cost of approximately \$855.9 million dollars under different budgets. Finally, and in conclusion, we would also be delighted to entertain additional comments or questions for the further discussion of each of these current MODA approaches and their possible use, value and ongoing improvement.

FRIDAY

FRI-1-M

Society Award Talks

Friday 9:30-12:00 - Room: Galata Tower

Chair: Jyrki Wallenius

FRI-2-A

Invited Session: New Approaches in MCDM

Friday 13:00-14:40 - Room: Galata Tower

Chair: Gülşah Karakaya

1. Ranking with Multiple Reference Points : Efficient Elicitation and Learning Procedure

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In the context of multicriteria ranking problems, we consider a ranking procedure based on reference points recently proposed in the literature. This method, known as Ranking with Multiple reference Points (RMP) makes use of the following preference parameters to specify the decision maker judgment: (i) a set of reference points and (ii) an importance relation on criteria coalitions. Using the RMP method, alternatives are compared to reference points considered successively in a certain order. An alternative is considered better than another if the coalition of criteria on which it is better than a reference point is more important than the coalition of criteria on which the other is better than the same reference point. Implementing the RMP method in a real world decision problem requires to elicit the

model preference parameters. This can be performed indirectly by inferring the parameters from stated preferences, as done in previous research papers. Learning an RMP model from stated preferences proves however to be computationally extremely costly and can hardly be put in practice using state of the art algorithms. We propose a Boolean satisfiability (SAT) formulation of the inference of an RMP model from a set of pairwise comparisons, which is much faster than the existing algorithms based on mathematical programming. We present the SAT clauses that aim at inferring the model and explain them. The SAT formulation is tested on artificial data sets. We set up an experimental framework and assess the computing time and the performance of the formulation in generalization. In the experiments, we vary the size of the learning set and the size of the model that has to be learn. Finally, we present a MAX-SAT formulation which allows inferring a RMP model when the learning set is not fully compatible with such a model. The MAX-SAT formulation is tested on artificial datasets.

2. PROMETHEE Approaches for Medical Decision Support Under Uncertainty

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Musculoskeletal diseases have a high burden on healthcare resources in Turkey due to increasing age of the population. Therefore, we aim to develop a decision support tool that can support and validate the decision makers' (doctors or physiotherapists) choices and offer other alternatives to patients who are far from the physiotherapy centres. Musculoskeletal diseases have a variety of treatment options such as medical interventions and physiotherapy applications like surgery, manual therapy and orthoses. Several factors are considered when assessing the outcomes of these treatments such as pain, side effects, cost and convenience for the patient. We

handle these factors as criteria and the treatment options as our potential alternatives. Accordingly, in order to detect the most effective treatments for patients, we use a Multi Criteria Decision Making (MCDM) approach. In our approach, treatment options can have probabilistic outcomes in some criteria. To represent this uncertainty, Bayesian Network (BN) models are used. A BN is a graphical probabilistic model that represents relations of variables and their probability distributions. In our problem, output of the BN shows the probabilistic outcomes of decision alternatives in the criteria considered for a given patient. After obtaining the outcomes from BN, we use the well-known outranking method PROMETHEE. To obtain the weights of criteria used in PROMETHEE, we consider carrying out Analytic Hierarchy Process with experts in the field of physiotherapy. To be able to work with probabilistic outcomes, we first make use of Monte Carlo Simulation to generate a large number of discrete scenarios. Using these scenarios, we work with both PROMETHEE I and II to evaluate the treatment options. PROMETHEE I produces a partial ranking of alternatives, whereas PROMETHEE II produces a complete ranking. We apply our approach to evaluate nine treatment options with six criteria. Working with probabilistic outcomes of criteria, our approach is able to provide decision support that can handle this uncertainty.

3. An Interactive Sorting Approach Based on Information Theoretic Measure

**Ali Özarslan, Middle East Technical University, Turkey, oali@metu.edu.tr*
Gülşah Karakaya, Middle East Technical University, Turkey, kgulsah@metu.edu.tr

In this study, we develop an interactive approach for sorting alternatives. We assume that the preferences of the decision maker are consistent with an additive function. We assign worst and best possible categories for each alternative and narrow down these category ranges using mixed integer programming (MIP) iteratively. We utilize binary variables to assign the alternatives for which the classes are not known exactly. We incorporate the worst and best possible category information to the MIPs whenever new information is obtained.

In each iteration, we find the assignment frequency of alternatives for each category using the values of the binary variables gathered from the MIPs and calculate the probability of an alternative to be placed in a category based on these frequencies. We then use the information theoretic measure, entropy, in the selection of the alternative that will be placed to a category by the decision maker. The entropy concept fits well to our measurement of uncertainty about the categories of the alternatives since the aim is to ask the decision maker an alternative that will yield much information to the decision process. We test the performance of our approach on an example problem from the literature and the results show that it works well.

4. Comparison of Solutions under a Weighted Tchebycheff Function

**Gülşah Karakaya, Middle East Technical University, Turkey, kgulsah@metu.edu.tr*
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In this study we address the comparison of a number of solutions that are defined by multiple objectives and evaluated with a weighted Tchebycheff function. Tchebycheff functions can be used for a variety of purposes when multiple criteria are considered. One such use is the evaluation of an approximation of a Pareto set. It is not straightforward to find the true Pareto set especially for multi-objective combinatorial optimization problems. Heuristics have been developed to approximate the Pareto set. To measure the quality of approximate Pareto sets and to compare such sets with each other, there are some performance indicators such as hypervolume measure, epsilon indicator, and integrated preference function (IPF) measure. A Tchebycheff function-based IPF measure can be used to estimate how well a set of solutions represent the Pareto set. It measures the quality of the representation well but is computationally demanding especially as the problem size gets larger. We improve the computation of the IPF measure to make it practical for complex problems. We develop the necessary theory to define some relations of the solutions in the weight space

so that the IPF calculation can be done efficiently. The theory not only facilitates the practicality of the IPF calculation but also enables to incorporate the preferences of a decision maker whose preferences can be approximately represented by a Tchebycheff function to converge preferred regions of the solution space in an efficient manner. We demonstrate our approach on example problems with two, three, and four objectives.

FRI-2-B

Contributed Session: Fuzzy sets and approaches

Friday 13:00-14:40 - Room: Maiden's Tower

Chair: Sait Gül

1. IT Project Performance Management in Fuzzy Environment: A Case Study

**Ayfer Başar, Istanbul Technical University, Turkey,
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The project is described as a temporary discrete endeavor to create a unique product, service, or result. Project management involves the processes about planning, executing, controlling and closing to deliver the project outcomes (PMI, 2017). Assessing the performance of projects accurately becomes challenging in all the industries and the failure directly affects the sustainability of the companies. Therefore, organizations look for the efficient techniques to measure and increase the project performance. Traditionally, project performance was calculated based on the fulfillment of the cost, time, and quality goals. Later, this approach was found insufficient and a set of new criteria are proposed for the project performance calculation (i.e. meeting the requirements of quality, safety, customers satisfaction, changes in the scope, innovation etc.) In addition to a wide range of criteria, different techniques have been applied to measure the success of projects in academic and professional studies (i.e. Earned Value Management - EVM, Earned Schedule - ES, and Earned Duration Management - EDM). Although the literature on project performance management is rich; the frameworks and solution methods handling

the uncertainty on IT project performance management have not been addressed in detail. This brings about many problems especially unmet cost, time, and quality goals. Thus, most of the projects are failed and IT companies waste their resources. Therefore, researchers and IT practitioners try to find new ways of measuring the performance of IT projects with the help of effective criteria and improve the results by focusing on the root causes of performance issues. Furthermore, since most IT companies place emphasis on meeting cost, quality, and time goals, there is a need to enhance the set of performance criteria in such a way that it covers other fundamental performance factors (i.e., ROI, net profit margin, customer and team satisfaction, developing skills etc.) especially in uncertain environment. This paper presents a novel methodology to measure the performance of IT projects in fuzzy environment by combining Balanced Scorecard (BSC) used for performance management and Hesitant Fuzzy Sets (HFS) used for subjective weighting of IT project performance factors. BSC is an internationally accepted method to model the performance management of IT projects by its balanced and multidimensional structure. On the other hand, HFS is a new area in the fuzzy literature. In this study, firstly, we hierarchically model the IT project performance problem with the help of BSC structure, and then find the importance values of 4 perspectives (finance, customer, internal business processes, and learning-growth) and 12 critical success factors (return on investment, net profit margin, and meeting the budget for finance; customer satisfaction, contribution to the market share, and creating the new market for the customer; meeting customer needs, meeting schedules, team efficiency for the internal processes; team satisfaction, developing skills, and contributing to the retention of team members for learning and growth) with the help of expert judgment and HFSs. We experimentally show that finance is the most important perspective while customer is also fundamental in terms of achieving IT vision and mission. Furthermore net profit margin, creating the new market, meeting schedules, and team satisfaction are the most important critical success factors in terms of finance, customer, internal business processes, and learning-growth respectively.

The results of the case study demonstrate that the performance of 7 IT projects are higher than 60%, and there is only one project with its performance below than 30% among 68 IT projects completed in a Turkish company in 2018. The outputs of this study are found acceptable by senior IT managers, project managers, customers, and team members of the company.

