ORAHS 2022

48th annual meeting
of the EURO Working Group
on Operational Research
Applied to Health Services

July 17th-22nd, 2022
Bergamo, Italy

CONFERENCE BOOKLET

ORAHS 2022 Committees

Conference chairs

Ettore Lanzarone, University of Bergamo, Italy
Giovanni Righini, University of Milan, Italy

Scientific Committees

Local Committee

Giuliana Carello, Politecnico di Milano, Italy
Sergio Cavalieri, University of Bergamo, Italy
Alberto Ceselli, University of Milan, Italy
Roberto Cordone, University of Milan, Italy
Martina Doneda, Politecnico di Milano, Italy
Francesca Maggioni, University of Bergamo, Italy
Sara Mattia, CNR-IASI, Italy
Elena Tànfani, University of Genoa, Italy
Maria Teresa Vespucci, University of Bergamo, Italy
Semih Yalçindağ, Yeditepe University, Turkey

ORAHS Board

Roberto Aringhieri (Joint Coordinator), Italy
Melanie Reuter-Oppermann (Joint Coordinator), Germany
Sally Brailsford, UK
Mike Carter, Canada
Leonid Churilov, Australia
Fredrik Dahl, Norway
Patrick Hirsch, Austria
Fermín Mallor Giménez, Spain
Stefan Nickel, Germany
Marion Rauner, Austria
Patrick Soriano, Canada
Christos Vasilakis, UK
Joe Viana, Norway

Welcome back!

ORAHS provides a network for researchers involved in the application of systematic and quantitative analysis in support of planning and management in the health services sector. The meeting is open to anyone with a quantitative background and those who have interest in the subject area.

ORAHS 2022 is the **ORAHS in the red zone**, focused on the organization and reaction of health systems when confronted with emergency situations like the COVID pandemic.

- Hospitals and public authorities: how to react to extreme scenarios rearranging their resources?
- Territorial health systems: how and to what extent complement the hospital system to cope with a pandemic?
- Clinical practice: decision support for diagnosis and treatments, when fighting against a new virus for the first time.

Several members of the Italian O.R. scientific community did their best to help the national health system in its battle against the COVID-19 pandemic.

Organizing ORAHS 2022 just in the heart of the 2020 red zone has a very special meaning.
It gives ORAHS deserved resonance in the regional and national health system, in public administration and on the media, raising public awareness about our discipline and its contribution to help decision-makers to save lives, minimize costs and solve problems.

Why the **University of Bergamo**?
It is the place of the first master's degree course Engineering and Management for Health in Italy, which merges biomedical engineering, management engineering and health care optimization.

Thanks for attending ORAHS 2022 and welcome to Bergamo!

Ettore Lanzarone
Giovanni Righini

Organizers

UNIVERSITÀ DEGLI STUDI DI BERGAMO | Dipartimento di Ingegneria Gestionale, dell'Informazione e della Produzione

UNIVERSITÀ DEGLI STUDI DI MILANO
DIPARTIMENTO DI INFORMATICA

Scientific sponsors

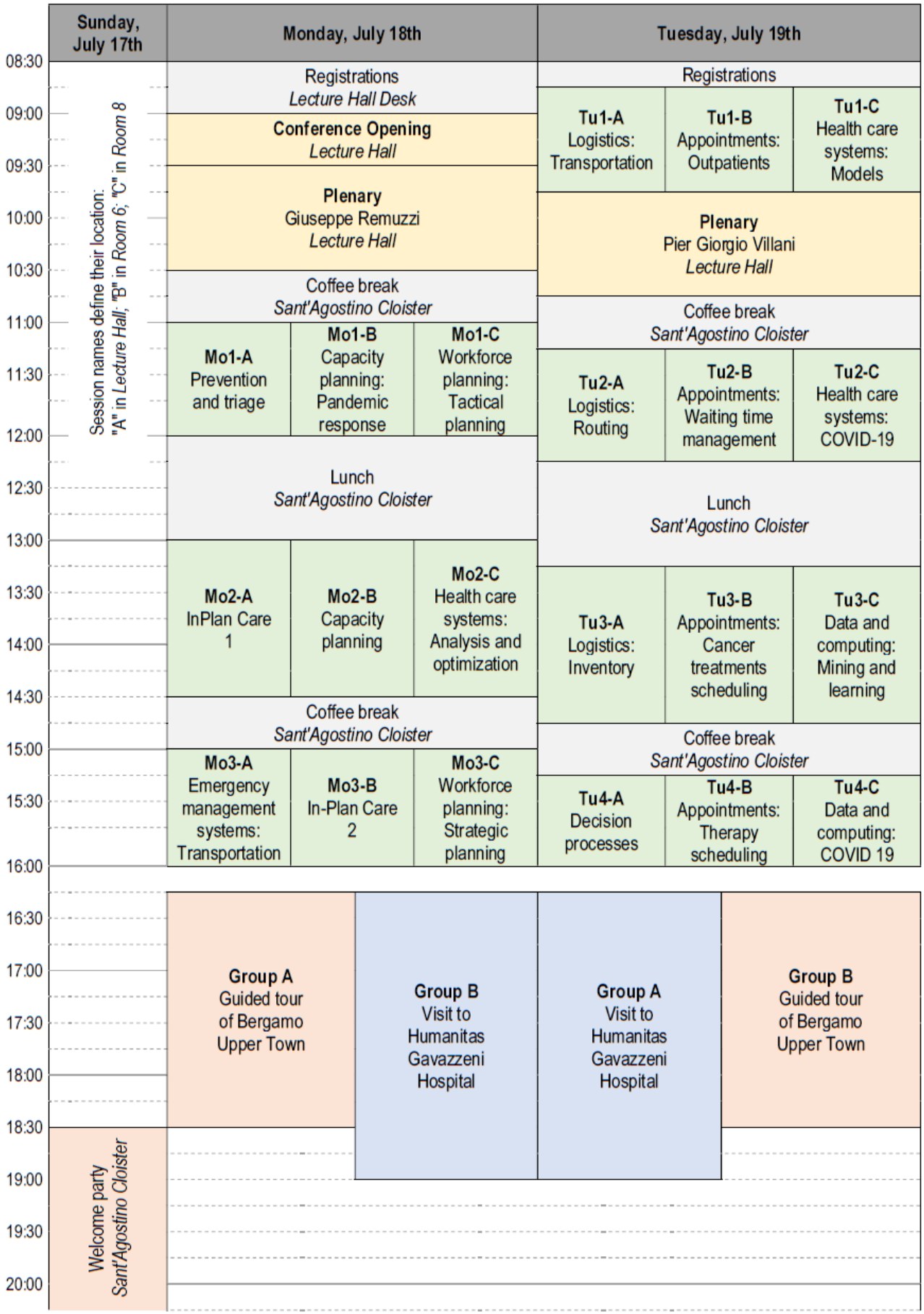
THE ASSOCIATION OF EUROPEAN OPERATIONAL RESEARCH SOCIETIES

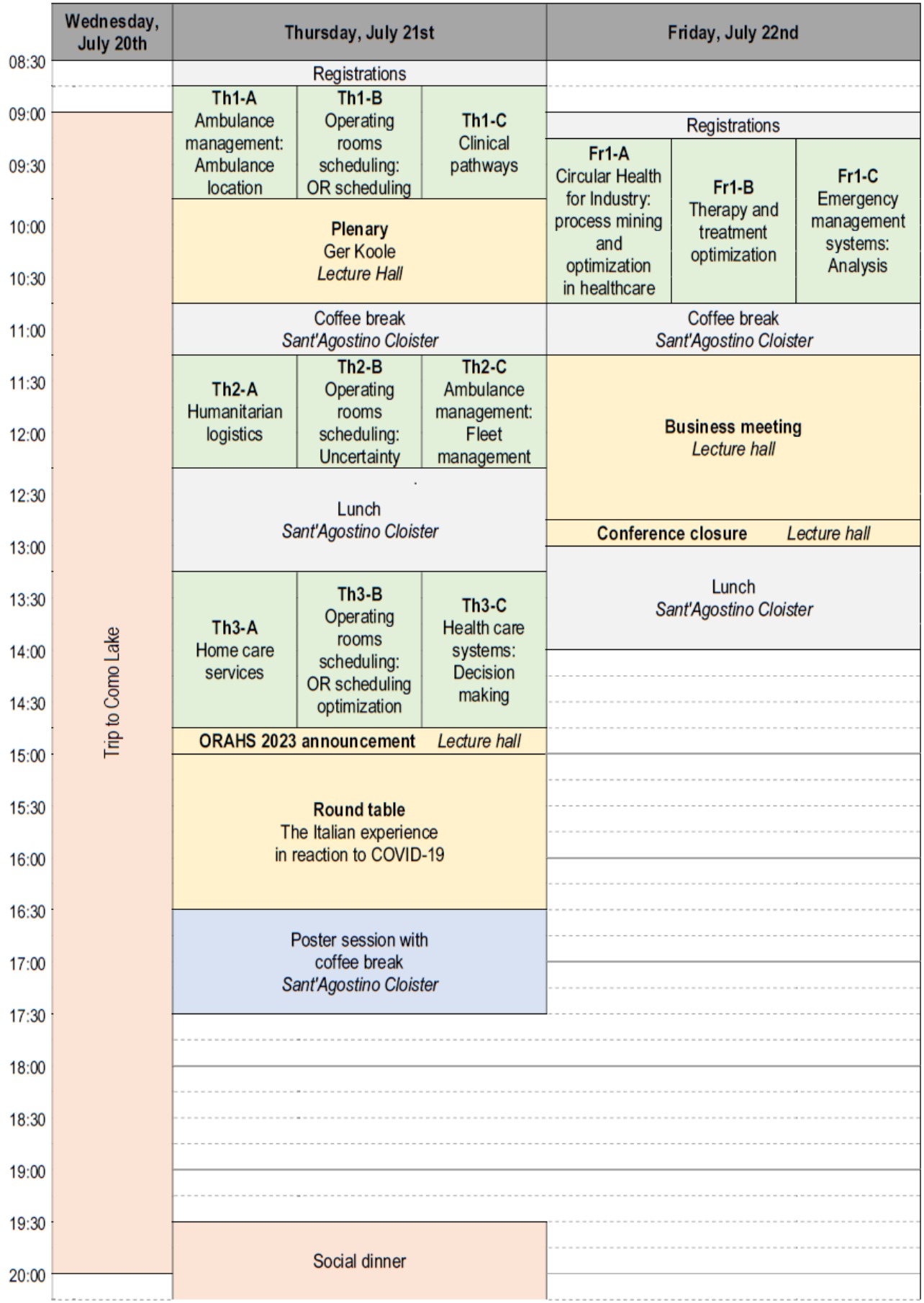
ASSOCIAZIONE ITALIANA DI RICERCA OPERATIVA

Endorsers

Gruppo Nazionale di Bioingegneria

Index


Sunday, July 17th
Monday, July 18th
Tuesday, July 19th
08:30
09:00
09:30
10:00
10:30
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
15:30
16:00
16:30
17:00
17:30
18:00
18:30
19:00
19:30
20:00
Session names define their location: "A" in Lecture Hall; "B" in Room 6; "C" in Room 8
Registrations
Lecture Hall Desk
Conference Opening
Lecture Hall
Plenary
Giuseppe Remuzzi
Lecture Hall
Coffee break
Sant'Agostino Cloister
Mo1-A Prevention and triage
Mo1-B Capacity planning: Pandemic response
Mo1-C Workforce planning: Tactical planning
Lunch
Sant'Agostino Cloister
Mo2-A InPlan Care 1
Mo2-B Capacity planning
Mo2-C Health care systems: Analysis and optimization
Coffee break
Sant'Agostino Cloister
Mo3-A Emergency management systems: Transportation
Mo3-B In-Plan Care 2
Mo3-C Workforce planning: Strategic planning
Registrations
Tu1-A Logistics: Transportation
Tu1-B Appointments: Outpatients
Tu1-C Health care systems: Models
Plenary
Pier Giorgio Villani
Lecture Hall
Coffee break
Sant'Agostino Cloister
Tu2-A Logistics: Routing
Tu2-B Appointments: Waiting time management
Tu2-C Health care systems: COVID-19
Lunch
Sant'Agostino Cloister
Tu3-A Logistics: Inventory
Tu3-B Appointments: Cancer treatments scheduling
Tu3-C Data and computing: Mining and learning
Coffee break
Sant'Agostino Cloister
Tu4-A Decision processes
Tu4-B Appointments: Therapy scheduling
Tu4-C Data and computing: COVID 19
Group A
Guided tour of Bergamo Upper Town
Group B
Visit to Humanitas Gavazzeni Hospital
Group A
Visit to Humanitas Gavazzeni Hospital
Group B
Guided tour of Bergamo Upper Town
Welcome party
Sant'Agostino Cloister


Wednesday, July 20th
Thursday, July 21st
Friday, July 22nd
08:30
09:00
09:30
10:00
10:30
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
15:30
16:00
16:30
17:00
17:30
18:00
18:30
19:00
19:30
20:00
Registrations
Th1-A Ambulance management: Ambulance location
Th1-B Operating rooms scheduling: OR scheduling
Th1-C Clinical pathways
Plenary Ger Koole Lecture Hall
Coffee break Sant'Agostino Cloister
Th2-A Humanitarian logistics
Th2-B Operating rooms scheduling: Uncertainty
Th2-C Ambulance management: Fleet management
Lunch Sant'Agostino Cloister
Th3-A Home care services
Th3-B Operating rooms scheduling: OR scheduling optimization
Th3-C Health care systems: Decision making
ORAHS 2023 announcement Lecture hall
Round table The Italian experience in reaction to COVID-19
Poster session with coffee break Sant'Agostino Cloister
Social dinner
Trip to Como Lake
Registrations
Fr1-A Circular Health for Industry: process mining and optimization in healthcare
Fr1-B Therapy and treatment optimization
Fr1-C Emergency management systems: Analysis
Coffee break Sant'Agostino Cloister
Business meeting Lecture hall
Conference closure Lecture hall
Lunch Sant'Agostino Cloister

Practical information

CONFERENCE VENUE

ORAHS 2022 will be held in the historic Upper Town (*Città Alta*) of Bergamo, in the buildings of the Sant'Agostino campus of the University of Bergamo, in Piazzale Sant'Agostino 2 (24129 Bergamo).

The venue is the former monastery of the Eremitani in Sant'Agostino. The *Lecture Hall* (*Aula Magna*) was the church of the monastery, founded in 1290 and consecrated in 1347. Its splendid frescoes, recently restorated, date back to the thirteenth century. After the end of the religious order, in the nineteenth century, the church and the monastery became seat of barracks and weapons depots; the frescoes were then hidden behind a brick wall curtain, which was removed only in the fifties and sixties of the twentieth century. In 2001, the cloisters were used as a campus of the University of Bergamo. In 2015, after the main nave restoration, the former church became the *Aula Magna* of the University. In 2018, a further restoration returned most of the interior frescoes of the church.