2. Selection of the Appropriate Solution Method for the Home Health Care Vehicle Routing Problem by Fuzzy Analytical Network Process: A Case Study of Erzincan

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In recent years, logistic activities attract more attention with their increasing importance in every sector. Health is one of the most important of these sectors. According to the World Health Organization (WHO), "Health logistics is an important part of technical assistance in emergency situations; it is to manage the transport of infectious substances for laboratory tests, including the maintenance and distribution of stocks, and to provide coordination during the outbreaks". The health institution brings together the client or the patient and the health care team or the doctor and takes on a role in preparing the optimal environment for the treatment to be implemented. The way in which health services are presented is one of the most important indicators of socio-economic development levels. Home Health Care (HHC) in Turkey aims to give health services to people who are bedridden in their residence. The health sector is a sector that can cause irreparable results if the services delay. For this reason, the logistic infrastructure should be strong and should be used effectively in health services. With the application of Vehicle Routing Problem (VRP) in many areas of the health sector, in which time is the biggest limitation, improvements in the sector of the route will

be provided and there will be savings in the transportation and storage and labor costs. With these features, VRP applications have been taking more and more place in the health sector. When the domestic and foreign literature on VRP studies in the field of health are examined; ambulance, dialysis, blood transfusion and home care services have been observed to be VRP studies. In this respect, the aim of this study is to determine the best VRP's solution method which can increase the efficiency of HHC by using Fuzzy Analytic Network Process (FANP). This model includes both criteria (number of patients, cost of solution, solution time, the number of vehicles and employees) and the alternatives (definite, intuitive and meta-heuristic solution methods). The analysis was carried out on the basis of information shared by Erzincan Provincial Directorate of Health and actual data sets obtained within the scope of Personal Data Protection Law. According to results, the most important criterion is solution time. Meta-heuristic solution methods is the appropriate method for the home healthcare vehicle routing problem.

3. Usage of Entropy-Based Objective Weighting in Neutrosophic Multiple Attribute Decision Making

**Sait Gül, Beykent University, Turkey,
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Multiple attribute decision making (MADM) approaches focus at selecting the best alternative from a set of alternatives by considering different attributes. Since evaluation of alternatives is based on the importance of the attribute which are represented by weights, decision analysts should choose a proper weighting method. There are two basic types of weighting. The first one is subjective weighting (for instance, pairwise comparison of AHP) that consults the expertise of decision makers (DMs) with the aim of revealing the hidden information in their conscious and showing them with numbers. The second weighting is called objective weighting. This type ignores the DMs' attribute prioritization and just looks the alternative points which are measured with respect to attributes. In literature, some drawbacks are specified for subjective weighting such as risks that may be originated from self-seeking DMs or possible long time periods that are required for data

collection from DMs. To overcome them, objective weighting methods are developed. In real life, decision problems and information about alternatives can be incomplete, indeterminate and inconsistent. To deal with this problem, there are some propositions in literature. Intuitionistic fuzzy set (IFS) which was introduced by Atanassov (1986) as an extension of Zadeh's fuzzy set theory (1965) was generalized to a new concept called neutrosophic set (NS) theory by Smarandache (1998). The membership degree is proposed as a real number in unit interval by Zadeh and two degrees are proposed to represent uncertain information in IFSs: degree of membership and degree of non-membership. NS is described independently by truth, falsity, and indeterminacy membership degrees: $A=\{x, TA(x), IA(x), FA(x) \mid x \in X\}$. In literature, the single valued NS (SVNS) and interval valued NS (IVNS) are proposed as the instances of NS. $TA(x), IA(x), FA(x) \in [0,1]$ are the membership degrees of a SVNS, consecutively. In IVNS, the membership degrees are represented as intervals. In existing literature, there are many papers studying the neutrosophication of classical MADM methods (N-MADM). For example, Basset et al. (2018) proposed a neutrosophic AHP; Kour and Basu (2017) developed a neutrosophic TOPSIS and Liang et al. (2017) constructed a SVTN-DEMATEL module. To our best of knowledge, there is no objective weighting methodology proposition in literature and all the current articles apply the subjective weighting of attributes. Entropy is an important mathematical tool for measuring uncertain information. Entropy-based objective weighting is based on an idea: an attribute is more important if there is a greater dispersion in evaluations of alternatives for this attribute. According to this definition, the dispersion of the data in the same attribute can be a measurement of its importance. There are many entropy measurement approaches in NS literature and various examples are given below. If the entropy of an attribute j is represented by En_j , its weight can be calculated by the formula of $w_j = (1-En_j) / (\sum_j(n-En_j))$ where n is the number of alternatives. In this study, we propose the usage of entropy measurement in determining the attribute weights for the first time in literature with a focus on objective weighting in N-MADM. 7 entropy methods for IVNSs are considered for solving

two different hypothetical decision making problems in order to present the proposed method's usability and efficiency. Exponential entropy by Ye and Cui (2018), 4 different methods developed by Ye and Du (2017), a method from each of Aydoğdu (2014), and Majumder and Samanta (2014) are used for the calculation of objective weights. The results of applications show that the entropy-based objective weighting is properly useful in IVNS based N-MADM. An ANOVA (analysis of variance) test is utilized for the comparison of the weight sets generated by 7 different entropy-based methods.

4. Objective Weighting of Decision-Makers and Attributes in Neutrosophic Group Decision Making: A Review

**Sait Gül, Beykent University, Turkey, saitgul@beykent.edu.tr*

Each MADM method requires information about weights representing the priorities of attributes. Similarly, in group decision making (GDM) decision makers (DMs) can usually possess different levels of expertise which can be measured by weights of them. In real-time problems, both types of weights can be incompletely known or completely unknown. There are two basic weighting procedures: subjective and objective techniques. In real life applications of MADM and GDM, information required can be incomplete, indeterminate and inconsistent. To handle this issue, the neutrosophic set (NS) theory was developed as an extension of fuzzy sets. NS is described independently by truth, falsity, and indeterminacy membership degrees: $A=\{x, TA(x), IA(x), FA(x) \mid x \in X\}$. In this study, the aim is to make a brief overview of objective weighting of attributes and DMs in N-GDM. After an extensive research and filtering process on scientific databases, such as Google Scholar and Web of Science, 27 papers handling objective weighting issues were found. By a detailed analysis, brief inferences which are given below are made. In literature, 26 papers of 27 utilized any objective attribute weighting methods and eight different approaches were noticed. The most utilized one is Maximizing Deviation by 11 papers (42%). Entropy takes the second place with 5 papers (20%). In the 3rd place, there are

optimization models from 4 papers (15%). The remaining methods are Grey system, mean-squared deviation, variation coefficient, TOPSIS, and multi-objective optimization. Deriving DMs' weights constitutes a relatively new domain in GDM area. In N-GDM literature, only 4 papers used an approach regarding weighting of DMs. TOPSIS-based approaches were used by 3 papers and one of them used variation coefficient method simultaneously. One paper utilized a score-function based approach. While 5 papers accepted the DMs' weights as given, 4 papers appealed qualitative group consensus. Also, we found 14 MADM applications in N-GDM literature. The mostly used ones are TOPSIS by 9 (33%), GRA by 7 (26%) and VIKOR by 3 papers (11%). Among 4 papers which considered the weights of DMs, 2 papers selected VIKOR, 1 paper chose an integration of TOPSIS and QUALIFLEX, and the last one used a score function based method. As additional findings, the N-GDM studies used various types of information as instances of NS. 11 papers (41%) worked with single-valued NS, and 6 papers (22%) utilized interval-valued NS. Each paper performed an application of their proposed methodologies but only 4 of them worked on real problems (15%). Finally, only 10 papers (37%) are published by SCI/SCI-E indexed journals. While the number of papers which appeared in SCI/SCI-E journals is just 2 before 2017, remaining 8 papers have been published during the last 2 years. Consequently, it is seen that the N-GDM literature requires more objective methodologies since the number of papers studied these weighting issues is few and the applications of developed methodologies are limited. 23 papers (85%) introduce only illustrative applications, not real ones. It is obvious that it is required to show their applicability in real life problems. The number of papers published in SCI/SCI-E indexed journals has been increased after 2017. So, this finding shows the increasing reliability of this novel decision making domain. All these findings can provide guidance to the future researches on objective decision making in neutrosophic environment.

FRI-2-C

Contributed Session: Advances in MCDA

Friday 13:00-14:40 - Room: Dolmabahçe Palace

Chair: Ana Sara Costa

1. Decision Making Procedure Using Strict Preference Information for Group Decision Based on Multi-Attribute Utility Analysis

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Multi-attribute utility analysis (MAUT) constructed by Keeney and Raiffa (1976) is a method for decision making for multi-criteria decision-making problem, which models the trade-off relationship between attributes considering the preference structure of a decision maker. The multi-attribute utility function consists of a utility function for a single attribute and a scaling constant representing a weight for a plurality of single attributes. The scaling constant quantitatively expresses the trade-off relationship between decision-making person's attributes, and in the procedure proposed by Keeney and Raiffa, it is uniquely identified by indifferent experiments. Based on the identified utility function, the decision maker can rationally choose one of the most preferred alternatives. However, when there are many attributes to estimate or when collective decisions are made by multiple stakeholders it is difficult to answer consistently through multiple questions to identify the preference structure. Since all decision makers do not have expertise, utility functions cannot be uniquely identified. Hayashida et al. (Hayashida et al., 2010, 2011) show the usefulness of MAUT in practical problems. As an extension procedure of MAUT Nishizaki et al. (2013) have proposed a decision procedure such that the decision maker or the corresponding stakeholder answer the strict preference relationship between some pairs of virtual

alternatives which can be easily answered to estimate the scaling constants of the corresponding multi-attribute utility function. Furthermore, in case that scope of the scaling constants cannot be determined based on a single exact relationship between the pairs of alternatives, a new questionnaire is generated based on the result of the answers. As a procedure based on such idea, a neural network MAUT (NN - MAUT) (Nishizaki et al., 2014) is proposed which a neural network is applied to estimate the scaling constants. Here, the weights and the thresholds of a neural network are updated by genetic algorithms. MAUT Excel (Hayashida et al., 2013) and MIDASS (Seo et al., 2004, 2007) have been constructed as decision support systems based on MAUT. This study proposes a procedure to select an alternative rationally even if a decision maker does not have enough expert knowledge. Nishizaki et al. (2013) assumed that a decision maker is asked some strict preference relationships between some pair of the virtual alternatives, and if there is no contradiction in the answers, the scaling constants are uniquely determined. This study proposes a procedure to select alternatives by estimating their distribution if the answer includes some contradiction. Note that the procedure of Nishizaki et al. (2013) deals with multi-attributes utility functions which are defined in multiplicative form, however, this study deals with utility functions which are defined in additive form to simplify the calculation procedure.

2. A Method of Reaching Consensus with the Multi-Actor Multi-Criteria Analysis (MAMCA) methodology

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The multi-actor multi-criteria analysis (MAMCA) is a methodology which allows for the inclusion of multiple stakeholders in the process of evaluation and decision making.

It is important in particular the field of transport project appraisal, as many projects fail to be implemented because of lack of support from one or more key stakeholders. In contrast to many multi-criteria decision analysis (MCDA) methods, multiple stakeholders can use different criteria trees in MAMCA (with their own preferences). The steps of the classic MCDA process include: definition of problems, alternatives and criteria, analysis of alternatives, determination and analysis of scores, and the drawing of conclusions. Unlike classic MCDA, MAMCA involves stakeholders after defining the alternatives. The stakeholder analysis is conducted, stakeholders are identified and the criteria tree for each of them can be constructed. In this way, MAMCA explicitly takes into account their own objectives. In the end, the advantages and disadvantages of each of the proposed scenarios are presented and possible consensus scenarios are discussed. Yet in some cases, it is challenging to reach a consensus based on MAMCA results. In this contribution, we propose a way to help facilitators and stakeholders to find a consensus utilizing the PROMETHEE method in MAMCA. Doan and De Smet recently developed an alternative weight sensitivity analysis for PROMETHEE based on mixed integer linear programming (MILP). MILP avoids altering all the weights and reduces the distance from the original weights compared to classic weight stability intervals (WSI) (which can find the minimum weight modification to change other alternatives to be ranked first). It can be applied in the MAMCA methodology to offer a consensus between different stakeholders by taking the inverse optimization point of view. The MILP-MAMCA method allows computing two possible indicators R1 and R2 (with two different ways to deal with the maximum weight modification), which indicate the distance among all stakeholders for each alternative to reach the consensus. We apply this new approach on two MAMCA project cases. Then we examine how to integrate this model into the existing MAMCA methodology and visualize the results with the MAMCA software.

3. Stochastic Analysis Applied to a Multiple Criteria Hierarchical Nominal Classification Method based on Similarity and Dissimilarity

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In multiple criteria nominal classification problems, the assignment of an action may include a set of possible categories, instead of only one, raising the challenge of how to support the Decision Maker (DM) in analyzing the accuracy of the assignment of each action. In this work, we propose a robust nominal classification method using criteria structured in a hierarchical way, adopting an integrated approach. Stochastic Multicriteria Acceptability Analysis (SMAA) and the nominal classification method CAT-SD (CATegorization by Similarity Dissimilarity) are put together to deal with nominal classification problems with hierarchical criteria and imprecise weight information. This proposal follows four main steps: (i) application of Multiple Criteria Hierarchy Process (MCHP) to CAT-SD; (ii) application of the imprecise SRF method, for each category, while the hierarchy of criteria and the possible interactions effects in criteria pairs are considered; (iii) combination of SMAA and the hierarchical CAT-SD (SMAA-hCAT-SD) by sampling sets of parameters compatible with the preferences of the DM previously provided; and (iv) obtain a final classification of the actions that fulfills a set of requirements given by the DM, by adoption of a novel procedure that allows considering the probabilistic assignments provided by SMAA-hCAT-SD. The results consider robustness concerns, while take into account the whole set of criteria or a certain node in the hierarchical structure. Thus, the DM can have a better and deeper understanding of the classification problem

at hand. The application of the proposed comprehensive method is illustrated through a didactic example. Acknowledgments: This work was supported by national funds through Fundação para a Ciência e a Tecnologia (FCT) with reference UID/CEC/50021/2019. Ana Sara Costa acknowledges financial support from Universidade de Lisboa, Instituto Superior Técnico, and CEG-IST (PhD Scholarship).

4. The Method of Multi-Attribute Non-Inferiority and Superiority Scores Heavy Averages (MANISSHA)

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In the current work, we show how to rank pre-specified alternatives by employing what will be referred to as the method of Multi-Attribute Non-Inferiority and Superiority Scores Heavy Averages (MANISSHA). This new method to multi-attribute ranking is founded on the three pillars: (1) non-inferiority and superiority scores, (2) heavy aggregation operators, and (3) Einstein sum operation. More precisely 1. The aforesaid non-inferiority and superiority scores of competing alternatives are produced using (crisp or valued) outranking relations. 2. The aforementioned scores are aggregated using the heavy weighted average (HWA) and/or the heavy ordered weighted average (HOWA) operators. 3. The values returned by the above operators are normalized in a new and unfamiliar manner and the resulting values are merged using the Einstein sum operation. 4. The competing alternatives are ranked from most to least preferred according to their Einstein sum operation output values. The proposed method is illustrated using a multi-attribute ranking problem and the obtained ranking results are compared to those yielded by the existing superiority and inferiority indexes based ranking methods: SIR-SAW, SIR-TOPSIS, SIR-VIKOR, and SISINA. Keywords: Multi-attribute ranking, Non-inferiority score, Superiority score, Einstein sum operation, Outranking relation.

FRI-2-E

Contributed Session: Evolutionary Algorithms and Multiobjective Optimization

Friday 13:00-14:40 - Room: Hagia Sophia

Chair: Michael S. Bittermann

1. A-GWASF-GA: The New Version of GWASF-GA to Solve Many Objective Problems

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A new version of the evolutionary algorithm based on GWASF-GA [1] is proposed in this work. GWASF-GA is an aggregation-based algorithm which uses the Tchebychev metric plus an augmentation term as fitness function and two reference points (the utopian and nadir points) to classify the individuals according to a set of widely-distributed weight vectors. Although this algorithm obtains a good approximation of the Pareto front (PF) for multi-objective optimization problems, this may be more difficult to obtain for many-objective optimization problems due to the fact that the weight vectors used are never updated along the search process. For this reason, we propose a new version of the algorithm, called A-GWASF-GA, in which a dynamic adjustment of the weight vectors is carried out. The main idea is to re-calculate some weight vectors in order to obtain solutions in parts of the PF with a lack of solutions. Firstly, a percentage (p) of the total number of evaluations is performed with the original GWASF-GA [1]. Secondly, during the rest of evaluations ($1-p$), we re-calculate na times the projection directions determined by a subset of Na weight vectors. The re-calculation process is based on a scattering level, a measure based on the distance of each solution and the solutions around it. According to the scattering level of the generated solutions, we detect the Na weight vectors projecting toward overcrowded areas of the PF and we re-calculate them so that

their new projection directions point towards areas of the PF which are not so well approximated. In order to show the effectiveness of A-GWASF-GA, we compare it with NSGA-III [2, 3], MOEA/D [4], MOEA/D-AWA [5] and the original GWASF-GA, considering ten problems with three, five, eight and ten objectives and with twenty and fifty decision variables. To evaluate their performance, we use the IGD metric [6]. The results of the computational experiment demonstrate the good performance of A-GWASF-GA in the novel many-objective optimization benchmark problems considered.

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2. A Reference Set Based Evolutionary Algorithm for Many-Objective Combinatorial Optimization Problems

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Methods for multi-objective optimization frequently suffer scalability issues when number of objectives is high. Recently, a number of many-objective evolutionary algorithms (MaOEAs) has been proposed to characterize and overcome the challenges presented when the number of objectives is higher than three. MaOEAs are categorized into several classes based on their key idea used and reference set based approaches are one of the most promising methods. In these approaches, a set of reference points is used to guide the search process and measure the quality of solutions. Reference set based methods differ from one another with respect to how they construct the reference set and how they measure the quality of the solutions during the evolution. It is crucial to develop an effective positioning and adaption strategy for the reference set. It is argued that an adaptive reference set strategy is necessary to deal with problems with objectives of different scales or problems having an irregular, degenerate, discontinuous, nonlinear Pareto fronts. Briefly, a good quality reference set should be less sensitive to the problem type and Pareto front geometry and should be scalable to many-objective problems. Most of the existing work on reference set based MaOEAs study well-defined continuous mathematical functions with designed Pareto front characteristics and studies on problem classes, such as combinatorial optimization, are still rare. In this study, we choose the many-objective versions of knapsack problem, quadratic assignment problem and minimum spanning tree problem as the benchmarks. Our proposed MaOEA combines the effective features of some existing many-objective evolutionary approaches together with several other prominent evolutionary strategies in an innovative fashion. It uses elitist non-dominated sorting and reference points that are mapped on a hyperplane. The hyperplane is constructed at the beginning of the algorithm by using the lexicographic optimal solutions and its position in the objective space remains fixed over the course of the algorithm. An adaptive reference point strategy is implemented during the evolutionary search based on gathered information from the population. Our algorithm also employs a non-dominated solution archive, a path relinking recombination scheme, complementing

parent selection mechanisms, mutation and local improvement operators. Numerical experiments demonstrate the success of the proposed algorithm compared to some existing approaches over the benchmark combinatorial optimization problems. The findings are inspiring and encouraging in terms of adapting reference set based techniques to many-objective combinatorial optimization problems.