These rooms are used for the ORAHS conference:

- Lecture Hall (*Aula Magna*) for plenary lectures and for parallel sessions;
- Room 6 (on the first floor of the cloister) for parallel sessions;
- Room 8 (on the first floor of the cloister) for parallel sessions;

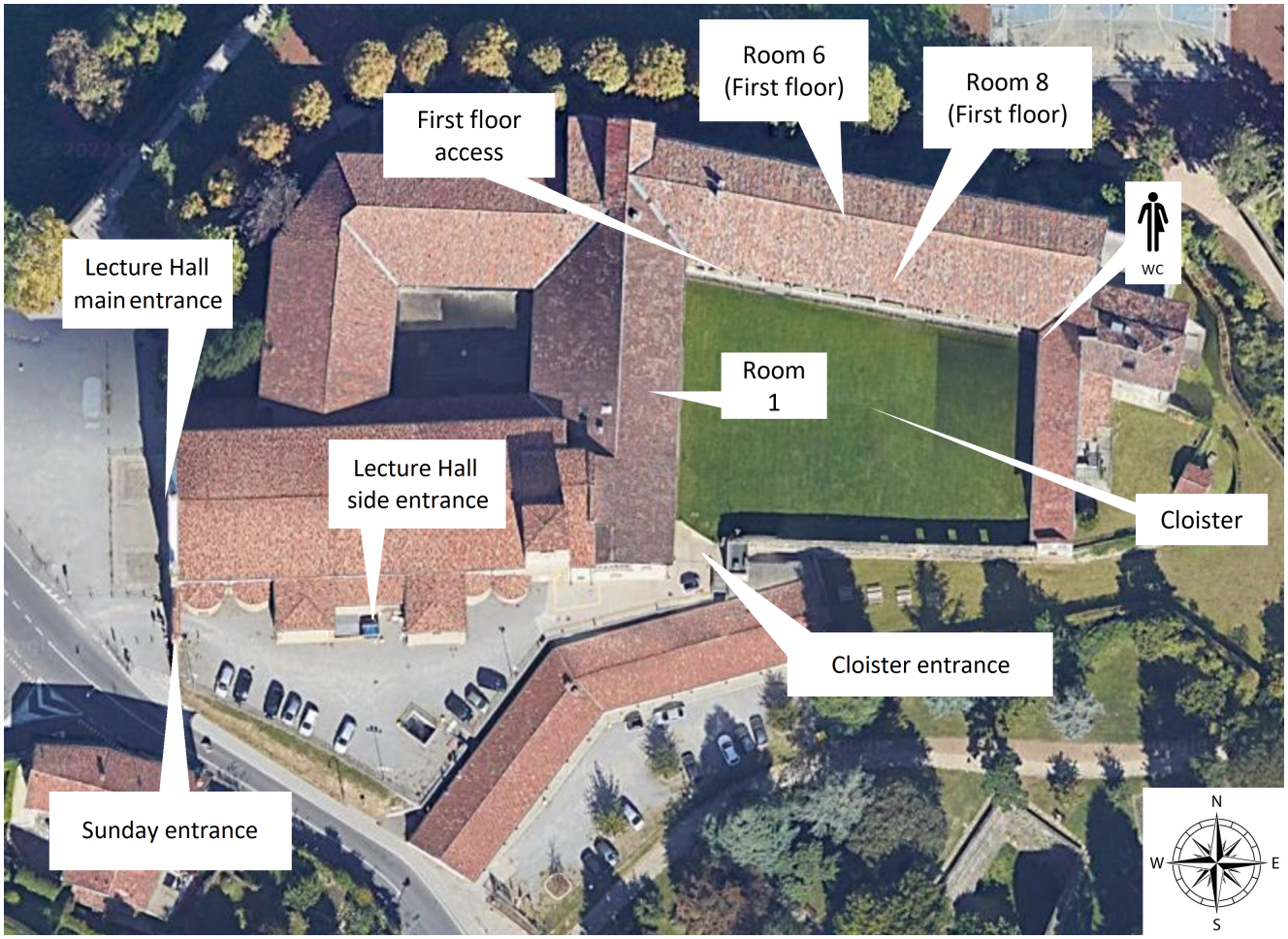
Room 1 is also reserved for the ORAHS conference, and is available for small meetings upon reservation at the conference desk.

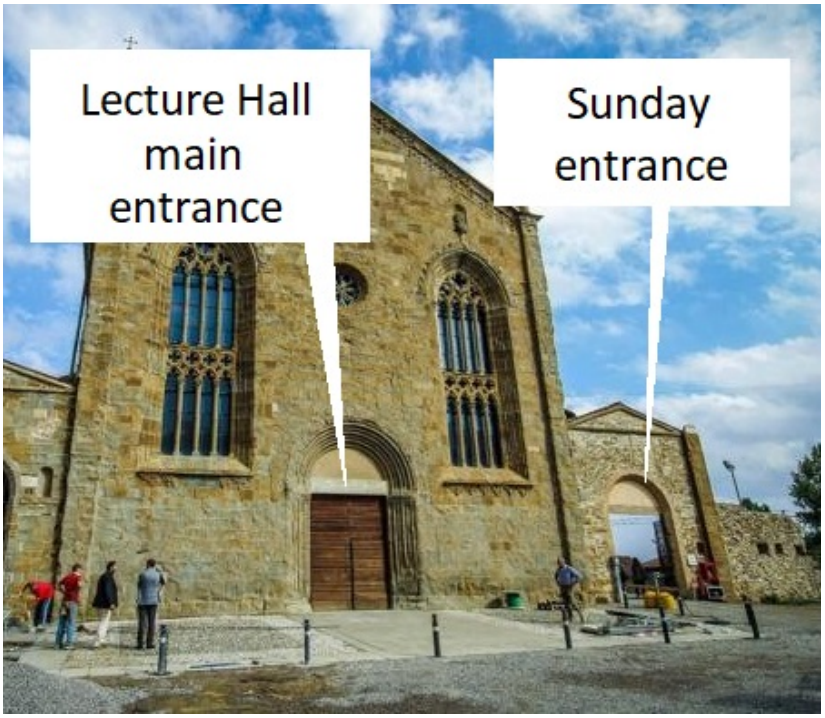
The welcome party on Sunday 17$^{\text{th}}$, the coffee breaks and the lunches will be held in the main cloister of the building. The poster session will take place in the cloister as well.

Due to the current renovation of some spaces, toilets are located in the cloister, on the north-east corner.

On Sunday 17$^{\text{th}}$, for the welcome party, the entrance will be from the parking lot to the right of the Lecture Hall to get directly to the cloister. On the other days, the entrance will be from the main entrance of the Lecture Hall. To go from the Lecture Hall to the cloister and vice versa, you can use the side entrance of the Lecture Hall (halfway on the right) passing through the parking lot.

The map below provides the position of these spaces.





To reach the venue via public transportation (also from the *Orio al Serio* Airport or the Bergamo railway Station), take the city bus line number 1: the *Porta Sant'Agostino* stop will leave you just outside the conference venue. The single-ride ticket also includes the use of all public transportation lines within the city area, including the cable railway (the *Funicolare*) to the Upper Town.

If you travel by car, be aware that on Sundays (from 10:00 to 12:00 and from 14:00 to 19:00) and on Thursdays, Fridays and Saturdays (from 21:00 to 01:00) it is not possible to access the Upper Town by car, unless you qualify for a special permit to do so (people with special mobility requirements, or customers of an hotel within the limited traffic area). Additionally, it may be difficult to find parking spot, especially during the weekends.

INFORMATION FOR SESSION CHAIRS

Session chairs will find a computer in the room, computer already connected to the projector:

- Lecture Hall – laptop on the podium in front of the speaker;
- Room 6 – desktop computer hidden under the table and accessible through the plugs on the monitor;
- Room 8 – laptop on the desk.

Presentations can be uploaded via sub key or by using the browser on the computer. We invite speakers not to use their computer, which could not be recognized by the system.

The plenaries and the parallel sessions in the Lecture Hall will be also broadcast via Microsoft Teams to meet the special requests of some speakers. Session chairs will find the meeting on Microsoft Teams already activated.

In case of problems, session chairs can ask for help from Ettore Lanzarone and Martina Doneda, or they can call the university ICT technician (Fabio Zanga +39 35 2052277) who will immediately come to support.

WI-FI CONNECTION

A wi-fi connection through the `UNIBG-STUDENTI` network is available in all University spaces for the registered participants. Each participant received an email with instructions and a personalized ID and password. Detailed documentation is available at www.unibg.it/wi-fi. In case of problem, you can ask for support at the conference desk. Please, be aware that for legal reasons the university logs all traffic.

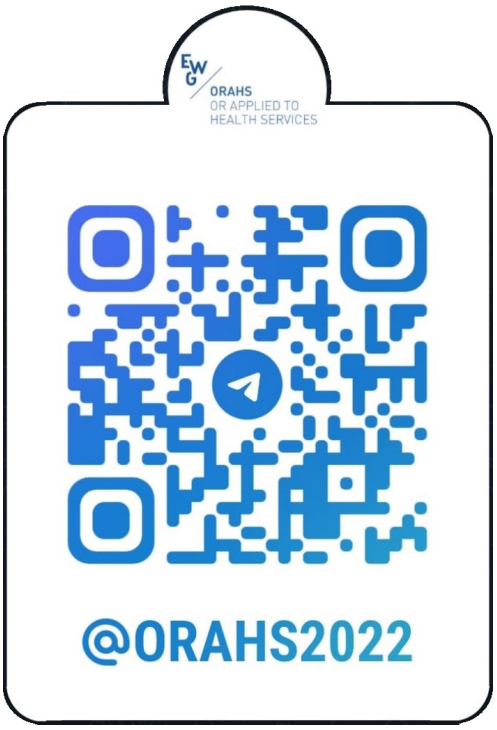
In addition, the `EDUROAM` connection is available in all University spaces.

TELEGRAM CHANNEL FOR LAST MINUTE UPDATE

A Telegram channel will be used to communicate any last-minute info. Follow the link:

`https://t.me/orahs2022`

or scan the QR code below to join the channel.



We remind that, with Telegram, it is not necessary to make the mobile number visible to the other participants to access the channel.

HUMANITAS HOSPITAL VISIT

Humanitas Gavazzeni is located in Via Europa 12, Bergamo (entrance to the emergency center).

A public transportation bus, but reserved for ORAHS participants, will leave from Piazzale Sant'Agostino at 16:15 and will arrive at the entrance to the emergency center. The same bus will bring back the participants from the emergency center to Piazzale Sant'Agostino with departure at approximately 18:45.

Due to the limited capacity of visitors in the hospital, each ORAHS participant will attend the visit either on Monday or Tuesday, according to the letter on the badge and the preferred day (if a preference has been expressed in the online questionnaire). Group A will visit the hospital on Tuesday, while group B on Monday. Please, **respect the day of the letter indicated on your badge** to meet the hospital's request.

Each day, the participants will be divided into 4 groups who will visit in rotation as many stations set up in the hospital. Each group will be assisted by a tour leader from the ORAHS 2022 committee and another from the Humanitas hospital. The ORAHS 2022 tour leaders are:

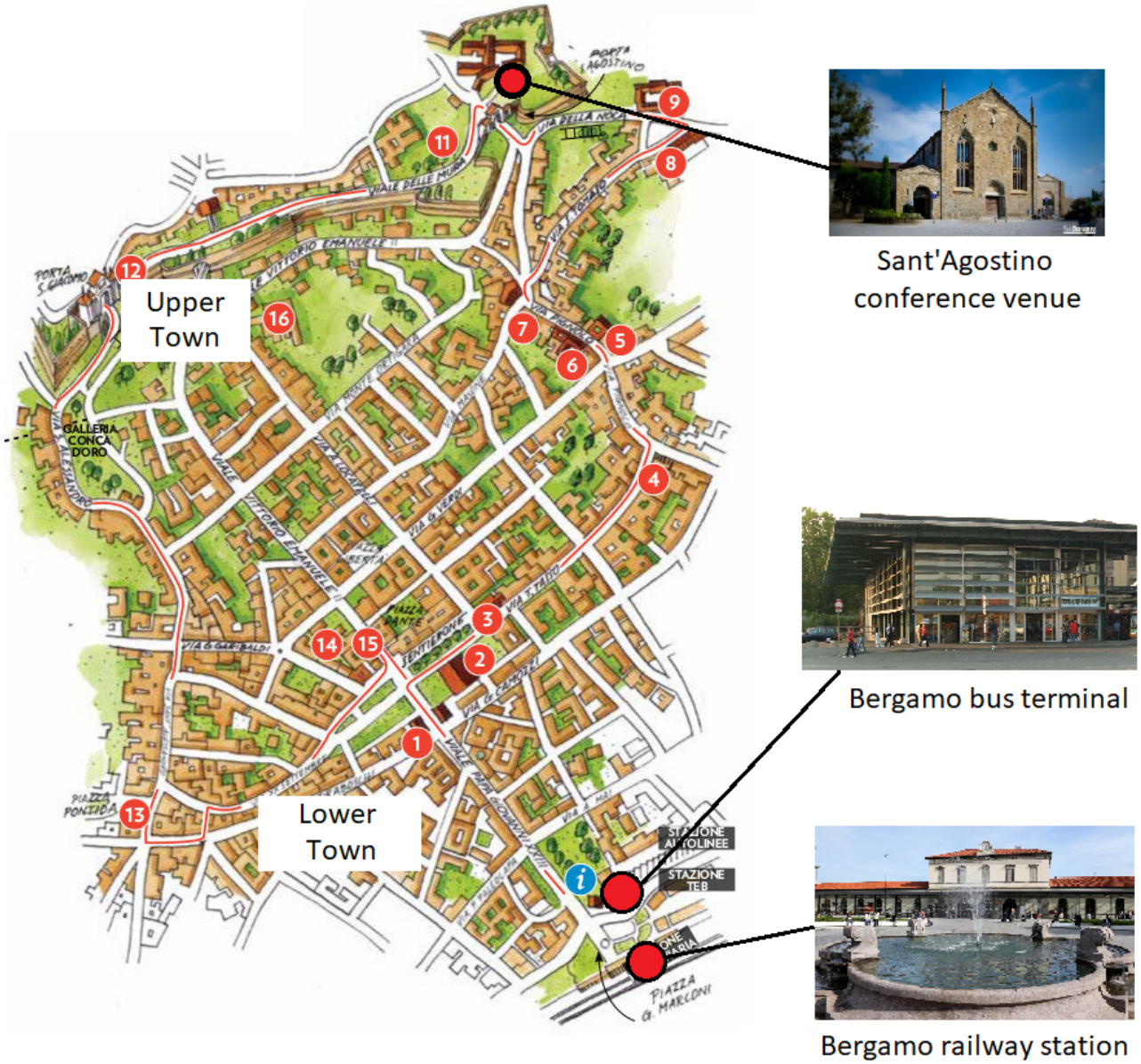
- *Monday:*
  Ettore Lanzarone, Giovanni Righini, Martina Doneda, Roberto Cordone.
- *Tuesday:*
  Ettore Lanzarone, Martina Doneda, Giuliana Carello, Sara Mattia.

The centerpiece of the visit is the new emergency center, built in 4 months to cope with the increased demand during the first waves of Covid.

NOTES FOR BUS TRANSFERS

Due to the medieval structure of the Upper Town and some restrictions imposed on urban traffic, the departure and arrival of buses will be at the Bergamo bus terminal in Piazzale Guglielmo Marconi 7.

The only exception is the return from Val Brembana on Monday for the accompanying persons, which will be close to Piazzale Sant'Agostino, to allow them to join the guided tour of the Upper Town.



The meeting point at the bus terminal is in front of the building depicted in figure.

COVID MANAGEMENT SUGGESTIONS

We invite all participants to wear a mask (preferably FFP2) in all conference rooms and closed spaces of the university.

If you need a swab, the pharmacy closest to the conference venue is the Guidetti Pharmacy in Via San Giacomo 2 (tel: +39 35 237220). Moreover, in Italy it is possible to have an antigenic swab in many pharmacies.

RECEIPT AND CERTIFICATE

Each registered participant will receive from Promoest (organising secretariat) the receipt of payment of the registration fee to the email address indicated during registration.

Moreover, participants who wish it will receive the certificate of attendance by requesting it to Ettore Lanzarone (ettore.lanzarone@unibg.it).

GALLIVAN AWARD

Since ORAHS 2017, the Gallivan Award is given to the best works presented by Ph.D. students. In particular, 3 students are awarded at each ORAHS edition thanks to the EURO General Support funding.

This year, a committee made by the ORAHS chairs (*Roberto Aringhieri and Melanie Reuter-Oppermann*) and the ORAHS 2022 organizers (*Ettore Lanzarone and Giovanni Righini*) carefully read the abstracts submitted by all Ph.D. students, and individuated a list of 10 finalists, whose list is at page 80, for the Gallivan Award completion (to which it was communicated 3 weeks before the conference).

As the Gallivan Award provides a poster presentation, the finalists also prepared a poster besides the oral presentation. Indeed, they will present the work during one of the parallel sessions, but at the same time they will discuss a poster that will be evaluated during the poster session by the jury of the Gallivan Award. Only the poster will be evaluated by the jury. This year, the jury is composed by Melanie Reuter-Oppermann (president), John Blake, and Gréanne Leeftink.

The winners of the Gallivan Award will be announced during the social dinner.

Conference opening

Lecture Hall – Monday 18^{th} – 9:00-9:30

Institutional greetings:

- Marcella Messina
  Delegate of Giorgio Gori,
  Mayor of Bergamo
  and
  Councilor for the social policies
  at the Municipality of Bergamo
- Matteo Kalchschmidt
  Delegate of Sergio Cavalieri,
  Rector of the University of Bergamo
  and
  Director of the Department of Management,
  Information and Production Engineering
  of the University of Bergamo
- Andrea Remuzzi
  President of the Master's Degree Course
  in Engineering and Management for Health
  at the University of Bergamo

Plenary talks

Lecture Hall – Monday 18^{th} – 9:30-10:30

What does it mean to have a health service

Giuseppe Remuzzi
Mario Negri Institute, Milan and Bergamo, Italy, giuseppe.remuzzi@marionegri.it

The Italian Constitution states that all citizens have the right to health. Article 32 states: 'The Republic protects health as a fundamental right of the individual and in the interest of the community, and guarantees healthcare for the indigent.' However, this statement did not translate into healthcare for all, at least not until 1978, when the National Health Service (Servizio Sanitario Nazionale (SSN)) was established, and later reformed in 1992-1993. The 1978 law is based on three fundamental principles: 1. Universality 2. Solidarity 3. Uniformity. These principles fully correspond with the conviction that health is a right, and not a service to be left to the dynamics of the free market. We must do everything we can to preserve our healthcare service, and defend it by correcting it where necessary, improving it still further, but without abandoning its founding principles. But the costs of healthcare are increasing year by year, in Italy like in all other industrialised countries. This is due to ageing populations and the discovery of new treatments and diagnostic tools that are often presented as indispensable and necessary to meet the needs of patients. So what? Since the state (in Italy as much as in other industrialised countries) is finding it increasingly difficult to cope with steadily growing needs, international agencies like the World Trade Organisation are pushing for the privatisation of health service provision and hoping that private funds can be added to healthcare funding. This requires citizens to pay for an increasing share of medical services (a burden that is added to taxation). But will people really have to resort to supplementary funds or insurance for everyone to be able to get the care they need? Probably not.

Lecture Hall – Tuesday 19^{th} – 9:45-10:45

Comparing services: why hospitals should call

Ger Koole
Vrije Universiteit, Amsterdam, The Netherlands, ger.koole@vu.nl

In this talk we will look at planning in both customer service and health care. We will compare both areas and identify possible directions in which health care can become both more efficient and patient oriented.

Lecture Hall – Thursday 21^{st} – 9:45-10:45

Mathematical Models and Health: what the Doctor thinks

Pier Giorgio Villani
Dept. of Emergency and Critical Care Medicine, Hospital of Cremona, Italy,

The origin of medicine is ancient. This primordial exercise lay between medicine, religion and magic[1]. The scientific transformation of medicine over the years has led to the constant application of statistical methods to define every aspect of the care process. We are currently facing the era of "Big Data" and "Information Technology" and the amount of information that is generated in all aspects of modern life, including healthcare, has increased exponentially[2]. The world of medicine and that of mathematics will have to find a meeting point in the future. This work simply wants to offer the doctor's point of view.

[1] G. Cosmacini. *L'arte lunga, storia della medicina dall'antichità a oggi.* Laterza 2006

[2] V. G B Liem, S. E Hoeks, F. van Lier, J. C de Graaff. *What we can learn from Big Data about factors influencing perioperative outcome.* Curr Opin Anaesthesiol (2018); 31(6) : 723 – 731

Round table:
the Italian experience in reaction to COVID-19

Lecture Hall – Thursday 21^{st} – 15:00-16:305

Stefano Boccini

Engineer, director of human resources and organization at the *IRCCS Istituto Clinico Humanitas and Castelli.*

Paola Cappanera

Associate Professor of Operations Research at the *University of Florence.* She is also the coordinator of *AIRO health*, the health care section of the Italian Association of OR.

Furio Coltri

He has been member of the board of directors for several years at the Milan deparment of the largest Italian association for blood donation (*AVIS*).

Nicholas Draghetti

Computer scientist expert in analytics and optimization, he is a senior IT Consultant at *Reply Laife.*

Andrea Remuzzi

Full professor of bioengineering at the *University of Bergamo, Italy*, and consultant at the *Mario Negri Institute.* He is author of the Lancet paper *COVID-19 and Italy: what next?*, and unit coordinator of the project TeleCOVID funded by the Lombardy Region.

ORAHS business meeting

Lecture Hall – Friday 22^{nd} – 11:15-12:45

The business meeting will be also broadcast via Microsoft Teams at the following link:

tinyurl.com/businessmeetingORAHS22

Scientific sessions – Monday, July 18th

Prevention and triage

Mo1-A – *Lecture Hall* – 11:00-12:00

Chair: Christina Bartenschlager

Simulation modelling of a cancer screening program from trial data

Marion Penn
University of Southampton, m.l.penn@soton.ac.uk

Sally Brailsford
University of Southampton, s.c.brailsford@soton.ac.uk

Rhorom Priyatikanto
University of Southampton, r.priyatikanto@soton.ac.uk

Christine Currie
University of Southampton, christine.currie@soton.ac.uk

Jonathan Klein
University of Southampton, j.h.klein@soton.ac.uk

Stephan Onggo
University of Southampton, b.s.s.onggo@soton.ac.uk

Tracey England
University of Southampton, t.j.england@soton.ac.uk

Steffen Bayer
University of Southampton, s.c.bayer@soton.ac.uk

Mike Hepburn
University of Southampton, mike.hepburn@soton.ac.uk

Effective cancer screening programs have the potential to identify cancers before they start causing symptoms, allowing patients with cancer to be identified and treated while the cancer is at an earlier stage in its progression. If the cancers are identified and treated earlier the required treatment may be less aggressive and/or the survival rates improved. For this study we were approached by a healthcare organisation looking to implement a new screening program for lung cancer. A small trial of the program had produced data for the target population but had also raised concerns about the resources needed for further testing of those the screening identified as potentially having cancer. The healthcare organisation particularly wanted to explore the potential health improvements of rolling out the program on a larger scale and the resource implications of doing so. This presentation will explore how we went from the trial data to a simulation model for ongoing screening. Including the challenges created by limited data such as: the long-term screening take up rates; the possible outcomes of follow ups on those who screened positive but didn't have identifiable cancer; uncertainty about the rates of progression for lung cancer.

Keywords: Screening and prevention; Modelling and simulation.

Prioritizing patients for behavioural interventions in cancer screening uptake: a machine learning approach

David Barrera Ferro
University of Southampton, o.d.barrera@soton.ac.uk

Sally Brailsford
University of Southampton, s.c.brailsford@soton.ac.uk

Adriane Chapman
University of Southampton, adriane.chapman@soton.ac.uk

Despite being a highly preventable disease, cervical cancer remains a public health concern. Although in high-income countries screening programs have been successful in reducing mortality rates, in lower and middle-income countries this is not the case. In Bogotá, after implementing a home-visits program to promote screening uptake, the no-show rate for the cytology appointments remains around 40%. Therefore, the local health office decided to design two behavioural interventions to increase uptake, among hard-to-reach women. While the first intervention is personalised and highly resource intensive, the second one is a mass strategy aimed at improving coverage. To ensure cost-effectiveness and financial sustainability of the system, there is a capacity constraint for each strategy. This work proposes a methodology to classify each cohort of patients into three groups: a group who would receive the personalised intervention (Group A), a group who would receive the mass intervention (Group B) and a group that would not receive any intervention at all (Group C). First, we used LASSO regression and Random Forest to predict individual attendance probabilities for the cervical cancer screening. Then, an optimisation model was used to improve the group fairness of the classification, following a post-processing approach. Our results show that is possible to address machine learning bias while maintaining high levels of accuracy.

Keywords: Analytics; Screening and prevention; Decision support.

A retrospective evaluation of score-based ex-post triage policies during the COVID-19 pandemic: simulation study by real-world intensive care data

Christina Bartenschlager
University of Augsburg, christina.bartenschlager@unikat.uni-augsburg.de

Background During the COVID-19 pandemic, authorities set up lockdown measures and infection-prevention strategies to avoid an overburdened health care system. In this context, a question on ex-post triage of intensive care patients arises. Ex-post triage is a rather young research area, which is dealt with primarily from a theoretical, ethical, and legal rather than from a quantitative perspective. Methods We focus this gap and provide quantitative analyses of score- and non-score-based ex-post triage policies using simulation and real-world electronic health record data in a COVID-19 setting. 10 different triage policies are compared by the mortality on ICU as indicator and Analyses of Variance including post hoc hypothesis tests. Results Our study shows that score-based ex-post triage policies perform superior compared to non-score-based ex-post triage. Based on our simulation model, a SAPS-score based ex-post triage is optimal and reduces mortality on ICU, depending on the scenario, by up to 18 percentage points. The longer the queue of critical care patients waiting for ICU treatment and the larger the maximum number of patients subject to ex-post triage, the greater the effect on the reduction of the mortality on ICU. Conclusion Although ex-post triage is to be understood as ultima ratio and, first, all political and health care measures are to be taken, a SAPS score-based ex-post triage policy applied in a reasonable time horizon is optimal in our simulation model.

Keywords: Covid-19 application; Modelling and simulation; Decision support.

Capacity planning: Pandemic response

Mo1-B – *Room 6* – 11:00-12:00

Chair: Thierry Garaix

Healthcare response tool for a territorial hospital group during a pandemic

Mohamed El Habib Messabis
École des Mines de Saint-Étienne, mohamed.messabis@emse.fr

Thierry Garaix
École des Mines de Saint-Étienne, garaix@emse.fr

Xiaolan Xie
École des Mines de Saint-Étienne, xie@emse.fr

The ongoing COVID-19 pandemic has put healthcare organizations around the world through immense levels of stress. Due to how rapidly it has spread, this disease has brought to light a great level of unpreparedness inside the healthcare systems, as well as a lack of robust patient management strategies essential to alleviate the pressure endured by healthcare facilities during a health crisis. Herein, the main focus lies on COVID-19 patients. Indeed, the purpose of this work is to develop a dynamic response tool to guide healthcare facilities in their resource and patient management decisions on a territorial level. In order to achieve that, a decision aiding problem is studied, it consists of the construction of a healthcare response network for COVID-19 patients and making decisions on patient assignment from the demand zones to the active healthcare facilities at each period of a given time horizon. The novelty of this response tool is that throughout a time horizon, healthcare facilities are added, removed, or have their capacity levels modified dynamically following the progress of the pandemic. To model this problem, some hypotheses regarding the healthcare facilities, patient arrival, and length of stay distributions are developed and utilized in the formulation of integer linear programming models that are solved using commercial solvers (Cplex). Other heuristic approaches are also considered for larger size problems.

Keywords: Capacity and network planning; Covid-19 application; Healthcare policy modelling.

Flexible restructuring of inpatient wards

Nalan Gulpinar
University of Warwick, nalan.gulpinar@wbs.ac.uk

Sebastian Rachuba
University of Wuppertal, rachuba@uni-wuppertal.de

Structures and sizes of inpatient wards at public hospitals have grown historically and only few changes are made to the allocation of beds to wards and departments. Restructuring of existing allocations is thought to be promising with regards to a more efficient bed utilisation, especially with seasonal demand. However, resulting changes cause disruption and would affect daily working practice. We present a mixed-integer optimisation model to support ward restructuring at a public hospital. We demonstrate effects of restructuring using real world data and analyze trade-offs between restructuring effort, the resulting costs and the quality of new structures.

Keywords: Strategic and operational planning; Staffing and capacity planning; Analytics.

Capacity planning in intensive care unit during a pandemic crisis

Camille Breen
École des Mines de Saint-Étienne, camille.breen@emse.fr

Thierry Garaix
École des Mines de Saint-Étienne, thierry.garaix@mines-stetienne.fr

Xiaolan Xie
École des Mines de Saint-Étienne, xie@emse.fr

Stéphane Kirche
Centre Hospitalier William Morey, stephane.kirche@ch-chalon71.fr

Alexandre Benoist
Centre Hospitalier William Morey, alexandre.benoist@ch-chalon71.fr

Nathalie Roch
Centre Hospitalier William Morey, nathalie.roch@ch-chalon71.fr

During epidemic crises, the health care systems meet organizational difficulties due to the scarcity of resources, the uncertainty of the demand, and the modifications of care pathways. Hospitals face two inconsistent problems: (i) admitting and treating the maximum number of COVID patients and (ii) maintaining the maximum activity rate for other critical diseases during the outbreak. This research aims to provide bed management tools in case of epidemics, using the study case of the COVID-19 crisis. We consider intensive care beds the most critical medical resource during the COVID crisis. We propose three types of methods: static, myopic, and a rolling horizon algorithm. Numerical experiments have been conducted on several epidemic models and for two distinct evaluation policies, a full admission of patients in overcrowded conditions or rejection.

Keywords: Covid-19 application; Capacity and network planning; Modelling and simulation.

Workforce planning: Tactical planning

Mo1-C – *Room 8* – 11:00-12:00

Chair: Pieter Smet

Balancing nurse workload through optimized patient admission scheduling

Pieter Smet
KU Leuven, pieter.smet@cs.kuleuven.be

Greet Vanden Berghe
KU Leuven, greet.vandenberghe@cs.kuleuven.be

Ensuring sustainable working conditions for employees plays a crucial role in their overall engagement and performance. This is especially important in hospitals, where job performance directly affects the quality of care provided to patients. Nurses' working conditions are considerably affected by their experienced workload, which should be balanced to avoid wards suffering from excessive nursing workload. In addition to their major specialism(s), hospital wards can typically also treat patients for a number of minor specialisms. The workload experienced by nurses when treating minor specialisms may be higher compared to their major specialism. This study investigates how optimized patient admission scheduling can be used to balance workload between hospital wards. The goal is to balance the workload between different wards. Due to the multi-period character of patient admission scheduling, temporal balancing is also desired such that wards experience a similar workload on different days. In order to achieve this, we propose an optimization-based approach which determines the admission date of patients and assigns them to suitable wards while optimizing new multi-period equity functions. Using real-world data, we analyze the results of a series of experiments to gain new insights into (i) the effects of using different equity functions and (ii) the influence of problem properties on workload balancing.