3. Information-Based Evolutionary Algorithm for Interactive Computational Design

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A novel approach to selection in evolutionary algorithms is described. It is referred to as information-based selection, since the probability of reproduction of a population member is determined by the amount of information the individual represents in the context of the search. The objective is to develop an algorithm for interactive computational design. In such applications, identification of optimal solutions is only one of two motivations, as maximizing information about the designer's tacit goals is the second one. This is in contrast to usual application of evolutionary algorithm for solving engineering or decision-making problems, as objective functions are usually given in advance in these problems. The method proposed in this work is to measure the amount of information a population member carries in two respects, and to fuse the two measurements thereafter. The first information measurement is based on a probabilistic model of the convergence behaviour of the algorithm. What is measured is how informative an individual is for reaching optimality. The second information measurement is based on a probabilistic model of the diversity diminishment during the search. What is measured is how informative an individual is for preserving the diversity of the population. When an individual is found that is informative in both respects, then this member is to deem precious in the context of interactive evolution. The preciousness is

quantified using logic operation of the fuzzy neural tree methodology, combining the two information measurement results. One notes that the preciousness measure applies for both, single objective and multi-objective design problems. In both cases the diversity preservation aspect is computed in the same manner, as we are concerned with diversity in the decision variable space; and the information fusion is also accomplished via the same computations in both cases. The difference between single- and multi-objective cases is with respect to the optimality aspect. In the single-objective case, optimality is measured by a scalar number. Thus modelling evolutionary convergence refers to probability distribution associated with this dimension. In the multi-objective case optimality is measured by non-dominance in the form of rank or strength, depending on the algorithm. Thus modelling the convergence refers to probability distribution associated with the rank or strength dimension. The characteristics of the novel method are verified for two multi-objective optimization problems. The first one is a known test problem, while the second one is from the architectural design domain. For both problems the information-based evolutionary algorithm is compared against the same algorithm implementing tournament selection. The experimental results show that the information-based approach maintains a balance between diversity preservation in the decision variable domain and selection pressure in the objective function domain, whereas the conventional algorithm sooner exhausts this diversity in favour of higher selection pressure. The gain in chromosome diversity by the novel algorithm comes at a price, namely inferior convergence, as this is hinted by the 'no-free-lunch' theorem. The increased diversity in the decision variable space indicates the suitability of the novel method for interactive computational design. A generic contribution of the work to multi-objective evolutionary optimisation is introduction of information fusion during selection as alternative to applying a fixed hierarchy among selection criteria. This work has been accomplished under the auspice of ITU BAP (Scientific Research Projects Coordination Unit of Istanbul Technical University); grant no. MGA-2018-41526. The support is gratefully acknowledged.

FRI-2-F

Contributed Session: Making Decisions with Environmental Concerns

Friday 13:00-14:40 - Room: Basilica Cistern

Chair: Nahid Rezaeinia

1. Assessment of Energy and Emission Reducing Measures in Container Terminals Using PROMETHEE

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While serving as an interface of sea and land-side, container terminals play an important role in global supply chains. The operators of container terminals, on the one hand, are facing pressure on maintaining or even getting a higher level of throughput by shipping companies, on the other hand, port-authorities and governments put pressure on energy saving and emission reduction. Therefore, the goal of many container terminals today is to reduce energy consumption while maintaining or improving the current service level. Since most of the energy of container terminals is needed for handling equipment, emissions can be reduced by using clean energy or by replacing old equipment with energy-saving devices. The project "Simulation-based evaluation of measures for the improvement of energy sustainability in port operations" (SuStEnergyPort), carried out by the University Duisburg-Essen and the Hamburg Port Consulting GmbH (HPC) aims at developing a structured, model-based methodology to identify suitable measures that port operators can use to improve their energy efficiency and utilization of renewable energy. In this project, a selection of promising measures for the abatement of CO₂ emissions is implemented in a simulation tool covering both logistic and energetic aspects. As some measures include using new handling equipment, e.g. straddle carrier, a Life Cycle Assessment (LCA) is used to measure and compare the

environmental impact. In this talk, we analyze and evaluate different energy consumption and emission reduction measures applicable to container terminals using PROMETHEE. The assessment is based on data derived from the projects case study, the container terminal Tollerort (CTT) in Hamburg, and the simulation tool. We consider ecological, economic and social criteria and analyze the trade-off between energy or emission saving and service levels. The SIMOS method is used to determine the weights of the criteria for multiple stakeholders of the container terminals, e.g. operators and port-authorities. On the basis of this assessment, a roadmap towards a more profitable and ecological port operation can be developed.

2. Strategic Location Selection for Solar Warehouses: The Green Logistics Perspective

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Environmental pollution that results from an increase in greenhouse gas emission is one of the major problems that humankind has been encountered. In order to deal with these problems, several approaches are largely experienced in the supply chain domain and one the most prominent creative solutions shown in this context is the extensive use of green warehouses, which are principally solar warehouses that generate electricity by solar energy panels on the roof tops. In practice, implementation of the solar warehouses is regarded as a new approach not only for the sustainable logistics concept, but also for advancing environmentally sensitive green logistics. Yet, while implementing solar warehouses as a significant approach in the supply chain domain, more particularly in the logistics area, the selection of a warehouse location remains as a multi criteria decision making (MCDM) problem, where numerous quantitative and qualitative criteria exist. In such abundancy, it becomes essential to identify which solar criteria should be

considered in solar warehouse location selection decisions since the strategic location of a solar warehouse is of vital importance for the energy efficiency and effectiveness. In addition to their identification, the prioritisation of these criteria also needs to be evaluated in order to provide a realistic and powerful solution on reducing the environment pollution. Thus, in order to deal with these problems, this study first aims to determine the solar criteria and their importance ratings for solar warehouses. Furthermore, it is also aimed to examine how these solar criteria affect strategic location selection decisions of solar warehouses. Accordingly, in this study, the solar warehouse location selection criteria and their ratings are determined through the Analytical Hierarchy Process (AHP), Analytical Network Process (ANP), and Techniques for Order Preference by Similarity to Ideal Solution (TOPSIS) methods. More specifically, the AHP is used to examine the importance of solar criteria for selecting the solar warehouse location. The first three criteria appeared from the findings, which have a weight of 67% in total, were added to the existing warehouse location selection criteria for green logistics as this leads to the second part of the application performed by the ANP. Finally, the outcomes obtained from the first two methods formed the decision matrix to be used in the TOPSIS technique, which concluded the best solar warehouse location among five province alternatives. At the end of these stages, the findings of this study show that İzmir has the highest order of preference, with the value of 0.61, among province alternatives, followed by İstanbul (0.58), Adana (0.51), Ankara (0.46), and Samsun (0.36). To conclude, the proposed model holds novelties in the establishment of solar warehouse selection criteria and in the prioritisation of solar warehouses. While doing these, the application of multiple MCDM techniques in this strategic decision plays a significant role to contribute to the literature. Moreover, the presented findings also contribute to the advancement of research on solar warehouse selection in the green logistics literature and to the practice related to strategic decision-making on location selection for solar warehouses. Keywords: Analytic Hierarchy Process (AHP), Analytic Networking Process (ANP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Strategic

Decision-Making, Green Logistics, Solar Warehouse.

3. Multicriteria Methods and the Hydropower Plants Planning in Brazil

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Over the years, Brazil has been taking advantage of its hydroelectric potential in order to make the country self-sufficient in electricity, based on a clean, renewable and low-cost source. The hydroelectric potential of Brazilian river basins (approximately 250,000 MW) is being progressively exploited since the beginning of the last century, and today, with 44% of the potential already exploited, this type of electricity generation represents 65% of the Brazilian electric power matrix, with more than 200 hydroelectric plants with capacity greater than 30 MW in operation. As a major user of water, the electricity sector has the responsibility and duty to plan the use of this resource as an input for the production of electricity in a rational and optimized way, alongside the other users of water in the river basin. The planning of the hydroelectric expansion in Brazil is done through a series of studies that consider different time horizons and successive approximations. One of the first steps to the development of hydropower plants is the River Basin Inventory Studies and its main objective is to design and analyze all possible alternatives of group of hydropower plants in a river basin in order to select the most preferred one, which will determine the hydroelectric potential to be exploited in the basin. After this stage, each hydropower plant that composes the alternative selected in the Inventory Studies will be studied separately to analyze its feasibility in detail. The methodologies of the Inventory Studies have undergone several updates, mainly concerning the decision making, incorporating the yearnings of the society so that this choice effectively reflects the most

preferred alternative. In the beginning (until the mid-1980s), only one criterion was considered related to the minimization of the energy generation cost (construction, operation and maintenance). From then, environmental issues became more relevant and a multicriteria decision process was carried out, incorporating in the 1990s the minimization of negative socio-environmental impacts and, later, in the 21st century, the maximization of positive socio-environmental impacts, the less significant criterion. Nowadays, to select the most preferred alternative, the three criteria are aggregated into a single index using the weighted sum method, and the alternative with the best value is selected. So, the multidisciplinary team conducting the study must define specific weights for each criterion, reflecting the opinion of the society. The choice of weights is a subjective task, it is difficult to quantify the decision makers' preferences, it may change during the decision process and in a group decision, the opinions and preferences can often diverge. Aiming the continuous improvement of the decision making of the Inventory Studies, in this article two multicriteria methods are tested in order to mitigate this difficulty, avoiding to ask precise values for the weights, but still allowing to distinguish the importance of the criteria. Applications have shown that the VIP Analysis and Electre III methods are very promising and strong candidates. The paper details the three criteria, compares the results of the weighted sum with those of these two methods and discusses how the parameters and other information demanded by these methods should be defined. For this, the methods were applied in a real Inventory Study of a Brazilian river basin. Lastly, expanding energy generation means addressing a paradox in society: people want more energy for development, but they also question how it is produced and how it affects the environment. Good planning and transparent decision-making processes are the way to resolve such conflicts. Thus, improvements in strategic decision making, such as the one in Inventory Studies, should always be pursued.

4. Evaluating a Forest Road Network by an Additive Value Model

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Road planning and development is an essential component in forest management. It improves operational forest harvesting through providing better access to timber harvest sites and availability of product market for rural population. In forest road planning, it is important to address safety of forest products transport, comfort and economy of vehicle operations. Caspian forests (i.e., forests in north Iran) that are located between north of Alborz Mountains and south of Caspian Sea are the only commercial forests of Iran. Because of high-quality timbers, access to this area has industrial importance for wood industry activists. In addition, the environmental protection of this area is important for forest management in Iran. Hence, for this area, having an efficient planning of road network that incorporates economic and environmental considerations is critical. A great body of literature addresses the use of multi-criteria decision-making methods for planning and evaluating various aspects of forest management. Analytic Network Process (ANP) has been utilized for evaluating performance of sustainable management strategies (Wolfslehner and Vacik, 2008). Naghdi and Babapour (2009) proposed an Analytical Hierarchy Process (AHP) for evaluating and classifying the effective factors in forest road construction. A hybrid MCDM method has been developed for evaluating attributes and alternatives in forest roads locating (Hashemkhani et al, 2011). Delphi and AHP method have been proposed for selecting important attributes and obtaining relative importance of

attributes in order to design efficient forest road network (Hayati et al., 2013). In this research, we propose a multi-criteria method in order to evaluate the existing road network in Caspian forest in Iran. We take into account quantitative and qualitative attributes such as road length, road width, road safety, ease of road construction, ease of progression to the mountainous area, less destruction of wildlife habitats and environmental features, ease of access to the road for villagers. The aim is to find a weight setting that reflects each attribute's importance in relationship to other attributes. UTA (UTilités Additives) method based on an additive value model is proposed for evaluation. The method takes a given ranking for a set of alternatives, which in this work consists of the existing road alternatives. The procedure of the method is inferring additive value functions to the alternative set. The method uses linear programming to assess functions and to find weights for attributes so that the rankings obtained through these functions on alternative set is as consistent as possible with the given one. To the best of our knowledge, this is the first study that uses the UTA method in the field of forest management. According to our experience UTA method, works well for this application. This method is flexible in terms of adding or changing attributes. Furthermore, due to elimination of some time-consuming process, such as pairwise comparisons, the use of this method is easy in comparison of some other methods such as AHP and ANP. Keywords: Forest roads, Multi-criteria decision making, Additive value model.

FRI-3-L

Closing Session

Friday 14:40-15:10 - Room: Galata Tower

Chair: Ilker Topcu

Author Index

A

Abdelkader, Mendas	35
Abdellah, Mebrek	35
Abushammala, Mohammed	116
Adebiyi, Sulaimon	72
Adiyeke, Esra	38
Afsar, Bekir	103
Agell, Núria	81
Aghaei Pour, Pouya	102
Aguirre, Eduar	53
Ahonen-Jonnarth, Ulla	149
Ak, Cem	123
Akhtar, Khalid	58
Aktaş, Dilay	77
Al-Rahbia, Alia	116
Alberti, Alexandre	49
Alptekin, Can	93
Altug, Gorkem	43
Alves, Maria João	79, 104
Amami, Dalel	83
Amira Nagham, Mokrani	91
Andersson, Hanna	149
Andreolli, Francesca	100
Anisic, Zoran	114
Arcidiacono, Sally Giuseppe	130
Arias, Adriana	47
Armas, Iuliana	53
Arslan, Ozan	123
Asan, Umut	113, 136
Aspen, Dina	35
Atac, Esra	59

Atan, Murat	138
Atıcı, Bengü	145
Aydın, Umut	89
Äyrämö, Sami	156
Azad, Nader	139
Azizi, Majid	80

B

Babashov, Vusal	68
Baburoglu, Oguz	37
Bahiense, Laura	60, 61
Barbati, Maria	42
Bashir, Bashir	64
Başar, Ayfer	161
Bayar, Mustafa	138
Bayazit, Ozden	33
Baydoğan, Mustafa	38
Baylan, Emin Başar	97
Bayram, Gökçen	84
Beauregard, Yvan	69
Belahcene, Khaled	159
Beldek, Tuğçe	42
Ben Amor, Sarah	68, 69
Berk, Erhan	133
Bilge, Umit	167
Bişkin, Büşra	107
Bittermann, Michael S.	168
Bohanec, Marko	98
Borbinha, José	166
Boujelben, Mohamed Aymen	110
Boujelbene, Younes	40
Boumesbah, Asma	67

Bouyssou, Denis	112
Boztepe, Rasih	170
Bökler, Fritz	126
Bökman, Fredrik	149
Bravo, Juan	47
Bregar, Andrej	55
Brunelli, Matteo	30, 75
Buyukozkan, Gulcin	162
Büyüközkan, Gülçin	82

C, Ç

Cabello, José M.	140
Cabrera-Guerrero, Guillermo	141
Cagdas, Gulen	150, 151
Cakir, Sercan	86
Camgöz Akdağ, Hatice	42
Campo, Emiro	64
Cano, Jose	64
Caprace, Jean-David	60, 61
Caprila, Alexandra	45
Cavalcante, Cristiano Alexandre	49
Cavallo, Bice	75
Çaybaşı, Gökhan	162
Cayir Ervural, Beyzanur	99
Cebesoy, Melodi	159
Cenani, Sehnaz	150, 151
Cerit, Bülent	124
Cetin, Onur	170
Çetinkaya, Ömer Mücahid	123
Ceyhan, Gokhan	78
Chakhar, Salem	110
Chen, Yu-Wang	73
Chergui, Mohamed El-Amine	67
Chugh, Tinkle	91
Ciftcioglu, Ozer	168

Cinaroglu, Songul	90
Civelek, Merve	144
Clímaco, João	69, 171
Cooper, Orrin	31, 34, 49, 62
Correa-Espinal, Alexander	64
Corrente, Salvatore	130, 166
Cortes Aldana, Felix Antonio	46
Cortés, Pablo	64
Costa, Ana Paula	88
Costa, Ana Sara	166
Costa, Fernanda	171
Cvetkoska, Violeta	147

D

D'Alpaos, Chiara	100
Daechert, Kerstin	63
Daher, Suzana	88
Dakare, Olamitunji	72
Dammak, Fatma	83
Dangol, Ramesh	32
Darende, Pinar	117
Dasdemir, Erdi	108
De Arruda, Edilson	61, 62
De Smet, Yves	55, 110, 111, 132, 165
De Souza, Marcelo Igor	60, 61
Decaestecker, Christine	132
Dehghani, Mohammad	85
Dehnokhalaji, Akram	89, 97
Dejaegere, Gilles	110
Delen, Dursun	99
Demir, Ezgi	59
Deniz, Nurcan	135
Dhurkari, Ram	146
Djamal, Chaabane	40, 91

Djeffal, El Amir	106
Doan Nguyen, Anh Vu	165
Doganay, Onur Tanil	92
Doubrava, Vít	92
Doumplos, Michalis	123
Duleba, Szabolcs	100
Duzdar Argun, Irem	58

E

Egdemir, Emine	133
Ehrgott, Matthias	142
Eisenstadt-Matalon, Erella	153
El Gibari, Samira	140
Engau, Alexander	157
Eren, Tamer	132
Erol, Eren	137

F

Faleschini, Flora	100
Fedrizzi, Michele	45
Ferreira, Rodrigo	87, 88
Figueira, José Rui	42, 50, 55, 56, 166
Figueiredo, Ciro	49
Filho, Angelo	118
Filiz Türkmen, Gizem	148
Fleming, James	45
Frini, Anissa	110, 131

G

Garcia-Melon, Monica	46, 72, 85
Gatica, Gustavo	141
Gavris, Alexandru	53
Geldermann, Jutta	169
Genc, Tolga	29
Ghaderi, Mohammad	127

Ghazli, Kahina	51
Ghorbel, Amira	40
Gillis, Nicolas	51
Gómez, Trinidad	140
Gonzalez Gallardo, Sandra	167
González-Urango, Hannia	72
Gonzalez-Urango, Hannia	84
Gottschalk, Hanno	92, 93
Greco, Salvatore	42, 56, 74, 131, 166
Groselj, Petra	145
Guajardo, Mario	172
Guerreiro, Andreia P.	128
Gurbuz, Mustafa Zahid	119
Gutierrez, Maicholl	141
Gül, Sait	162, 163
Güleç, Nurullah	35
Günhan, Büşra	70