Keywords: Patient scheduling.

Local search techniques for a medical student scheduling problem

Eugenia Zanazzo
University of Udine, zanazzo.eugenia@spes.uniud.it

Sara Ceschia
University of Udine, sara.ceschia@uniud.it

Agostino Dovier
University of Udine, agostino.dovier@uniud.it

Andrea Schaerf
University of Udine, schaerf@uniud.it

We consider the Medical Student Scheduling (MSS) problem in the formulation proposed by Akbarzadeh and Maenhout (C&OR 2021), which is a simplified version of the general problem previously proposed by the same authors (EJOR 2021). In the MSS problem, medical students have to be assigned in subsequent periods to a set of wards in designated hospitals, in order to complete their training by performing internships on the disciplines carried out in the specific wards. This version of the problem takes into account, among other constraints and objectives, precedences among disciplines, student preferences, waiting periods, and hospital changes. The typical horizon considered is one year, split into either 12 periods of one month or 24 periods of two weeks. The objective of the problem is to design a timetable that maximizes both student's desire and fairness among students, satisfying rules, regulations, and requirements for the medical school and the hosting hospitals. We developed a local search technique for the MSS problem, based on a combination of two different neighborhood relations and guided by a Simulated Annealing procedure. We also implemented an instance generator and we used it to create challenging instances with up to 320 students. Our solution method has been able to find consistently the optimal solution for all instances of the dataset proposed by Akbarzadeh and Maenhout (C&OR 2021), in much shorter runtime than their exact technique.

Keywords: Staffing and capacity planning; Workforce planning and scheduling; Resource scheduling.

Personnel staffing and scheduling during COVID-19 pandemic: a contact network-based analysis

Ana Batista
Helmholtz-Zentrum Dresden-Rossendorf, a.batista-german@hzdr.de

Abhishek Senapati
Helmholtz-Zentrum Dresden-Rossendorf, a.senapati@hzdr.de

Mansoor Davoodi Monfared
Helmholtz-Zentrum Dresden-Rossendorf, m.davoodi-monfared@hzdr.de

Justin Calabrese
Helmholtz-Zentrum Dresden-Rossendorf, j.calabrese@hzdr.de

The COVID-19 pandemic has disrupted global operations, compromising people's health and safety. Several organizations have been forced to shift their operations to a hybrid system (working from home) to prevent the spread of the virus and ensure employee safety. Although working from home is effective for some organizations, others need to find a balance between workplace occupancy and risk of infection to keep their operations functioning efficiently. We address this issue through contact network analysis by investigating the impact of employee interactions on virus spread in closed environments. We develop a staffing model for the scheduling of employees, considering contact networks. The goal is to maximize occupancy while minimizing the risk of infection. We aim to find the optimal composition of staff differing by priority to be allocated over a specified discrete-time horizon. We propose a Mixed Integer Non-Linear Programming (MINLP) model considering a Microscopic Markov Chain Approach (MMCA) to determine the probability of infection in a contact network based on the employee's interactions. We assess the effectiveness of the approach through simulation, considering several contact network structures and interventions such as testing, vaccination, and personal protection. Through extensive computational analysis, we show that workplace occupancy can be efficiently balanced while keeping safety in the workplace.

Keywords: Covid-19 application; Workforce planning and scheduling; Resource scheduling.

InPlan Care 1

Mo2-A – *Lecture Hall* – 13:00-14:30

Chair: Melanie Reuter-Oppermann

Integrated operating room and recovery ward nurse planning at the University Hospital Augsburg

Jan Schoenfelder
University of Augsburg, jan.schoenfelder@unikat.uni-augsburg.de
Sebastian Rachuba
University of Wuppertal, rachuba@uni-wuppertal.de

With more than 60% of hospital admissions being surgical procedures, the engine that drives hospitals is the operating room (OR). Apart from its financial relevance as the main source of revenue and costs, it is also important for management and planning purposes. This is particularly pertinent to the post-operative recovery stays in the surgical wards, where inpatients are under the care of nurses during their length of stay. Nurse scheduling is typically subordinate to OR planning and based on the occupancy resulting from the OR plan. Our research question is whether and to what extent – compared to the sequential planning process – simultaneous OR scheduling and management of a pool of nurses for different surgical specialties can improve the quality of care and increase the satisfaction of both patients and nurses. We present two mixed-integer programming models, one for sequential decision making and one for integrated OR and recovery ward planning. A weekly surgery schedule is created to maximize OR utilization while balancing the number of expected daily discharges and maintaining the target patient-to-nurse ratios in the recovery wards, thereby reducing both understaffing and overstaffing. We conduct a case study based on data from the University Hospital Augsburg to investigate whether the integrated model for OR and recovery ward planning can increase operational efficiency and balance nurse workload compared to sequential decision making.

Keywords: Operating room planning and scheduling; Workforce planning and scheduling; Staffing and capacity planning.

Integer programming heuristic for the Patient-to-Room Assignment problem at ward level

Felix Engelhardt
RWTH Aachen University, felix.engelhardt@rwth-aachen.de
Christina Büsing
RWTH Aachen University, buesing@math2.rwth-aachen.de
Tabea Brandt
RWTH Aachen University, brandt@combi.rwth-aachen.de

Patient-to-Room Assignment (PRA) is the problem of allocating rooms to patients in a hospital. In this talk, we consider an offline setting at ward level. Arrival and discharge dates of each patient are fixed and no male and female patients may share a room. Patient pairings are assigned a preference and the total overall patient satisfaction is to be maximised. Private patients require preferential single rooms. Furthermore, transferring patients during their stay is to be avoided. Our heuristic approach is based on forbidding transfers in the Integer Programming (IP) formulation. IP has frequently been dismissed in literature as being of limited use for solving PRA. On the one hand, modelling without transfers frequently leads to infeasible solutions. On the other hand, modelling patient stays for each day does badly computationally for larger instances. We show that modelling using only transfers for previously assigned patients both performs well computationally and consistently generates feasible solutions. Our computational study on real data indicates that transfers can in most cases be avoided. Starting with the restricted problem makes an operational usage a realistic option, as the restricted problems can be solved within seconds. Thus, reducing the search space makes Integer Programming a feasible approach in practise leading to optimal or near-optimal patient to room assignments.

Keywords: Patient scheduling.

Challenges and pitfalls of integrated planning problems in healthcare

Melanie Reuter-Oppermann
Technical University of Darmstadt, melanie.reuter-oppermann@tu-darmstadt.de

Christina Büsing
RWTH Aachen University, buesing@math2.rwth-aachen.de

Sebastian Rachuba
University of Wuppertal, rachuba@uni-wuppertal.de

Clemens Thielen
Technical University of Munich, clemens.thielen@tum.de

Efficient service provision in hospitals and, thereby, high quality of care requires the necessary resources such as personnel and beds to be dimensioned correctly and to be available in the right place at the right time. Typically, resource related planning problems are treated separately for each resource without integrated planning across several resources. This leads to globally sub-optimal decisions and unused potential for high quality health care services. Many such decisions are often managed by clinical staff despite the fact that they are not trained for this kind of complex decisions. In turn, it reduces their available time for patient treatment and care. A holistic view on integrated planning problems in health care is beneficial, particularly making use of state-of-the art research focusing on topical problems in hospitals. While technological and methodological advances make it possible to handle such complex dependencies, the number of reports on successful implementations in practice is rather low. This discussion session aims to provide a forum to discuss challenges and pitfalls of integrating previously distinct planning decisions into a joint decision setting to overcome well-known silos in hospitals.

Keywords: Healthcare logistics; Modelling and simulation; Patient flow.

Capacity planning

Mo2-B – *Room 6* – 13:00-14:30

Chair: Felipe Rodrigues

Intensive care unit / step-down unit queuing game with service time decisions

Felipe Rodrigues
Western University, frodrig7@uwo.ca

This research is an extension of an earlier investigation of the length of stay (LOS) competition that exists between the Intensive Care Unit (ICU) and the Step-Down Unit (SDU) in a given patient's critical care pathway. This game is characterized as a queuing game of two servers in tandem, only now without a buffer between them, and with the individual unit's length-of-stay as decision variable. Analysis of the competition was done under four different scenarios: (i) both units cooperate; (ii) the units do not cooperate and make decisions simultaneously; (iii) the units do not cooperate but the unit upstream, the ICU, is the leader; (iv) the units do not cooperate, the downstream unit, the SDU, is the leader. We found closed form solutions and found the conditions for optimality, as well as what scenarios yield the best performance, both at the unit and at the system level. Later we performed a numerical analysis for validation and illustration purposes. The results show that the length of stay decisions of each unit depends critically on the payoff function's form and the exogenous patient demand. Secondly, with a linear payoff function, the SDU is only beneficial to the system if its cost is greater than its unit reward at the ICU level. Perhaps most importantly, the critical care pathway performs better under coordination and/or leadership at the ICU level, which does not necessarily corroborates with current critical care practice.

Keywords: Patient flow; Capacity and network planning; Strategic and operational planning.

Forecasting ICU census by combining time series and survival models

Lori Murray
Western University, lori.murray@uwo.ca

Felipe Rodrigues
Western University, frodrig7@uwo.ca

John Wilson
Western University, jwilson@ivey.uwo.ca

Greg Zaric
Western University, gzaric@ivey.uwo.ca

Capacity planning of ICUs is essential for effective management of health safety, quality of patient care, and the allocation of ICU resources. In Canada, the Multiple Organ Dysfunction Syndrome (MODS) score and the Nine Equivalents of Nursing Manpower Use Score (NEMS) are used to quantify severity of patient illness and nursing workloads, respectively. Whereas ICU length of stay (LOS) may be estimated using patient information such as intensive care scoring systems, ICU census is impacted by patient LOS and arrival patterns. We present an ICU census forecasting model that combines time series and survival models for capacity planning purposes. Our capacity planning model was tested using data collected at a Canadian hospital during the global pandemic. This type of forecasting model may aid clinicians and managers when planning ICU capacity as well as staffing and surgical demand planning over a short time horizon.

Keywords: Staffing and capacity planning; Forecasting; Decision support.

Robust capacity planning for sterilization department of a hospital

Elvan Gokalp
University of Bath, eg768@bath.ac.uk
Ece Sanci
University of Bath, es2138@bath.ac.uk

Sterile services departments are special units designed to perform sterilization operations in an efficient way within a hospital. The delays in sterilization services cause significant disruptions on surgery schedules and bed management. To prevent the delays, an upper time limit can be imposed on the time spent in the sterilization services. In this paper, we propose a mathematical modelling approach for the optimum capacity planning of a sterilization service unit considering the uncertainties in the sterilization process. The model aims to find the optimum capacity on four tandem steps of the sterilization whilst at the same time minimizing the total cost and keeping the maximum time in the system below a limit. Assuming general distributions for service and interarrival times, an approximation structure based on robust optimization is used to formulate the maximum time spent in the system. We analysed the structural property of the resulting model and found that the relaxed version of the model is convex. The real data from a large sterilization services unit is used for computational experiments. The results indicated that the approximation fits well against the simulated maximum time in the system.

Keywords: Staffing and capacity planning; Modelling and simulation; Analytics.

Capacity planning in a nursing home context

Nanne Dieleman
Vrije Universiteit, n.a.dieleman@vu.nl
Martijn Buitink
De Nederlandsche Bank, martijnbuitink@me.com
René Bekker
Vrije Universiteit, r.bekker@vu.nl
Dennis Moeke
HAN University of Applied Sciences, dennis.moeke@han.nl

In the Netherlands, both the elder population and the shortage on the long-term care labour market is increasing. This puts a financial strain on health care costs, which makes it crucial to optimise relevant processes. Long-term care is often provided in nursing homes. In these nursing homes, residents are helped by care workers to execute their daily living tasks, such as taking medication and cleaning. As most residents have different needs and daily schedules, it is important to provide the right type of care at the right moment. This is the setting of an interesting capacity planning problem. We propose a framework to structure and simplify the planning phases in nursing homes. Moreover, besides providing a framework, we also propose solution methods for each phase, such as a shift scheduling algorithm based on a MILP. An important contribution is the development of an Evolutionary Algorithm (EA) that determines, for each task, which employee handles it and at what time. This is not straightforward to accomplish, and we do so by basing the fitness calculation of the EA on an LP model. We show that our framework significantly reduces the weighted sum of waiting and early time of the tasks compared to current standards.

Keywords: Home care and Long Term Care; Optimization algorithm; Staffing and capacity planning.

Health care systems: analysis and optimization

Mo2-C – *Room 8* – 13:00-14:30

Chair: John Blake

Implication of new primary care and demand scenarios on patients' accessibility

Chiara Morlotti
University of Bergamo, chiara.morlotti@unibg.it

Giuseppe Bruno
University of Naples Federico II, giuseppe.bruno@unina.it

Mattia Cattaneo
University of Bergamo, mattia.cattaneo@unibg.it

Antonio Diglio
University of Naples Federico II, antonio.diglio@unina.it

Stefano Paleari
University of Bergamo, stefano.paleari@unibg.it

Carmela Piccolo
University of Naples Federico II, carmela.piccolo@unina.it

Ensuring a high level of accessibility to healthcare services is a key policy goal. In these terms, the Italian National Recovery and Resilience Plan (NRRP) dedicates a great attention to territorial medicine, including investments devoted to the re-organization of primary care services. In this study, we assess the variations in accessibility to primary care services under different scenarios, where both demand and supply changes are investigated. Scenarios are simulated combining the current and future distribution of primary care services, and population spatial evolution over time. On the supply side, we ground on an extensive dataset of General Practitioners' (GPs) services belonging to a Nordic Italian region. On the demand side, we elaborate census-level detailed information and estimate population local redistribution based on territorial features, such as distances to central business districts (CBDs), infrastructures, and amenities. Accessibility is measured by relying on a tailored two-step floating catchment method which accounts for the actual temporal availability of GPs, allowing to accurately measure the demand/supply mismatch across both space and time. The study aims to draw several insights for policymakers, assessing the potential effects determined by the implementation of new developed models of territorial medicine.

Keywords: Decision support; Capacity and network planning; Forecasting.

Estimating the effect of additional recruits to a national stem cell registry using simulated patient matching

John Blake
Dalhousie University, john.blake@blood.ca

Less than 30% of unrelated adult stem cell transplants in Canada are sourced from Canadian donors. Thus, initiatives are underway to adjust the registrant profile of the Canadian registry. In this paper, we present a simulation-based study to evaluate the marginal impact on patient matching of recruiting differing numbers of individuals to the Canadian registry. A Monte Carlo method was used to create simulated recruits for the registry. Recruits are assigned a pair of HLA haplotypes from historical data files and then matched against patient records. The number of matches generated by a recruit cohort is measured and compared against matches that could have been made from the existing registry. It was found that the number of matches between newly registered donors and patients increases linearly with the number of new recruits. Results suggest that the value of recruiting is maximized in situations where recipients are more likely to accept a complete, rather than partial, match. Results also suggest that recruiting Caucasian and First Nations donors yields match rates exceeding their share of the recruit cohort when exact matches are required. If an imperfect match level is expected, the simulation suggests that diversity is important, since donor utilization tends to follow the ethnic distribution of recruit cohort.