H

Hakanen, Jussi	102, 117, 156
Hämäläinen, Raimo	134
Hamurcu, Mustafa	132
Harale, Nitin	44
Hayashida, Tomohiro	65, 119, 164
Hecht, Robert	86
Henggeler Antunes, Carlos	79, 104
Hernandez Castellanos, Carlos	51
Hodgett, Richard	74
Hsu, Ching-Chun	116
Huang, Chi-Yo	116
Huang, He	165
Huang, Shan-Lin	71
Hubinont, Jean-Philippe	55

I, İ

Infante, Eduardo	60, 61
İnkaya, Tülin	77
Ishizaka, Alessio	42, 110
Isik, Mine	99

J

Jabbarzadeh, Armin	139
Jahanzaib, Mirza	58
Jiménez-Martín, Antonio	66
Johansen, Børge Andreas	35
Juszczuk, Przemysław	120, 121, 142

K

Kabadayi, Nihan	85
Kabak, Özgür	35, 36, 90, 125
Kadaifci, Cigdem	43
Kaliszewski, Ignacy	106, 120, 121, 142
Kanazawa, Yuuki	65
Karabay, Nail	109
Karadayı, Melis Almula	89, 137
Karakaya, Gülşah	160
Karasakal, Esra	144, 145
Karasakal, Orhan	145
Kargar, Mehdi	75
Karpak, Birsen	32
Karsu, Özlem	64
Katsigiannis, Fotios	137
Kazançoğlu, Yiğit	115
Kerbérénès, Antoine	152
Keskin, İrem Nur	63
Keskinocak, Pınar	29
Khaniyev, Tahir	117

Khurram Ali, Hafiz	58
Kılıç, Hakan	90
Kik, David	52
Kilani, Arij	40
Kirlik, Gökhan	39
Kizil, Kerim Uygur	59
Klamroth, Kathrin	50, 81, 92
Koçoğlu, Firat	123
Koker, Derya	37
Koksal, Gulser	76
Konur, Dincer	130
Konyalioglu, Kemal	42
Korhonen, Pekka	29, 89, 97, 104
Korkut, Kübra	124
Köksalan, Murat	76, 78, 107, 108, 109, 160

Krasny, Pawel	41
Krátký, Tomáš	91
Krellenberg, Kerstin	86
Kucukali, Ozdemir	125
Kucukaltan, Berk	170
Kułakowski, Konrad	46
Kumar Mangla, Sachin	115

L

Labib, Ashraf	110
Lage, Carla	87
Lagos, Carolina	141
Lalic, Bojan	114
Lannez, Sebastien	155
Li, Xia	71
Liang, Fuqi	30
Lokman, Banu	77, 78
López-Ibáñez, Manuel	138
Lundy, Michele	74

Luo, Jin-Hua	71
Luque, Mariano	167

M

Macharis, Cathy	165
Macuada, Claudio	57
Makranfar, Zohra	94
Mansikka, Heikki	134
Mantogiannis, Vasileios	137
Manyoma, Pablo	47, 86
Marchant, Thierry	112
Marjanović, Ivana	83
Marjanovic, Ugljesa	114
Marsaro, Mônica	49
Martins, Isabelle	60, 61
Mateos, Alfonso	66
Mebrek, Abdellah	94
Mechitov, Alexander	29, 48
Medic, Nenad	114
Medrano, F. Antonio	152
Miclea, Adriana	44
Miettinen, Kaisa	91, 101, 102, 103, 117, 138
Miguez, Marcelo	171
Miroforidis, Janusz	106, 120, 121, 142
Moncef, Abbas	39
Montazer, Gholamali	113
Moraes, Fernanda	60, 61
Morales, Daniela	47
Moralioğlu, Begum	150
Moshaiov, Amiram	153
Moshkovich, Elena	29, 48
Moslem, Sarbast	100
Mota, Caroline	49
Mouhib, Youness	131

Moulai, Mustapha	51
Moumni, Nourchen	166
Mousavi, Seyed Mohsen	101
Mousseau, Vincent	110, 159
Mu, Enrique	31
Mukhametzyanov, Irik	96

N

Nasrabadi, Nasim	89, 97
Negüs, Fahri	82
Neyra Belderrain, Mischel Carmen	88
Nishizaki, Ichiro	65, 119, 164
Nohadani, Omid	142
Nowak, Maciej	101

O

Ober-Blöbaum, Sina	51
Oddershede, Astrid	57
Ojalehto, Vesa	156
Olhofer, Markus	102
Omoera, Charles	72
Onan, Kivanc	119
Ono, Masato	164
Ouerdane, Wassila	159
Ouznadji, Said	40
Oyenuga, Olamilekan	72
Ozpeynirci, Ozgur	143, 144
Oztek, Yaman	82
Ozturk, Onur (Çimtaş)	112
Ozturk, Onur (uOttawa)	139

Ö

Önsel Ekici, Şule	125
Özarlan, Ali	160
Özateş Gürbüz, Melis	76

Özaydın, Özay	54, 99
Özçakar, Necdet	170
Özdemir, Mustafa	133
Özgen, İrem	113
Özkan Özen, Yeşim Deniz	115
Özkardeş, Sibel	95
Özmez, Ali	93
Özpeynirci, Selin	143, 144

P

Palominos, Pedro	58
Panaro, Simona	42
Paquet, Marc	69
Paquete, Luís	50
Pavlou, Antonis	123
Peasley, Michael	31
Peker, İskender	162
Pelissari, Renata	68
Pereyra-Rojas, Milagros	31
Pérez-Gladish, Blanca	72
Pessatto Mondadori, Jorge Augusto	88
Pessôa, Leonardo Antonio	87
Piercy, Craig	154
Pirlot, Marc	112, 159
Planellas, Marcel	81
Podkopaev, Dmitry	101, 120, 121, 142
Pohl, Erik	169
Polat, Seçkin	113
Popović, Žarko	83
Popovici, Diana	53
Porro, Olga	81
Q	
Qazi, Wajeeha	116
Quezada, Luis	58

R

Raupp, Igor	171
Rebaï, Abdelwaheb	166
Reinhardt, Gilles	68
Rezaei, Jafar	30, 31
Rezaeinia, Nahid	172
Rodemann, Tobias	102
Rodrigues, Márcio	57
Romero, Jorge	46
Rosenfeld, Jean	132
Roumeissa, Kerboui	39
Rouyendegh, Babak	117
Roy, Bernard	56
Ruiz, Ana B.	167
Ruiz, Francisco	103, 140

S

Saarela, Mirka	156
Saborido, Rubén	167
Sagır, Mujgan	133
Şahin Zorluoğlu, Özge	36
Sahinkoc, Mert	167
Saidi, Ahmed	94
Saini, Bhupinder	117
Salah, Mohamed Essalah	40
Samanlioglu, Funda	123
Sanchez, Monica	81
Sandholm, Tuomas	126
Santiago, Katarina	88
Savaş, Sezer	151
Sayın, Serpil	39
Scharpenberg, Christina	169
Schultes, Johanna	92
Schulze, Britta	50, 63

Sekizaki, Shinya	65, 119, 164
Shavazipour, Babooshka	138
Shayganmehr, Masoud	113
Shentall, Glyn	142
Shibukawa, Naoyuki	65
Sinayiř, Nihat Can	78
Silva, Lucio	88
Siraj, Sajid	74
řírová, Eva	57
Sitarz, Sebastian	101
Skulimowski, Andrzej	105
Soares, Henrique	61
Sobrie, Olivier	159
Spengler, Thomas S.	52
Stanković, Jelena	83
Steuer, Ralph	154
Stewart, Theodor	55
Stiglmayr, Michael	50, 92
Stubington, Emma	142
Swain, Anjan Kumar	146
Szmurło, Robert	142

T

Tasic, Nemanja	114
Tavora, Giselle	60, 61
Teichert, Katrin	63
Teixeira de Almeida, Adiel	87, 88
Tello, Faustino	66
Tezcaner Öztürk, Diclehan	107, 108, 109
Thameri, Messaoud	40
Toktas Palut, Peral	119
Toma-Danila, Dragos	53
Topcu, Ilker	80, 125, 148
Tozan, Hakan	137

Trzaskalik, Tadeusz	101
Tuncer řakar, Ceren	107, 159
Tureci, Hannan	107
Tzeng, Gwo-Hshiung	71

U, Ü

Ucal Sari, Irem	125
Uenishi, Hirokazu	65
Ülengin, Burç	89
Ülengin, Füsün	54, 80, 89, 125
Ulus, Firdevs	63
Unver, Berna	80, 125
Uzturk, Deniz	82
Uzun Bayar, Irmak	138

V

Vanderpooten, Daniel	152
Vanfossan, Samuel	130
Vanpeperstraete, Jean-Michel	152
Vargas, Luis	143
Verma, Manish	140
Vinagre-Fernandez, Maria Regla	72
Virtanen, Kai	134

W

Wallenius, Hannele	154
Wallenius, Jyrki	29, 89, 97, 154
Wang, Yu-Tai	116
Weidner, Petra	51
Wichmann, Matthias G.	52
Wiecek, Margaret	122
Wu, Jei-Zheng	43

X

Xu, Peng	29
----------	----

Y

Yamamoto, Hiroyuki	119
Yamasaki, Takuya	65
Yang, Chia-Lee	116
Yanık, Seda	78, 94, 95
Yanmaz, Ozgur	43, 136
Yavuz, Idil	34
Yet, Barbaros	159
Yilmaz, Beyza Özlem	137
Yilmaz, Salim	94
Yunculer, Kutay	149

Z

Zaabar, Imen	69
Zadnik Stirn, Lidija	145
Zaim, Selim	99
Zakaria, Sadouni	35
Zavadil, Lukáš	91
Zawadzka, Anna	142
Zhang, Yao	40
Zohra, Mekranfar	35
Zopounidis, Constantin	123

List of Chairs

Amami, Dalel	TUE-3-A (Tuesday 13:50-15:30)
Asan, Umut	THU-1-C (Thursday 9:00-10:40)
Azad, Nader	THU-1-E (Thursday 9:00-10:40)
Ben Amor, Sarah	TUE-1-A (Tuesday 9:00-10:40)
Bittermann, Michael S.	FRI-2-E (Friday 13:00-14:40)
Bohanec, Marco	TUE-4-A (Tuesday 16:00-17:40)
Brunelli, Mateo	TUE-1-C (Tuesday 9:00-10:40)
Cakir, Sercan	TUE-3-B (Tuesday 13:50-15:30)
Cavalcante, Cristiano	MON-3-C (Monday 13:50-15:30)
Cenani, Sehnaz	THU-4-C (Thursday 14:20-16:00)
Cooper, Orrin	MON-2-B (Monday 11:10-12:50)
Costa, Ana Sara	FRI-2-C (Friday 13:00-14:40)
Daher, Suzana	TUE-3-C (Tuesday 13:50-15:30)
Darende, Pinar	WED-1-C (Wednesday 9:00-10:40)
Doumpos, Michalis	WED-1-E (Wednesday 9:00-10:40)
Duzdar Argun, Irem	MON-4-B (Monday 16:00-17:40)
Ehrgott, Matthias	THU-1-F (Thursday 9:00-10:40)
Engau, Alexander	THU-4-F (Thursday 14:20-16:00)
Ferreira, Rodrigo J P	TUE-3-C (Tuesday 13:50-15:30)
Figueira, Jose Rui	MON-2-F (Monday 11:10-12:50)
	WED-3-P (Wednesday 13:10-14:25)
Garcia-Melon, Monica	TUE-1-B (Tuesday 9:00-10:40)
Gül, Sait	FRI-2-B (Friday 13:00-14:40)
Hakanen, Jussi	MON-2-E (Monday 11:10-12:50)
Hämäläinen, Raimo	THU-1-B (Thursday 9:00-10:40)
Harale, Nitin	MON-3-A (Monday 13:50-15:30)
Hayashida, Tomohiro	WED-1-D (Wednesday 9:00-10:40)
Kabak, Özgür	TUE-3-D (Tuesday 13:50-15:30)
	TUE-4-D (Tuesday 16:00-17:40)
Kaliszewski, Ignacy	TUE-4-E (Tuesday 16:00-17:40)
Karakaya, Gülşah	FRI-2-A (Friday 13:00-14:40)
Karasakal, Esra	THU-4-A (Thursday 14:20-16:00)
Karpak, Birsen	MON-3-D (Monday 13:50-15:30)

Karsu, Özlem	MON-4-D (Monday 16:00-17:40)
Köksalan, Murat	MON-4-E (Monday 16:00-17:40)
	MON-1-P (Monday 9:40-10:40)
	TUE-4-F (Tuesday 16:00-17:40)
	WED-2-P (Wednesday 11:10-12:10)
	THU-3-U (Thursday 13:10-14:10)
Lokman, Banu	TUE-1-E (Tuesday 9:00-10:40)
Martins, Isabelle D.	MON-4-C (Monday 16:00-17:40)
Mateos, Alfonso	MON-4-F (Monday 16:00-17:40)
Medic, Nenad	WED-1-B (Wednesday 9:00-10:40)
Miettinen, Kaisa	TUE-4-C (Tuesday 16:00-17:40)
Moslem, Sarbast	TUE-4-B (Tuesday 16:00-17:40)
Mota, Caroline	MON-3-C (Monday 13:50-15:30)
Önsel Ekici, Şule	WED-1-F (Wednesday 9:00-10:40)
Özaydın, Özay	MON-2-D (Monday 11:10-12:50)
	MON-3-F (Monday 13:50-15:30)
Pirlot, Marc	WED-1-A (Wednesday 9:00-10:40)
Rezaei, Jafar	MON-2-A (Monday 11:10-12:50)
Rezaeinia, Nahid	FRI-2-F (Friday 13:00-14:40)
Romero, Jorge	MON-3-B (Monday 13:50-15:30)
Rosenfeld, Jean	THU-1-A (Thursday 9:00-10:40)
Sayın, Serpil	TUE-2-P (Tuesday 11:10-12:10)
Steuer, Ralph	THU-4-E (Thursday 14:20-16:00)
Stewart, Theodor	MON-4-A (Monday 16:00-17:40)
Stiglmayr, Michael	TUE-3-E (Tuesday 13:50-15:30)
Şahin Zorluoğlu, Özge	MON-2-C (Monday 11:10-12:50)
Tezcaner Öztürk, Diclehan	TUE-4-F (Tuesday 16:00-17:40)
Topcu, Ilker	MON-0-O (Monday 9:00-9:40)
	THU-2-P (Thursday 11:10-12:10)
	THU-4-B (Thursday 14:20-16:00)
	FRI-3-L (Friday 14:40-15:10)
Ulengin, Fusun	TUE-1-F (Tuesday 9:00-10:40)
Ulus, Firdevs	MON-4-E (Monday 16:00-17:40)
Wallenius, Jyrki	FRI-1-M (Friday 9:30-12:00)
Weidner, Petra	MON-3-E (Monday 13:50-15:30)
Yanık, Seda	TUE-3-F (Tuesday 13:50-15:30)

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Session Information

Session Identifier	Session	Time	Room
MON-0-O	Opening Session	Monday 9:00-9:40	Mustafa Kemal Amfisi
MON-1-P	Plenary Session 1 - Pinar Keskinocak	Monday 9:40-10:40	Mustafa Kemal Amfisi
MON-2-A	Contributed Session: Advances in MCDM Theory - Behavioral and Computational Issues	Monday 11:10-12:50	Galata Tower
MON-2-B	Invited Session: Theory and Applications of ANP	Monday 11:10-12:50	Maiden's Tower
MON-2-C	Contributed Session: MCDM for Group Decisions	Monday 11:10-12:50	Dolmabahçe Palace
MON-2-D	Special Session: AHP in Practice as "Decision Conference" in Turkey - sponsored by ARAMA	Monday 11:10-12:50	Topkapı Palace
MON-2-E	Invited Session: Data Science meets Multiple Criteria Decision Making	Monday 11:10-12:50	Hagia Sophia
MON-2-F	Contributed Session: MCDM for Project Selection	Monday 11:10-12:50	Basilica Cistern
MON-3-A	Contributed Session: Advances in MCDM Theory - Applications in Diverse Industries	Monday 13:50-15:30	Galata Tower
MON-3-B	Contributed Session: Consistency Issues in AHP	Monday 13:50-15:30	Maiden's Tower
MON-3-C	Invited Session: Building MCDM/A Models: Practical and Methodological Issues	Monday 13:50-15:30	Dolmabahçe Palace
MON-3-D	Tutorial: Improve Your Decisions by Learning and Experiencing the ANP Best Practices- Part I	Monday 13:50-15:30	Topkapı Palace
MON-3-E	Contributed Session: Recent Advances in Multiobjective Optimization	Monday 13:50-15:30	Hagia Sophia
MON-3-F	Contributed Session: MCDM for Facility Location and Logistics	Monday 13:50-15:30	Basilica Cistern
MON-4-A	Contributed Session: Advances in MCDM Theory	Monday 16:00-17:40	Galata Tower
MON-4-B	Special Session: AHP/ANP Applications in Production and Manufacturing – sponsored by BORCELİK	Monday 16:00-17:40	Maiden's Tower
MON-4-C	Contributed Session: Multiple Criteria Decision Aiding	Monday 16:00-17:40	Dolmabahçe Palace
MON-4-D	Tutorial: Improve Your Decisions by Learning and Experiencing the ANP Best Practices- Part II	Monday 16:00-17:40	Topkapı Palace
MON-4-E	Invited Session: Solution Methods for Various Multiobjective Optimization Problems	Monday 16:00-17:40	Hagia Sophia
MON-4-F	Contributed Session: Multiobjective Metaheuristics for Challenging Applications	Monday 16:00-17:40	Basilica Cistern