Keywords: Modelling and simulation; Strategic and operational planning; Healthcare logistics.

Reducing psychiatric ICU out-of-area placements under financial constraint

Christos Vasilakis
University of Bath, c.vasilakis@bath.ac.uk

Simon Moss
NHS Continual Care Group, simon.moss3@nhs.net

Richard Wood
BNSSG Clinical Commissioning Group, richard.wood16@nhs.net

Transferring individuals for treatment outside their geographic area occurs when healthcare demand exceeds local supply. This can result in significant financial cost while impacting patient outcomes and experience. The aim of this study was to assess initiatives to reduce psychiatric intensive care unit (PICU) out-of-area bed placements within a major healthcare system in South West England. Discrete event computer simulation was used to model patient flow across the healthcare system's three PICUs. A scenario analysis was performed to estimate the impact of management plans to decrease admissions and length of stay. The amount of capacity required to minimise total cost was also considered. Without increasing in-area capacity, mean out-of-area bed requirement can be reduced by 25.6% and 19.1% respectively through plausible initiatives to decrease admissions and length of stay. Reductions of 34.7% are possible if both initiatives are employed. Adjusting the in-area bed capacity can also lead to aggregate cost savings. This study supports the likely effectiveness of particular initiatives in reducing out-of-area placements for high-acuity bedded psychiatric care. This study also demonstrates the value of modelling in an area that has seen little such attention to date.

Keywords: Healthcare policy modelling; Staffing and capacity planning; Modelling and simulation.

Optimizing long- and mid-term decisions for reverse supply chain networks

Cristinca Fulga
Bucharest University of Economic Studies, fulga@csie.ase.ro

In this paper, we determine the supply chain structure together with the planning decisions that optimize simultaneously the net present value in the presence of uncertain parameters, and one type of operational supply chain risk, which is rooted in one of the intrinsic uncertainties of a supply chain, more precisely in the uncertainty in products demands. The model considers all main supply chains operations, production, assembly, storage, distribution, collection, sorting, remanufacturing and disposal. In the reverse flow, products are collected by the retailers from markets and sorted with the main goal of planning/implementing/ controlling the efficient and effective inbound flow and storage of goods in order to recover value and proper disposal. The key random factor of the proposed model is the vector of products demands, which makes also random the net present value. The novelty of this paper is the model for the design and planning of supply chains with the simultaneous consideration of the forward supply chain activities, reverse logistics activities, operational risk induced by the uncertainty of products demands, and decision maker's loss-aversion. The model maximizes the expectation of the random function net present value, and simultaneously minimizes the risk measure that captures decision maker's loss-aversion.

Keywords: Modelling and simulation; Decision support.

Emergency management systems: Transportation

Mo3-A – *Lecture Hall* – 15:00-16:00

Chair: Valérie Bélanger

Towards a more efficient deployment of emergency medical resources in rural areas

Marta Cildoz
Public University of Navarre, marta.cildoz@unavarra.es

Cristina Azcarate
Public University of Navarre, cazcarate@unavarra.es

Daniel García de Vicuña
Public University of Navarre, daniel.garciadevicuna@unavarra.es

Martín Gastón-Romeo
Public University of Navarre, martin.gaston@unavarra.es

Laura Frías-Paredes
Public University of Navarre, laura.frias@unavarra.es

Fermin Mallor
Public University of Navarre, mallor@unavarra.es

Health system managers face the challenge of planning and providing continuous care for urgencies and emergencies in rural areas upon the current context of changes in demographics, communication networks, and new ways of providing healthcare (medicalized ambulances, helicopters, etc.). In this work, we address the problem of resource reorganization to continue providing care of quality more efficiently. We consider the organization of the existing service network and propose an integer linear optimization model to determine the geographical location and opening hours of permanent care centers with the support of mobile resources (ambulances). It has the objectives of providing quality care (measured by emergency service access time), keeping costs at minimum, and balancing the workload of permanent centers. This model extends the classic problems of localization by integrating time-dependent demand and both permanent and mobile resources. It has been applied to the current rural health network in Navarra. The model has been implemented in a computational tool, which integrates a graphical module for visualizing the solutions to help stakeholders to analyze the problem and to choose the preferred solution to be implemented in practice.

Keywords: Emergency Medical Service; Strategic and operational planning; Healthcare logistics.

Analysis and simulation of aeromedical interhospital transportation: the case of the Quebec aeromedical evacuations program

Valérie Bélanger
HEC Montréal, valerie.3.belanger@hec.ca

Joëlle Cormier
HEC Montréal, joelle.cormier@hec.ca

Marie-Ève Rancourt
HEC Montréal, marie-eve.rancourt@hec.ca

Interhospital emergency transfer is a critical operation to provide specialized care to patients in remote areas by bringing them to tertiary centres. For rural hospitals located far away from any centre, aerial transport is the most efficient and fastest way to get the patients in a second hospital, better suited for their urgent needs. The renewal of an aircraft fleet intended for aeromedical transport presents challenges as to offer a good service level at a controlled cost. Characteristics such as the capacity and range of the aircraft, the presence and length of runways, as well as the demand patterns needs to be taken into account in the decision-making process. The aim of this project is to develop a methodology that supports the strategic decisions of acquiring a new fleet of planes. By building a simulation model that corresponds to the network and protocol of a specific territory, we can test

different fleets, and compare service levels. The dynamic nature of demand, transhipment and weather-induced delays in aeromedical transport are included in the discrete-event simulation. This project is in partnership with the Quebec aeromedical evacuations program and the ministry of Health and Social services. Results provide valuable insights to the decision makers to support fleet renewal. They also shed light on the key trade-offs in the strategic and operational functioning of an aeromedical evacuation service.

Keywords: Emergency Medical Service; Modelling and simulation.

Drone models in healthcare

Melanie Reuter-Oppermann
Technical University of Darmstadt, melanie.reuter-oppermann@tu-darmstadt.de

Sara Ellenrieder
Technical University of Darmstadt, ellenrieder@is.tu-darmstadt.de

In recent years, delivery drones have received significant attention in the media as well as in research. While companies like Amazon triggered high expectations, we do not see a widespread deployment of drones to improve logistic networks yet, especially not in Europe. In contrast, there are many examples worldwide that show how drones can significantly improve healthcare delivery, e.g. distributing medicine or vaccines. Due to recent developments in technology and business models for drone operations, it can be expected that drones are likely to be deployed by various organisations in the next 2 to 5 years. In this talk, we want to discuss different use cases for the deployment of drones within healthcare, e.g. for blood logistics in South Africa or for the delivery of automated external defibrillators in Germany. We present mathematical and simulation models as well as underlying data sets from our two research projects "BISKIT" that aims to design a decision support system for blood logistics in South Africa, and "SPELL" that builds a platform and an ecosystem for data-based and AI-based services and tools to support emergency medical services and crisis management.

Keywords: Emergency Medical Service; Decision support; Modelling and simulation.

InPlan Care 2

Mo3-B – *Room 6* – 15:00-16:00

Chair: Sean Manzi

Distributionally robust optimization of the integrated master surgery scheduling problem with downstream capacity constraints

Hayo Bos
University of Twente, hayobos@gmail.com

Richard Boucherie
University of Twente, r.j.boucherie@utwente.nl

Gréanne Leeftink
University of Twente, a.g.leeftink@utwente.nl

Erwin W. Hans
University of Twente, e.w.hans@utwente.nl

The current challenge in health care capacity management is to plan capacities from a holistic and integral perspective. For example by scheduling resources of a department while accounting for resources in other departments. The Master Surgery Scheduling Problem with downstream resource constraints is an example of such a problem. We propose a Distributionally Robust Optimization based approach with the Wasserstein ambiguity set for this problem, which can easily be applied to similar tactical health care related problems where downstream resource constraints are at hand. We test and benchmark our method on both generated data and a real-life case study from a medium sized Dutch hospital.

Keywords: Operating room planning and scheduling; Modelling and simulation; Patient flow.

Balancing planning certainty and flexibility: master surgery scheduling in practice

Fabian Schäfer
Technical University of Munich, fab.schaefer@tum.de

Alexander Hübner
Technical University of Munich, alexander.huebner@tum.de

This study explores the practice of operating room (OR) planning in German hospitals. We surveyed to understand how master surgery scheduling (MSS), outlined in operations research literature, is applied to practical OR scheduling. We examined only maximum-care hospitals in Germany with a minimum bed capacity of 1000 beds. This limitation ensures that the study provides insights across the entire spectrum of surgical planning, including elective and emergency patients. We used the Grounded Theory Method (GTM) to approach our research in an unbiased manner. After interviewing eleven OR managers and four experts, we obtained the stage of theoretical saturation. The results show tension in OR planning between the required flexibility due to short-term fluctuations in demand and ensuring planning certainty, especially concerning personnel issues. An appropriate interface structure in the hospital that balances this conflict of goals in the short to long term is central OR management.

Keywords: Operating room planning and scheduling; Resource scheduling; Process optimisation.

Large scale health system modelling using a network based approach

Sean Manzi
University of Exeter, s.s.manzi@exeter.ac.uk

The integrated planning of healthcare provision, requires an understanding of how different parts of that system interact and influence one another. Network analysis is one approach for understanding this interactivity between different parts of the health system. This form of network-based operational modelling of health services treats the service being used by a patient as the nodes in the network and the sequential use of those services by patients as the edges. In this way a data driven network representation of a health system can be rapidly built using routinely collected patient level data. The system structure and activity within that system can be visually and quantitatively appraised as a complete whole rather than in part. Viewing the activity and interactions between services across a system can benefit integrated healthcare planning at strategic, tactical and operational levels whether for activity monitoring, identifying performance issues or identifying unmet need. This approach has been developed into a free and open source software platform which aims to facilitate the use of a network based approach to large scale health system modelling. The network models of health system activity are supported by statistical process control, time-series analysis and comparative bar charts to provide healthcare organisations with an understanding of their system wide operations to facilitate better integrated planning.

Keywords: Healthcare Information System; Decision support; Strategic and operational planning.

Workforce planning: Strategic planning

Mo3-C – *Room 8* – 15:00-16:00

Chair: Maddalena Nonato

Robust annual scheduling of medical residents using prioritized multiple training schedules to combat operational uncertainty

Sebastian Kraul
University of Augsburg, sebastian.kraul@unikat.uni-augsburg.de

Jens Brunner
University of Augsburg, jens.brunner@uni-a.de

Medical residents often have to pass through many departments, which place different requirements on them. They are informed about the upcoming departments by an annual schedule to keep the individual departments' service level as constant as possible. Due to poor planning and uncertain events, deviations in the schedule can occur. These deviations affect the service level in the departments as well as the satisfaction of the residents. This project analyzes the impact of priorities on residents' annual planning to overcome unknown departmental changes. We present a novel two-stage formulation that combines residents' tactical planning with daily and duty rostering's operational level. We determine an analytical bound for the problem that is significantly superior to the LP bound. Additionally, we approximate a bound based on the solution approach. In a computational study, we analyze the performance of various bounds, our solution approach, and the effects of additional priorities in residents' annual planning. We show that additional priorities can significantly reduce the number of unknown shifts to be worked. Finally, we derive a practical number of priorities from the results.

Keywords: Workforce planning and scheduling; Teaching; Statistical modelling.

Long-term patient-physician assignment in a cooperative network of physicians in a region

Anne Zander
University of Twente, a.b.zander@utwente.nl

Suppose we have a cooperative network of physicians that need to serve the patient demand from a designated region. To ensure continuity of care and a long-term balance between capacity and patient demand, we need to decide on patient-physician assignments and capacity adjustments, possibly including location decisions for new physicians. I propose to support those decisions using a rolling horizon approach, i.e., by planning for several periods ahead but only acting on the decision for the current period. In this case, this is achieved by combining several solutions of deterministic integer linear programs (ILPs) that take a prediction of the future capacity requirement of patients into account. The ILPs minimize the deviation between the expected patient demand and the physician's capacity over time, as well as capacity changes and traveling distances of patients. Using a stochastic discrete-event simulation with parameters based on real-world data shows that taking decisions while looking ahead several periods instead of only focusing on the current situation allows to significantly lower the mismatch between demand and capacity over time. Hence, this method helps to ensure access to care for patients and fair workload distribution between physicians.

Keywords: Capacity and network planning; Staffing and capacity planning; Decision support.

Achieving fairness in medical staff midterm scheduling by answer set programming: a case study

Maddalena Nonato
University of Ferrara, nntmdl@unife.it

Paola Cappanera
University of Florence, paola.cappanera@unifi.it

Marco Gavanelli
Universiy of Ferrara, marco.gavanelli@unife.it

Marco Roma
University of Florence, marco.roma@unifi.it

We deal with a staff scheduling problem concerning physicians working at few hospitals in a local area network. Due to the pandemic situation, these hospitals experienced several reorganizations in terms of both staff and services allocation, which exacerbated previous strains to manually provide working schedules. As any feasible schedule has the same monetary cost the main focus is on feasibility. However, fairness related issues sharply arise in the midterm. As the variety of tasks is high and each physician has different skills, achieving fairness by rotating tasks among people is not viable. Because of this diversity, there is no ideal workload threshold whose distance from may return a measure of fairness and more elaborated attributes must be measured to make a comparison possible. In our proposal, fairness is sought off by diversification in the short term and achieved in the long one. To this aim, service is scheduled over a midterm time period long enough to allow a certain degree of diversification within the schedule of each physician, as well as a fair distribution of the heaviest tasks among all physicians. Long planning horizons yield large size problems, posing a challenge on performance. We tackle the problem by Answer Set Programming, as it easily handles preferences and soft constraints. In the presentation we will focus on various modeling options regarding fairness representation and how to enforce it over time and will present results based on real data.

Keywords: Workforce planning and scheduling; Optimization algorithm; Modelling and simulation.

Scientific sessions – Tuesday, July 19^{th}

Logistics: Transportation

Tu1-A – *Lecture Hall* – 8:45-9:45

Chair: Ana María Anaya-Arena

Allocating epidemic response teams and vaccine delivery by drone using a hybrid simulation-optimisation approach on different network structures

Linke Potgieter
Stellenbosch University, lpotgieter@sun.ac.za
Dean Matter
Stellenbosch University, deanmatter@gmail.com

The tumultuous inception of an epidemic is usually accompanied by difficulty in determining how to respond best. To provide guidance towards improved allocation of epidemic response teams and vaccine delivery by drone, a hybrid simulation-optimisation approach are proposed. The resource allocation models formulated maximise expected prevented exposures on each day of a simulated epidemic, by allocating response teams and vaccine deliveries according to the solutions of two respective integer programming problems — thereby influencing the simulated epidemic through the SEIRVD model. These models, when compared with a range of alternative resource allocation strategies, were found to reduce both the number of cases per epidemic, and the number of vaccines required. Results for different network structures, representing interconnected populations in rural and urban settings, indicate that the effectiveness of different response strategies varies according to network type. It is therefore important to consider a network's population distribution when making resource allocation decisions

Keywords: Epidemiology and disease modelling; Decision support; Resource scheduling.