Session Identifier	Session	Time	Room
TUE-1-A	Invited Session: MCDM/A for Assessment Issues in Healthcare and LCA	Tuesday 9:00-10:40	Galata Tower
TUE-1-B	Contributed Session: AHP/ANP Applications in Academia and Education	Tuesday 9:00-10:40	Maiden's Tower
TUE-1-C	Contributed Session: Preferences, Comparisons and Uncertainties	Tuesday 9:00-10:40	Dolmabahçe Palace
TUE-1-E	Invited Session: Multiobjective Optimization Applications	Tuesday 9:00-10:40	Hagia Sophia
TUE-1-F	Contributed Session: Understanding Consumers and Markets	Tuesday 9:00-10:40	Basilica Cistern
TUE-2-P	Plenary Session 2 - Kathrin Klamroth	Tuesday 11:10-12:10	Mustafa Kemal Amfisi
TUE-3-A	Contributed Session: Multiple Criteria Ranking or Sorting	Tuesday 13:50-15:30	Galata Tower
TUE-3-B	Contributed Session: AHP/ANP Applications in Urban and Regional Development	Tuesday 13:50-15:30	Maiden's Tower
TUE-3-C	Invited Session: MCDM/A Models with Flexible and Interactive Preference Modeling	Tuesday 13:50-15:30	Dolmabahçe Palace
TUE-3-D	Contributed Session: Data Envelopment Analysis	Tuesday 13:50-15:30	Topkapı Palace
TUE-3-E	Invited Session: Continuous Multiobjective Optimization with Engineering Applications	Tuesday 13:50-15:30	Hagia Sophia
TUE-3-F	Contributed Session: Data, Applications and MCDM	Tuesday 13:50-15:30	Basilica Cistern
TUE-4-A	Contributed Session: Multiple Criteria Ranking and Sorting Methodology	Tuesday 16:00-17:40	Galata Tower
TUE-4-B	Contributed Session: Practical Applications of AHP/ANP	Tuesday 16:00-17:40	Maiden's Tower
TUE-4-C	Contributed Session: Interactive Multiobjective Optimization	Tuesday 16:00-17:40	Dolmabahçe Palace
TUE-4-D	Tutorial: MOLP vs. DEA - Relatives or Friends	Tuesday 16:00-17:40	Topkapı Palace
TUE-4-E	Contributed Session: Advanced Optimization Techniques and Multiple Objectives	Tuesday 16:00-17:40	Hagia Sophia
TUE-4-F	Invited Session: Multiobjective Route Planning	Tuesday 16:00-17:40	Basilica Cistern
WED-1-A	Contributed Session: Outranking Methods	Wednesday 9:00-10:40	Galata Tower
WED-1-B	Special Session: AHP/ANP Applications in Industry 4.0 - sponsored by ÇİMTAŞ	Wednesday 9:00-10:40	Maiden's Tower
WED-1-C	Contributed Session: MCDM for Environmental Decisions	Wednesday 9:00-10:40	Dolmabahçe Palace
WED-1-D	Contributed Session: Evolutionary Algorithms, Preferences and Applications	Wednesday 9:00-10:40	Topkapı Palace
WED-1-E	Contributed Session: Portfolio Optimization Models	Wednesday 9:00-10:40	Hagia Sophia
WED-1-F	Contributed Session: Practical Applications of MCDM in an Interconnected World	Wednesday 9:00-10:40	Basilica Cistern

Session Identifier	Session	Time	Room
WED-2-P	Plenary Session 3 - Tuomas Sandholm	Wednesday 11:10-12:10	Mustafa Kemal Amfisi
WED-3-P	Doctoral Dissertation Awards	Wednesday 13:10-14:25	Mustafa Kemal Amfisi
THU-1-A	Contributed Session: Multiple Criteria Ranking or Sorting	Thursday 9:00-10:40	Galata Tower
THU-1-B	Contributed Session: AHP/ANP Applications in Aviation	Thursday 9:00-10:40	Maiden's Tower
THU-1-C	Contributed Session: Contemporary Approaches in MCDM	Thursday 9:00-10:40	Dolmabahçe Palace
THU-1-E	Contributed Session: Bringing Multiobjective Optimization to Applications	Thursday 9:00-10:40	Hagia Sophia
THU-1-F	Contributed Session: Practical Applications of MCDM	Thursday 9:00-10:40	Basilica Cistern
THU-2-P	Plenary Session 4 - Luis Vargas	Thursday 11:10-12:10	Mustafa Kemal Amfisi
THU-3-U	Business Meeting	Thursday 13:10-14:10	Mustafa Kemal Amfisi
THU-4-A	Invited Session: Hybrid Approaches in MCDM	Thursday 14:20-16:00	Galata Tower
THU-4-B	Contributed Session: Business Applications of AHP/ANP	Thursday 14:20-16:00	Maiden's Tower
THU-4-C	Invited Session: MCDM in Solving Urban Problems using Big Data	Thursday 14:20-16:00	Dolmabahçe Palace
THU-4-E	Contributed Session: Practical Approaches to Challenging Problems in Multiobjective Optimization	Thursday 14:20-16:00	Hagia Sophia
THU-4-F	Contributed Session: MCDM for Strategic, Tactical and Operational Decisions	Thursday 14:20-16:00	Basilica Cistern
FRI-1-M	Society Award Talks	Friday 9:30-12:00	Galata Tower
FRI-2-A	Invited Session: New Approaches in MCDM	Friday 13:00-14:40	Galata Tower
FRI-2-B	Contributed Session: Fuzzy sets and approaches	Friday 13:00-14:40	Maiden's Tower
FRI-2-C	Contributed Session: Advances in MCDA	Friday 13:00-14:40	Dolmabahçe Palace
FRI-2-E	Contributed Session: Evolutionary Algorithms and Multiobjective Optimization	Friday 13:00-14:40	Hagia Sophia
FRI-2-F	Contributed Session: Making Decisions with Environmental Concerns	Friday 13:00-14:40	Basilica Cistern
FRI-3-L	Closing Session	Friday 14:40-15:10	Galata Tower

CONFERENCE ORIENTATION



ITU MANAGEMENT FACULTY

- * Registration
- * Parallel Sessions
- * Coffee Breaks
- * Society Award Talks
- * Closing Session



MUSTAFA KEMAL AMFISI

- * Opening Session
- * Plenary Talks
- * Group Photo
- * Doctoral Dissertation Awards
- * Business Meeting



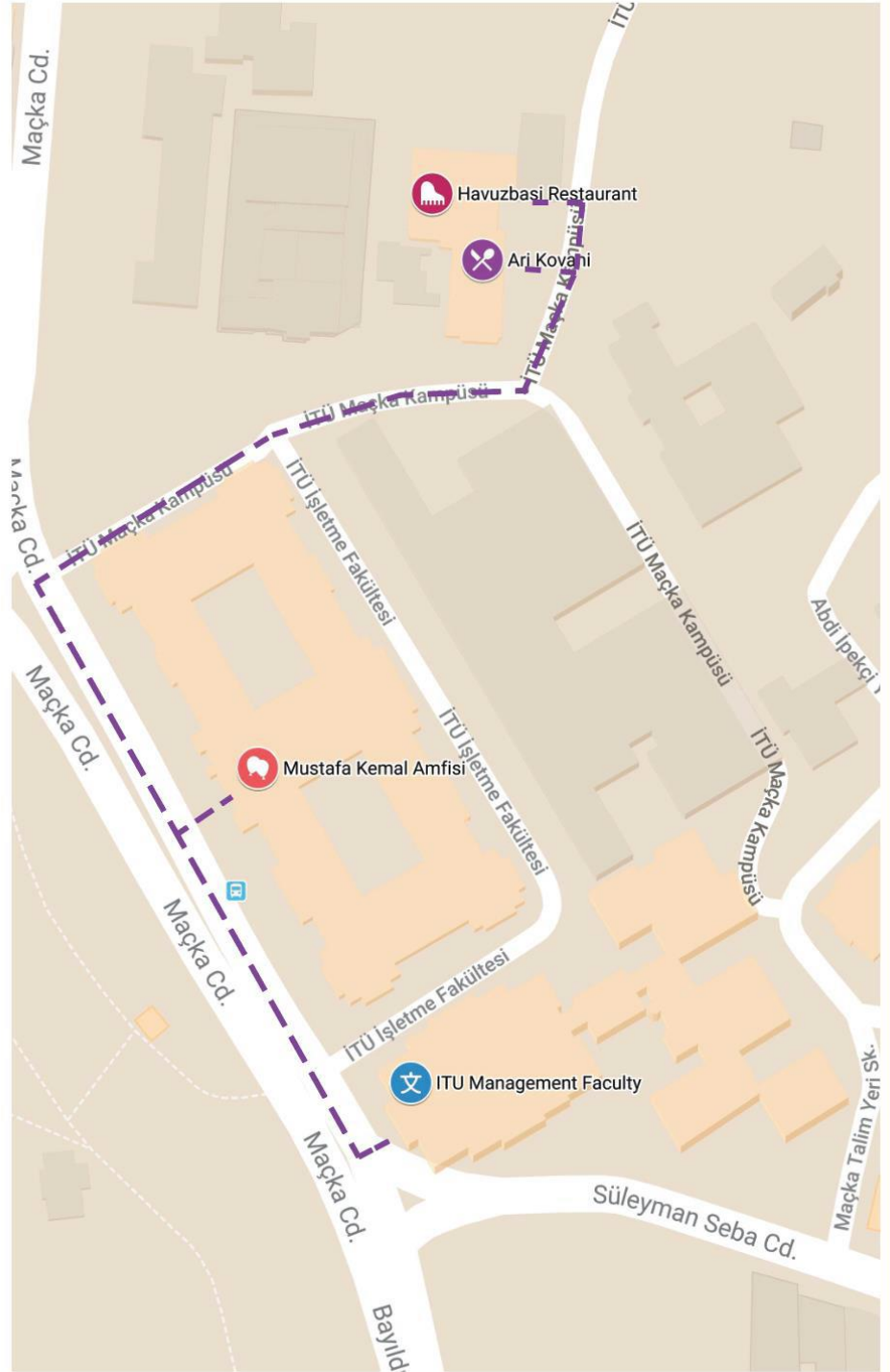
HAVUZBASİ RESTAURANT

- * Welcome Reception



ARI KOVANI

- * Lunches



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ARAMA

KATILIMLI YÖNETİM DANIŞMANLIĞI



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