Vaccine distribution problem: a case study

Claudia Piffari
University of Bergamo, claudia.piffari@unibg.it
Alexandra Lagorio
University of Bergamo, alexandra.lagorio@unibg.it
Roberto Pinto
University of Bergamo, roberto.pinto@unibg.it

Vaccine logistics has become, because of the pandemic, one of the most important topics discussed in the health-care sector. The interest in the logistic aspects of vaccine distribution should not be a priority only in emergencies: having an efficient and strong vaccine supply chain for the distribution and administration of traditional vaccines can be an important base for the development of a national distribution pathway in emergency circumstances. This paper presents a case study regarding the influenza vaccine supply chain in the district of Bergamo. In Italy, flu vaccination is offered, among others, to individuals suffering from diseases that could increase complications risks. They receive vaccines in hubs to which are assigned based on the proximity to their municipality of residence. Incorrect choices in the location of centres can lead to difficult access to vaccinations for this type of vulnerable patient and could translate into a bad service level for the citizens. The aim of the case study is the identification, through facility location problem algorithms, of the optimal location of the vaccinal centres and the development, through the application of vehicle routing problem algorithms, of the optimal transport route for vaccine doses from the central warehouses to the hubs. Even if such topics are quite common in the managerial literature, the originality of this work is related to the practical application of well-established models to a real-world case.

Keywords: Strategic and operational planning; Healthcare logistics; Optimization algorithm.

Iterative time-decomposition matheuristic for the biomedical sample transportation problem

Ana María Anaya-Arenas
Université du Québec à Montréal, anaya-arenas.ana_maria@uqam.ca

Chiara Mazzanti
CNR-IMATI, chiara.mazzanti@mail.polimi.it

Valérie Bélanger
HEC Montréal, valerie.3.belanger@hec.ca

Ettore Lanzarone
University of Bergamo, ettore.lanzarone@unibg.it

Angel Ruiz
Université Laval, angel.ruiz@fsa.ulaval.ca

This talk will present an iterative time-decomposition matheuristic for solving the biomedical sample transportation problem (BSTP), which is a routing problem with multiple and interdependent visits in the context of healthcare services. In this problem, each healthcare or specimen collection center collects biomedical samples from individuals. Because the lifespan of a specimen lasts only a few hours from collection to analysis, several collection centers must be visited more than once a day to collect the specimens and ensure that they are analyzed before perishing. Setting a maximum time to analyze the samples imposes a time interdependency between visits to the same center and the maximum duration of their corresponding routes. This is a complex routing problem, and commercial solvers have been inefficient at solving it. Hence, we propose an algorithm that uses a time-decomposition technique to reduce the interdependency and apply a Fix-&-Optimize technique to solve the problem efficiently. The matheuristic proves to be efficient in solving a set of real-life instances with high interdependency requirements from the Quebec laboratory network under the management of the *Ministère de la Santé et des Services Sociaux* (Ministry of Health and Social Services)

Keywords: Optimization algorithm; Healthcare logistics.

Appointments: Outpatients

Tu1-B – *Room 6* – 8:45-9:45

Chair: Rosita Guido

On-line multi-appointments scheduling: a dynamic approach for hip and knee replacement

Ahmed Bakali El Kassimi
École des Mines de Saint-Étienne, ahmed.bakali@emse.fr

Xiaolan Xie
École des Mines de Saint-Étienne, xie@emse.fr

The total hip and knee arthroplasty (THA/TKA) are ones of the most common surgeries in France with more than 224170 hospitals stay in 2018. However, many organizational problems arise in the management of patient care pathway particularly in pre-op multi-appointments scheduling. The lack of coordination between services, the appointment scheduling neglecting patients' characteristics and the lack of a decision support system are some of the main factors.This work proposes a practical methodology for on-line multi-appointments scheduling problems. A three-stage approach is proposed including multi-appointment pattern design, assignment of multi-appointments to different patient types and dynamic appointment scheduling. The key concerns are the minimization of the number of hospital visits by the consideration of long-term capacity requirement and the patient priority level. The proposed approach is tested on a real-life case study on pre-surgery appointments for hip and knee replacement in a healthcare institution in Saint-Étienne, France and is compared to some others simple benchmarking policies. We are convinced that this methodology can be of a great benefit to health care institutions and patients as it can improve appointments management and patients' well-being throughout their care course.

Keywords: Patient scheduling; Optimization algorithm; Care Pathway.

Designing a surgeon blueprint schedule for resource allocation to patient appointment series

Sara Bigharaz
Norwegian University of Science and Technology, sara.bigharaz@ntnu.no

Henrik Andersson
Norwegian University of Science and Technology, henrik.andersson@ntnu.no

Anders N. Gullhav
Norwegian University of Science and Technology, anders.gullhav@iot.ntnu.no

The continuously rising demands for healthcare services and high costs of technologies have led to numerous challenges for healthcare systems. Hence, developing schedules for efficient use of resources can achieve a smooth and coordinated process for personnel and satisfaction for patients. The effective treatment of patients relies heavily on the integration of services at the outpatient clinic and operating rooms (ORs). The problem studied in this work is based on the situation at the Orthopedic Department at St.Olav's hospital in Norway. Here, the patients undergo initial assessment by surgeons during a consultation appointment at the outpatient clinic, and if the surgeons recognize the patients' need for surgery, they are scheduled for surgery at the ORs. After surgery, the patients visit the surgeons at the outpatient clinic for follow-up consultations. Thus, patients need to visit resources for multiple appointments at the outpatient clinic and ORs in a timely manner. To address this problem, we consider improved planning at the tactical level to allocate the patients to resources in time slots. One way of planning on the tactical level is blueprint scheduling which is recognized as a plan that assigns time slots to tasks, personnel or groups of patients. By using optimization, we aim to design a blueprint schedule in which resource capacities are allocated to groups of patients. A computational study of the problem is performed based on data from the case hospital.

Keywords: (Multi) appointment scheduling; Access and waiting list.

Multi appointment scheduling optimization for outpatient departments

Rosita Guido
University of Calabria, rosita.guido@unical.it
Domenico Conforti
University of Calabria, domenico.conforti@unical.it

In this work, we address an urgent and real-world problem consequence of pandemic caused by Corona Virus-Sars 19. Many countries suspended non-essential activities with drastic effects on the health care systems around the world. Patients missed opportunities for preventive care and for early detection and effective management of chronic conditions. Currently, patients that need of appointments in hospitals are susceptible to long wait times. Hospitals and health care systems would need to develop strategies and identify new models to handle post-Covid crisis. Here, we address a multi-appointment scheduling problem in hospitals. We propose a general framework to optimize hospital services to allow for greater flexibility and capacity in treating outpatient and elective patients that aims at reducing patient waiting time. This framework is based on a new paradigm: to address these issues effectively, hospital organizations will need to increase cooperation across the hospital departments and resources capacity sharing. We formulate a multi-objective optimization model that tries to effectively schedules and manages patient appointments. The aim is to maximize both same-day appointments for a patient and resource utilization and reduce patient's waiting time. Better scheduling leads to higher patients' satisfaction and reduces societal costs.

Keywords: (Multi) appointment scheduling; Access and waiting list; Care Pathway.

Health care systems: Models

Tu1-C – *Room 8* – 8:45-9:45

Chair: Paul Forte

Modelling care seeking

Steffen Bayer
University of Southampton, s.c.bayer@soton.ac.uk

Forecasting the demand for healthcare services is crucial for many areas of healthcare planning. Long-term planning such as workforce planning or hospital planning requires a demand forecast as does the planning of specific services. While health status or incidence of disease might be a starting point for projecting service demand, other considerations are important, especially when the nature of the illness, condition or service in question affords a degree of discretion whether or not to use healthcare services. Moreover, people often have, depending on the healthcare system, choices of where to seek care. Whether and where to seek care will depend on factors such as cost, convenience, perceived need, perceived quality, waiting times etc. Especially for longer-term projections such as required in workforce models, the assumption that the relationship between care need and care-seeking remains the same is not warranted as expectations and understanding of the populations are changing over time. The modelling framework presented here combines elements of discrete event simulation and agent-based modelling and can be applied to a diverse set of examples of care-seeking behaviour.

Keywords: Modelling and simulation.

A simulation model for determining intermediate care capacity requirements along the complex discharge pathway

Zehra Önen-Dumlu
University of Bath, zod23@bath.ac.uk

Paul Forte
NHS BNSSG CCG, paul.forte@nhs.net

Alison Harper
University of Exeter, a.l.harper@exeter.ac.uk

Christos Vasilakis
University of Bath, c.vasilakis@bath.ac.uk

Richard Wood
BNSSG Clinical Commissioning Group, richard.wood16@nhs.net

Martin Pitt
University of Exeter, m.pitt@exeter.ac.uk

The discharge of patients from hospital to short-term, follow-on community health and social care - either in their own home or in another bedded care facility - is a complex process. It is often characterised by delays arising from the unavailability of suitable community care capacity in appropriate locations at the right time; a key determinant for access and which leads, inevitably, to rationing and queues. While there has been significant research addressing the pressures and patient flow within secondary care settings, much less attention has been paid to downstream services in the community which not only face similar challenges in meeting demand but also have direct implications for secondary care capacity. This modelling study aims to support decision makers determining capacity requirements at community care service nodes within a major healthcare system in England. We propose purpose-built and open-source discrete-time simulation models that capture patient flow from secondary care hospital discharge readiness through bedded and home-based community health services and social care services. We present several Covid and non-Covid related scenario analyses to illustrate the likely impact that different input parameters - such as arrival rate fluctuations and variation in length of stays - have on community capacity requirements and the potential consequences of delayed transfers of care on hospitals.

Keywords: Modelling and simulation; Patient flow; Strategic and operational planning.

The art of making a 'sticky' model

Paul Forte
NHS BNSSG CCG, paul.forte@nhs.net
Zehra Önen-Dumlu
University of Bath, zod23@bath.ac.uk

A perennial anxiety of model developers is whether anyone wants to use the outcome of their hard work or has the capability to do so. Technical modelling elegance is not always rewarded on this earth. Most of us are aware that identifying and engaging stakeholders is central to successful modelling design and realisation. This is complex enough when the modelling purpose and stakeholder responsibility is clear. However, in the IPACS project (Improving Patient flow from Acute hospital to Community health and Social Care) we face higher orders of complexity as we seek to model a patient's care journey across multiple organisations. Getting older patients especially safely home and rehabilitated is at the heart of a caring and functional health and social care system. It carries significant implications for system resources and patient welfare but there are many stakeholders whose objectives often simultaneously combine and conflict. In addition - at least in England at present - no single stakeholder organisation has overall responsibility for the system of interest. Attempting to successfully navigate and address these issues provides interesting challenges for 'sticky modelling' which are outlined and discussed in the context of the IPACS project. Ensuring a robust modelling application which addresses identified needs, can be applied in different localities, and be judged by non-technical stakeholders to have delivered identifiable benefit, is the ultimate goal.

Keywords: Decision support; Strategic and operational planning; Patient flow.

Logistics: Routing

Tu2-A – *Lecture Hall* – 11:15-12:15

Chair: Tonguç Ünlüyurt

Addressing a residential long-term care unit routing problem

Maria Teresa Godinho
Polytechnic Institute of Beja, mtgodinho@ipbeja.pt

We address a challenge proposed by the Unidade Local de Saúde do Baixo Alentejo. The Unidade Local de Saúde do Baixo Alentejo (ULSBA) manages the national health service in the Alentejo's Region, Portugal. Its Tansport Department (NCT) is responsible for scheduling all the required trips for that day. The required trips may be as diverse as taking the CEO to a meeting, providing the transport of medicines, or organizing home healthcare services. The aim is to find a way to change the operating system now available to an easier one, preferably highly automated and requiring few user intervention. During the process, it was agreed that this (huge) problem would be addressed in stages – in this work we study the Residential Long-term Care Unit routing needs. The Residential Long-term Care Unit provides home support to patients with conditions that require specialized healthcare, but do not require hospitalization. The Unit is made up of multidisciplinary healthcare teams that pay visits to the patients in their homes. Due to medical reasons or self-convenience of the patients, some of the visits have to be paid in given time-slots. The associated routing problem consists in finding the optimal set of routes that allows to visit all the patients while fulfilling the time requirements. We propose an integer linear programming approach to this problem. Computational results will be presented.

Keywords: Healthcare logistics; Home care and Long Term Care; Optimization algorithm

An exact algorithm for the resource constrained home health care vehicle routing problem

Tonguç Ünlüyurt
Sabancı University, tonguc.unluyurt@sabanciuniv.edu

We consider the vehicle routing problem with resource constraints motivated by a home health care application. The patients can be serviced by the appropriate vehicles that may carry a nurse, or a health aid or both. The number of nurses and health aids are limited. We also need to satisfy time window constraints for each patient. We try to find feasible routes to minimize the total distance travelled. In our problem, we have different types of patients that require a nurse or a health aid or both. We propose a branch and price algorithm to solve the problem. Our proposed branch and price scheme utilizes a label correcting algorithm with ng-path relaxation and a heuristic pricing method. We demonstrate the effectiveness of our algorithm on random problem instances that we have generated based on Solomon instances up to 100 patients. We also discuss some extensions and ongoing work related to this problem.

Keywords: Optimization algorithm; Resource scheduling; Home care and Long Term Care

Real-time management of patients' transport requests

Vinicius Martins Ton
Université Laval, vinicius.martins-ton.1@ulaval.ca

Nathália Cristina Ortiz Da Silva
Instituto Federal do Rio Grande do Sul, nathalia.silva@erechim.ifrs.edu.br

Angel Ruiz
Université Laval, angel.ruiz@osd.ulaval.ca

Jose Eduardo Pecora
Universidade Federal do Paraná, pecora@ufpr.br

Cassius Scarpin
Universidade Federal do Paraná, cassiusts@gmail.com

Valérie Bélanger
HEC Montréal, valerie.3.belanger@hec.ca

Patients' flow is a crucial hospital activity and impacts the quality of service provided and the hospital's operations and costs. The transportation office receive several transport requests daily to schedule and assign staff members to handle these tasks. The poorly management of patient transportation can lead to prolonged patient waiting times and underutilization of the resources. This situation is modeled as a parallel machine scheduling problem with sequence-dependent setup times representing the time required for a porter to move from a request's end location to the subsequent request's start location. However, in real-life, the transportation office receives the requests in real-time unpredictably. To deal with such a dynamic context, the schedule of all waiting requests should be performed periodically and triggered by specific events. We propose several strategies to trigger the rescheduling of waiting requests and four approaches (a mathematical formulation, a constructive heuristic, a local search heuristic, and a Tabu search metaheuristic adapted from the literature) to solve each rescheduling problem. A simulation scheme is proposed to evaluate the potential of the rescheduling strategies and the proposed scheduling methods to tackle instances inspired by a real mid-size hospital. The local search, which produces the best results, achieves significant reductions in response time, total distance walked by porters, and percentage of late requests.

Keywords: Patient flow; Modelling and simulation; Healthcare logistics.

Appointments: Waiting time management

Tu2-B – *Room 6* – 11:15-12:15

Chair: Yannick Kergosien

Minimizing outpatients' waiting time in same-day multi-appointment settings

Simon Moulard
Université de Tours, simon.moulard@univ-tours.fr
Yannick Kergosien
Université de Tours, yannick.kergosien@univ-tours.fr
Pierre Desport
Université Angers, pierre.desport@univ-angers.fr

Since several years in France, we observe a growing development of ambulatory care for such reasons as reducing hospitalization costs and relieving hospital congestion. Ambulatory care services involve several types of care units and require effective daily planning to maintain a high quality of care and a smooth flow of patients with limited or pooled resources. We consider a daily multi-appointment scheduling problem in an outpatient department. The care of patients is organized using predefined care pathways. A care pathway is composed of multiple care activities (e.g. diagnostics, consultations, etc.) that must respect partial precedence constraints and delays between two consecutive activities. Each care activity requires a set of resources (rooms, nurses, physicians, specific medical equipments, etc.). These resources are limited, may have unavailability periods and can be used for different purposes in different care pathways. The objective is to define the arrival time of each patient and the starting time and allocation of resources for each care activity in order to minimize the total waiting time of patients over a day. To solve the problem, we propose two types of mathematical models and heuristics. We test our methods on instances inspired from real data provided by a French hospital.

Keywords: (Multi) appointment scheduling; Optimization algorithm; Care Pathway.

Creating and evaluating joint waiting lists in a hospital network using stochastic optimization and discrete event simulation

Mariana Oliveira
University of Lisbon, mariana.m.oliveira@tecnico.ulisboa.pt
Sebastian Rachuba
University of Wuppertal, rachuba@uni-wuppertal.de
Daniel Santos
University of Lisbon, daniel.rebelo.santos@tecnico.ulisboa.pt
Ana Paula Barbosa-Póvoa
University of Lisbon, apovoa@tecnico.ulisboa.pt

To guarantee proper and timely access to elective surgical care, it is necessary to balance physical and human resources at hospitals with the evolution of demand. One way to achieve this balance is by transferring patients between hospitals, which is common in Portugal. Patients can be transferred to different hospitals once they reach their clinically recommended maximum waiting time before surgery, which, in turn, leads in high costs for the hospitals to which they were originally assigned. To address this problem a combination of a stochastic optimization model together with a discrete-event simulation is proposed to determine a set of robust clusters of hospitals which share waiting lists according to their total capacity allowing to reduce both costs and tardiness of scheduled patients. While the optimization model decides on the composition of clusters and patient allocation, the simulation model dynamically evaluates different demand and capacity scenarios and assesses constraints' violation, over-utilization of resources, and enables parameter tuning for the optimization model. The resulting joint waiting lists suggest only little amount of external and internal transfers between and within clusters to improve waiting time and costs when compared to the case of individual waiting lists.

Keywords: Access and waiting list; Capacity and network planning; Healthcare logistics.

Robust appointment scheduling with waiting time guarantees

Carolin Bauerhenne
Technical University of Munich, carolin.bauerhenne@tum.de
Rainer Kolisch
Technical University of Munich, rainer.kolisch@tum.de

Appointment scheduling under uncertainty encounters a fundamental trade-off between maximizing capacity utilization and minimizing customer waiting times. Most existing approaches to appointment scheduling tackle this trade-off using a weighted sum approach, resulting in a low consideration of individual customer waiting times and thus of customer satisfaction. In contrast, we study how to maximize capacity utilization while guaranteeing acceptable waiting times for all customers. Therefore, we derive a mixed-integer linear model in a robust optimization framework with box uncertainty sets. We prove NP-hardness of the general problem and present optimal polynomial-time scheduling and sequencing rules for special cases. These rules generalize the well-known Bailey-Welch rules and the least variance rules to consider not only but in particular maximum waiting times. Furthermore, our case study with real data from a radiology department of a large hospital demonstrates that our approach not only guarantees acceptable waiting times but, compared to existing robust approaches, also reduces costs incurred by idle time, for the worst-case and on average.

Keywords: (Multi) appointment scheduling; Optimization algorithm.

Health care systems: COVID-19

Tu2-C – *Room 8* – 11:15-12:15

Chair: Luca Grieco

Interdisciplinary or driven decision support for strategic COVID-19 patient transfers in Germany using hybrid simulation

Sven Watzinger
Karlsruhe Institute of Technology, sven.watzinger@kit.edu

David Olave-Rojas
Karlsruhe Institute of Technology, david.olave@kit.edu

Hanna-Joy Renner
University Hospital Schleswig-Holstein, hanna-joy.renner@uksh.de

Janina Bathe
University Hospital Schleswig-Holstein, janina.bathe@uksh.de

Jan Wnent
University Hospital Schleswig-Holstein, jan.wnent@uksh.de

Jan-Thorsten Gräsner
University Hospital Schleswig-Holstein, jan-thorsten.graesner@uksh.de

Stefan Nickel
Karlsruhe Institute of Technology, stefan.nickel@kit.edu

The COVID-19 pandemic led to an increase in demand for intensive care capacity worldwide and also in Germany. In the event of capacity overloads of hospitals, patients in Germany are usually transferred decentrally between hospitals in the same region. At the beginning of the pandemic it became apparent that whole regions could reach their capacity limit making the decentral system infeasible and requiring nationwide transfers. To organize such transfers the so-called cloverleaf system was developed, dividing the country into five zones (cloverleafs). The nationwide transfers were then organized between those cloverleafs. After identifying the patients that are to be transferred out of a cloverleaf, two main questions have to be answered from a logistical perspective: To which hospitals should the patients be transferred? With which transport vehicle should the patients be transferred? In order to support in answering these questions the interdisciplinary project SCATTER was initiated. In this project we developed a hybrid simulation model combining discrete event and agent-based modelling, based on real-world data and in close collaboration with medical doctors. In a first step, a selection of transfer strategies was evaluated with the future possibility of incorporating optimization models. In our talk we will present preliminary results of the project and discuss the challenges and future research directions.

Keywords: Covid-19 application; Modelling and simulation; Decision support.

Understanding vaccine allocation strategies for COVID-19

Rajdeep Singh
IIT Madras, rajdeepsonu@gmail.com

Krishna Mohan Thazhathu Valiyaveettil
University of Exeter, k.m.tv@exeter.ac.uk

R K Amit
IIT Madras, rkamit@iitm.ac.in

Development of vaccines against the SARS-CoV-2 virus in record time provides optimism on the rising number of infections and deaths. However, with the demand exceeding the supply by a large factor, each dose must be judiciously allocated to have the maximum possible effect on reducing the number of infections. This research analyses the SIRDV compartmental model through the perspective of system dynamics. We look at different

realistic scenarios that can help the policy makers decide the course of action in terms of allocation of available doses. The second wave of COVID-19 as experienced by the Indian state of Tamil Nadu forms the backdrop of the study. The model is validated by comparing the number of daily confirmed cases, daily number of recoveries and the daily number of deaths with the real world data. We observe that prioritising the first dose over the second dose leads to lesser number of infections and deaths. Also, extending the inter-dose interval from 3 weeks to 12-16 weeks leads to lower number of daily deaths. Scenarios pertaining to changing vaccine effectiveness and vaccine availability are also studied.

Keywords: Covid-19 application; Epidemiology and disease modelling; Resource scheduling.

Informing cancer services in the wake of the COVID-19 pandemic using discrete event simulation

Amalia Gjerloev
University College of London, uczragj@ucl.ac.uk

Sonya Crowe
University College of London, sonya.crowe@ucl.ac.uk

Christina Pagel
University College of London, c.pagel@ucl.ac.uk

Luca Grieco
University College of London, l.grieco@ucl.ac.uk

With the Covid-19 pandemic, healthcare systems have seen a huge influx of patients, a strain on hospital resources and increased pressure to operate efficiently in order to save patient lives. Cancer services have been particularly impacted and face a large backlog and long waiting times following a dramatic fall in referrals at the start of the pandemic. In order to improve resource allocation, scheduling and understanding of the pandemic's impact on patient care, we are developing a model of the cancer pathway, focusing initially on lung cancer. This will inform the framework for a Discrete Event Simulation, a useful tool in characterising what-if scenarios and analysing patient flow. From discussions with operational staff at a large teaching hospital, we have established that the lung cancer pathway has many possible paths that each patient can take, which presents challenges for the modelling and for finding a holistic solution for improving patient care services. In this presentation, I will expand on how we have parameterised our model, how we have engaged with clinicians and operational leaders, and how we have overcome some of the difficulties with data extraction.

Keywords: Modelling and simulation; Strategic and operational planning; Resource scheduling.

Logistics: Inventory

Tu3-A – *Lecture Hall* – 13:15-14:45

Chair: Maria Teresa Vespucci

Deep reinforcement learning for platelet inventory management

Joseph Farrington
University College of London, ucabjmf@ucl.ac.uk

Kezhi Li
University College of London, ken.li@ucl.ac.uk

Martin Utley
University College of London, m.utley@ucl.ac.uk

Wai Keong Wong
NHS Foundation Trust, w.wong@nhs.net

The inventory management of platelets is complicated by their short shelf life. Finding optimal replenishment policies for perishable products is known to be computationally challenging because the state must include the age profile of the stock. Deep reinforcement learning (DRL) uses neural networks to efficiently represent large state spaces and has been used to find effective policies for managing perishable inventory. We formulated the platelet replenishment problem with stochastic demand from a recent study as a Markov decision process and implemented this as an OpenAI gym environment. We reimplemented the four policies from the recent study, with parameters fit using stochastic mixed integer linear programming (SMILP), and compared these to two policies trained using DRL methods (DQN, PPO) on 1,000 randomly sampled evaluation episodes. PPO consistently incurred the lowest mean daily cost of these six approaches: only 0.3% higher than the optimal policy found using value iteration and 8% higher than a model with perfect information about future demand. The best SMILP policy incurred a mean daily cost 1.2% higher than the optimal policy. The strong performance of DRL on this simplified task, for which we can compare the quality of the policies to those found using value iteration and SMILP, provides a basis for developing environments that more closely reflect real life decision making, such as making orders by blood group, where value iteration would be intractable.

Keywords: Artificial Intelligence; Modelling and simulation; Decision support.

Reducing cost and waste in hospital inventory management: a demand-driven replenishment strategy

Gaspard Hosteins
Technical University of Denmark, gasho@dtu.dk

Allan Larsen
Technical University of Denmark, alar@dtu.dk

Dario Pacino
Technical University of Denmark, darpa@dtu.dk

Christian Sørup
Rigshospitalet, christian.michel.soerup@regionh.dk

Logistics represents a large share of hospitals' operating budgets. However, it only holds a supporting role in hospitals' primary task of providing care to patients. Hospital inventory strategies typically rely on high safety stocks instead of data-driven methods, thus leaving potential for optimisation. Hospitals are organised in medical departments, with separate storage and budgets. Hospital inventory management deals with various medical products of diverse criticality and uncertain demand inside a complex multi-echelon storage structure. Public hospitals require a service-oriented approach that differs from classic industry profit-based inventory management. Data-driven decision support systems are widely spread in the private sector, whereas medical practitioners without advanced analytical backgrounds often take the inventory decisions in hospitals. Operational data are becoming

increasingly available in hospitals, raising the potential for industry-inspired data-driven approaches. This paper offers a case-based analysis using data from a Danish public hospital. Our goal is to understand and model the hospital's demand for drugs and devise a demand-driven replenishment system. This work is inspired by state-of-the-art industry Collaborative Planning, Forecasting and Replenishment systems (CPFR) and tailored to hospitals' service-oriented nature. The proposed approach aims to reduce on-hand inventory, cost, and waste while maintaining or improving service level.

Keywords: Healthcare logistics; Modelling and simulation.

A stochastic programming model for energy demand management in healthcare facilities

Maria Teresa Vespucci
University of Bergamo, maria-teresa.vespucci@unibg.it

Paolo Pisciella
Norwegian University of Science and Technology, paolo.pisciella@ntnu.no

We propose a stochastic programming model for determining the electricity to be purchased on the Day-Ahead market in every hour of the following day, in order to meet the energy requirements for ventilation, air conditioning, lighting and medical appliances. The amount of electricity needed depends on stochastic parameters such as outside temperature, daylight and activity level in rooms: scenarios are used to represent the uncertainty regarding the values taken by these parameters in the following day. The decision regarding the amount of electricity to be purchased on the Day-Ahead market also depends on the day-ahead electricity prices and on forecasts of intra-day prices, also represented by scenarios. The stochastic programming model determines the amount of electricity to be purchased on the Day-Ahead market and, for every scenario, the amount of electricity to be purchased on the Intra-Day market, as well as the optimal schedule of electric powered devices. The model objective function is the sum of the total daily electricity cost, paid on Day-Ahead and Intra-Day markets, and of a penalty term to be applied when air conditioning and ventilation do not satisfy the requested comfort conditions. A case study shows that the stochastic approach can lead to substantial savings compared to the deterministic approach.

Keywords: Decision support; Modelling and simulation; Process optimisation.

Appointments: Cancer treatment scheduling

Tu3-B – *Room 6* – 13:15-14:45

Chair: Giuliana Carello

An approach to an outpatient chemotherapy service decision-making application using fuzzy DELPHI and fuzzy ELECTRE III

Alejandra Duenas
ICN Business School, alejandra.duenas@icn-artem.com

Christine Di Martinelly
University of Lille, c.dimartinelly@ieseg.fr

Annabelle Glaize
IESEG School of Management, a.glaize@ieseg.fr

Isabelle Fagnot
KEDGE Business School, isabelle.fagnot@kedgebs.com

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

Keywords: Decision support; Care Pathway.

A prediction-based approach for online dynamic radiotherapy scheduling

Louis-Martin Rousseau
Polytechnique Montréal, louis-martin.rousseau@polymtl.ca

Patient scheduling is a difficult task as it involves dealing with stochastic factors. Scheduling radiotherapy treatments for cancer patients face a similar problem. A mix of patients with different urgency levels poses difficulties in resource allocation which requires taking into account future arrivals of high-priority patients. The common solution of reserving a flat percentage of treatment capacity for emergencies might cause overdue treatments in urgent patients on some days while not fully exploiting treatment capacity on some other days, which also leads to delays in treatments of low-priority patients. This problem is especially severe in large and crowded hospitals. In this paper, we propose a prediction-based approach for online dynamic radiotherapy scheduling, which dynamically adapts the scheduling decision based on an observation of the current resource allocation profile. The approach is based on a regression model which is trained to recognize the links between patient arrival patterns and their ideal waiting time in optimal offline solutions. The numerical results show that our prediction-based approach efficiently prevents overdue treatments for emergency patients while maintaining a good waiting time for other patients compared to other scheduling approaches based on a flat-reservation policy. We also demonstrate how the proposed approach supports explainability and interpretability.

Keywords: (Multi) appointment scheduling; Artificial Intelligence; Resource scheduling.

Scheduling chemotherapy treatments in a shared cancer center

Giuliana Carello
Politecnico di Milano, giuliana.carello@polimi.it

Mauro Passacantando
University of Pisa, mauro.passacantando@unipi.it

Elena Tànfani
University of Genova, etanfani@economia.unige.it

The need for chemotherapy treatments is expected to increase in the next years. Chemotherapy treatments are usually delivered in an outpatient setting. Recently, cancer centres shared by different specialties have been proposed. Managing the activities of shared cancer centres involves different decisions hierarchically linked: resources capacity planning, resource allocation to specialities and clinicians rostering, and patients' appointments scheduling. In this work, we assume that the resources have been assigned to the pathologies, and that in each day the assignment of rooms to pathologies and clinicians is given. The days of the week in which patients can be treated, depending on their pathology, is therefore known. We consider the problem of assigning patients to days in the considered planning horizon. Further, we solve the appointment scheduling problem for each day. The problem can be seen as a multi-appointment scheduling problem where we have to decide the starting time of each activity, such as oncologist visit and infusion delivery, for each patient. We consider different objectives using a patient centered approach aimed at maximizing the quality of the patient experience. We formulated the problem as a multi-objective optimization model and we tackle the problem by sequentially solving three ILP models, in a lexicographic multi-objective fashion. The models and solution procedure are tested on real data from an Italian hospital.

Keywords: (Multi) appointment scheduling; Resource scheduling; Workforce planning and scheduling.

Data and computing: Mining and learning

Tu3-C – *Room 8* – 13:15-14:45

Chair: Francesca Maggioni

The use of data analytics in simulation modelling: A systematic review

Fatin Ramli
University of Sheffield, firamli1@sheffield.ac.uk

Praveen Thokala
University of Sheffield, p.thokala@sheffield.ac.uk

Thaison Tong
University of Sheffield, t.s.tong@sheffield.ac.uk

Background: Use of data analytic methods in simulation modelling offers great potential to improve decision making. Objective: This study presents a systematic review of previous studies that used data analytics to support simulation modelling. The objective is to provide insights into the methods, software and applications associated with data analytics in simulation modelling. Methods: A systematic review was performed in PubMed, Medline, Scopus and Web of Science databases. The literature searching was enhanced by references and citation searches to ensure all relevant papers to the articles are included. Results: Nineteen studies were identified in areas as diverse as business, computer science, healthcare and medicine, operations research, engineering and architecture. The most common data analytic technique was machine learning, and the most common simulation modelling technique was discrete-event simulation Conclusion: The findings show an increase in published papers over time, showing increased research interest. This happened because there is a demand to develop the area of data analytics to support simulation. Research and knowledge development in the area plays an important role for the needs of the future.

Keywords: Modelling and simulation; Analytics.

Optimizing the discharge of patients in ICU: a machine learning and simulation approach

Mickael Gaury
University of Bordeaux, mickael.gaury@kedgebs.com

Gautier Stauffer
GSCOP Grenoble INP, gautier.stauffer@grenoble-inp.fr

Boris Detienne
University of Bordeaux, boris.detienne@math.u-bordeaux1.fr

Mehdi Amiri-Aref
Kedge Business School, mehdi.amiri-aref@kedgebs.com

The intensive care units (ICU) of hospitals have attracted a lot of attention lately due to the Covid pandemic. In such services, given the limited resources, physicians are under extreme pressure to take the right decision regarding the discharge of patients. These daily decisions have a huge impact on the health of the patients and the management of the ICU. Indeed, discharging a patient too early can result in an unplanned return to the ICU, while discharging a patient too late can lead to a saturation of the service. Our work focuses on the development of decision-support tools to help practitioners decide when to discharge patients. Our study is conducted with data collected from over 2,000 patients involved in over 10,000 daily decisions at a French hospital from 2015 to 2020. We have first developed a decision tree model that predicts a level of confidence (in [0,1]) that a patient would return or not in ICU if it is discharged today. This provides some form of consensual assessment of the risk of discharging a given patient. The corresponding tool was validated by the physicians of the ICU service. We will describe the methodology used and the results. We are now building upon the corresponding tool and more advanced machine learning models to simulate the performances of the ICU under different policies regarding the discharge of patients. The corresponding research is under development, and we will present preliminary results.

Keywords: Decision support; Artificial Intelligence; Modelling and simulation.

Machine learning based classification models for COVID-19 patients

Francesca Maggioni
University of Bergamo, francesca.maggioni@unibg.it

The SARS-CoV-2 pandemic has pushed the National Health Service to extraordinary pressure, causing situations of imbalance between the request and availability of assistance. When the number of patients exceeds the available resources, doctors need to establish priorities among the patients to be treated. This talk describes novel data-driven optimization models to support doctors' decisions to solve one of the main problems encountered during the first months of the Covid-19 pandemic: predict the mortality risk for Covid-19 in order to address the most appropriate therapeutic path. The models are trained using clinical data obtained at the access to the Emergency Department of 150 Sars-CoV-2 infected patients admitted to ASST-Val Camonica, in March 2020. A comparison of classification models among 30 different types, including decision trees, discriminant analysis, support vector machines, logistic regression, nearest neighbours, naive Bayes is performed. To handle the uncertainty in data, we also formulate robust and distributionally robust optimization models. The best prediction results are obtained with an optimized decision tree model, allowing to identify the most important factors. The tool can be used after triage to more accurately assess the severity of a Covid-19 patient's condition, allowing doctors to optimize patient accommodation by identifying those in need of intensive care and those instead of sub-intensive care.

Keywords: Decision support; Covid-19 application; Data analysis and risk management.

Decision processes

Tu4-A – *Lecture hall* – 15:15-16:00

Chair: Monica Oliveira

Can multicriteria decision analysis assist hospital-based HTA of medical devices? Results from two case studies developed in Portuguese hospitals

Monica Oliveira
University of Lisbon, monica.oliveira@tecnico.ulisboa.pt

Beatriz Coelho
University of Lisbon, beatriz.lgcoelho@gmail.com

Susana Afonso
University of Lisbon, susanahafonso@gmail.com

Liliana Freitas
University of Lisbon, liliana.freitas@tecnico.ulisboa.pt

Hugo Quintino
Hospital do Espírito Santo de Évora, hquintino@hevora.min-saude.pt

Edgar Mascarenhas
University of Lisbon, edgar.mascarenhas@tecnico.ulisboa.pt

Teresa Cipriano Rodrigues
University of Lisbon, teresacrodrigues@tecnico.ulisboa.pt

Ana Vieira
University of Lisbon, ana.lopes.vieira@tecnico.ulisboa.pt

Hospitals are the main entry point for many innovative and often costly medical devices, with decision-makers facing increasing pressures given demands for high-quality care and budget constraints. A priori sound, timely and context-specific evaluation processes are needed to ensure investment in value-for-money technologies. Multiple Criteria Decision Analysis (MCDA) has been increasingly explored to support Health Technology Assessment (HTA) decisions, and arguments in favour of MCDA include the potential to simultaneously capture relevant value dimensions (including equity and organizational impacts) and the ability to consider health stakeholder views and value judgements in an explicit manner. However, few studies have been applied to medical devices in hospitals. This study reflects upon the experience of developing socio-technical approaches combining participatory processes and the MACBETH multicriteria value measurement method to evaluate medical devices in two case studies, one for evaluating emerging biomarkers for the diagnosis of HER2+ breast cancer at Hospital Espírito Santo de Évora, and another assessing strategies for contracting next-generation sequencing gene panels for the diagnosis of advanced solid tumours at Instituto Português de Oncologia de Lisboa. Results show the usefulness of MCDA to build actionable tools to be routinely used and adjusted for the context. Future research may develop technologies to make model building more expedite.

Keywords: Decision support; Cost effectiveness and health economics; Performance evaluation.

Logistics for diagnostic testing: an adaptive decision-support framework

Hannah Bakker
Karlsruhe Institute of Technology, hannah.bakker@kit.edu
Fabian Dunke
Karlsruhe Institute of Technology, fabian.dunke@kit.edu
Stefan Nickel
Karlsruhe Institute of Technology, stefan.nickel@kit.edu
Viktor Bindewald
University Of Siegen, viktor.bindewald@uni-siegen.de

Diagnostic testing is a fundamental component in effective outbreak containment during every phase of a pandemic. Test samples are collected at testing facilities and subsequently analyzed at specialized laboratories. In high-income countries where health care providers are often privately owned, the assignments of samples from testing facilities to laboratories are determined by individual stakeholders. While this decentralized system effectively matches supply and demand during normal times, dispersed outbreaks, e.g., encountered during the COVID-19 pandemic, lead to imbalanced requests for diagnostic capacity. With no coordinating entity in place, local backlogs build up rapidly increasing waiting times for test results and thus impeding subsequent containment efforts. We develop a rolling horizon framework that repeatedly solves a mathematical programming snapshot problem based on the current number of test samples. The procedure dynamically adapts to requirements resulting from the pandemic activity and supports rather than replaces decentralized operations. We assess the quality of our procedure in a case study based on the COVID-19 outbreak in 2020 in Germany. Experimental results demonstrate the potential of coordinating mechanisms to reduce waiting times for test results. Significant improvements are achieved even when interventions in the decentralized assignment process only occur in response to heightened pandemic activity.

Keywords: Healthcare logistics; Decision support; Covid-19 application.

Appointments: Therapy scheduling

Tu4-B – *Room 6* – 15:15-16:00

Chair: Joe Viana

The impact of time preferences on diabetic patients' adherence to therapy

Hakan Kılıç
Koç University, hkilic17@ku.edu.tr

Evrim Didem Gunes
Koç University, egunes@ku.edu.tr

Oğuzhan Deyneli
Koç University, odeyneli@ku.edu.tr

Şeyda Özcan
Koç University, sozcan@ku.edu.tr

Non-adherence to therapy for patients with diabetes is expected to result in the deterioration of their health status and otherwise preventable hospitalizations that create a costly burden to the healthcare system. In their long-term chronic disease therapies, patients' self-management efforts lead to better future health. However, a patient's time preferences in terms of impatience, procrastination and self-awareness about procrastination might diminish the perceived future health benefits of adherence to therapy and motivate the patient to not adhere. We empirically examine this impact of time preferences on patient adherence. The previous work on this topic presents mixed conclusions about the relationship between adherence and time preferences. Moreover, there is no study investigating the effect of self-awareness. In addition to filling this gap, we aim to establish new insights by considering all dimension of adherence (medication, self-monitoring, follow-up visits, diet, exercise) together with possible operations management control by continuity of care and number of physician visits. A survey is being conducted targeting adult patients with type 1 or 2 diabetes. Preliminary results of the ongoing study will be shared.

Keywords: Cost effectiveness and health economics.

Discrete event simulation model to analyse the impact of COVID-19 on radiotherapy practice

Joe Viana
BI Norwegian Business School, joe.viana@bi.no

Elisabeth Jambor
Technical University of Kaiserslautern, ejambor@rhrk.uni-kl.de

Melanie Reuter-Oppermann
Technical University of Darmstadt, melanie.reuter-oppermann@tu-darmstadt.de

Ralf Müller-Polyzou
Leuphana University, ralf.mueller-polyzou@stud.leuphana.de

Radiotherapy cancer treatment is resource intensive and process optimisation to improve patient flow, whilst guaranteeing quality and safety. Process deviations must be well tested. Operational changes in radiotherapy centres were necessary to protect patients and staff from COVID-19. The aim of this simulation study was to quantify the impact of pandemic-related staff absence and selected protection measures on radiotherapy centre patient waiting times and throughput. A generic discrete event simulation model was developed to analyse patient flow changes when implementing COVID-19 control measures. A private German radiotherapy centre case is presented to investigate three sets of scenarios 1) the effects of health care staff and equipment shortfalls without COVID-19 measures, 2) set 1, with COVID-19 measures and a low 7-day COVID-19 incidence, and 3) set 1, with COVID-19 measures and high COVID-19 incidence. Staff absence increases average patient waiting time and reduces patient throughput which can lead to negative patient outcomes, independent of the COVID-19 incidence. The greatest waiting time increase occurs when two radiation therapists are on duty. The absence of a linear accelerator for treatment leads to long average waiting times . Model results suggest that centre administrators are a potential bottleneck if they must perform COVID-19 protection measures in addition to their administrative tasks. Outsourcing COVID-19 related tasks could mitigate this effect.

Keywords: Patient flow; Covid-19 application; Modelling and simulation.

Data and computing: COVID-19

Tu4-C – *Room 8* – 15:15-16:00

Chair: Marco Premoli

Reusing and upgrading regional COVID regulation monitoring tool to a post-COVID maternity crisis in Ile-De-France (IDF) Region

Raphaël Fosse
ARS Île-de-France, raphael.fosse@ars.sante.fr

Catherine Crenn-Hebert
APHP and ARS Île-de-France, catherine.crenn-hebert@aphp.fr

Eric Lachassinne
APHP and ARS Île-de-France, eric.lachassinne@ars.sante.fr

Nabi Mebarki
SESAN, nabia.mebarki@sesan.fr

Maxime Alvany
SESAN, maxime.alvany@sesan.fr

Thomas Gouzlan
SESAN, thomas.gouzlan@sesan.fr

Matthieu Hanf
SESAN, matthieu.hanf@sesan.fr

Jane-Lore Mazue
ARS Île-de-France, jane-lore.mazue@ars.sante.fr

Virgil Kakolo
ARS Île-de-France, virgil.kakolo@ars.sante.fr

Arnaud Foucrier
ARS Île-de-France, arnaud.foucrier@ars.sante.fr

Île-de-France was one of the french covid red zone, leading Regional healthcare Agency to develop tools to monitor the beds and human resources tensions on hospitals in times of crisis, including a specific website based tool with two objectives : get weekly data from hospitals – recurrent forms- and provide dashboard to monitor it. Weekly reminder was emailed to hospitals to submit their data on three themes : beds capacity for medicine and critical care, level of cancelled planned surgery and medicine care, and need for HR reinforcement. Then interactive dataviz provided a dashboard to support Agency decision. In winter 2021 this tool has been upgraded to bronchiolitis pediatric epidemic. New upgrade for summer 2022 for another post Covid crisis : tensions in maternity with lack of HR and high workload, leading to beds closures and reorientation of pregnant people in the Paris Region. This upgrade adds a neonatal and an obstetrics parts, with the same items as the original tool (beds capacity and HR), and new features to follow up volume of pregnant people inscriptions, and real deliveries. The purpose is to monitor closely the regional capacity in maternities, considering the inscriptions capacity as an indicator to the overload and lack of HR. This upgrade was submitted prior to launch to professionals to assure comprehension, accurate data and compliance, especially in a period where hospitals are overstretched by administrative demands.

Keywords: Resource scheduling; Decision support; Healthcare Information System.

Integrating decision support tools in the COD-19 platform

Alberto Ceselli
University of Milan, alberto.ceselli@unimi.it
Michele Barbato
University of Milan, michele.barbato@unimi.it
Cristiano Carlevaro
Spindox Spa, cristiano.carlevaro@spindox.it
Giuseppe Confessore
CNR-ISMN, giuseppe.confessore@ahead-research.com
Gloria De Luca
ACT Operations Research IT Srl, gloria.deluca@ahead-research.com
Marco Premoli
University of Milan, marco.premoli@unimi.it

In early 2020 Northern Italy had to reorganize its public health system, in an extremely short amount of time to prevent collapse. A home health care service for mild COVID-19 patients (COD-19) was activated to relieve the pressure on hospitals, while simultaneously improving the level of service to these patients. The COD-19 service is designed to rely on a dedicated software platform, which serves for both operational support during emergencies and for strategic and tactical planning. We report our actions to provide institutional decision makers with advanced planning and operational tools which integrate the COD-19 platform.

We present three software tools to manage epidemic emergencies, which are based on mathematical programming and machine learning models, allowing for quantitative data analysis. Our tools are designed to provide support both in a proactive way during early pandemic stages, and in a reactive way during and after emergency peaks.

We report experiments on real data from the COVID-19 pandemic emergency in northern Italy, which indicate our approach to be effective. Our research provides new insights into the application of operations research and data analysis techniques to epidemic emergency management at different stages and scales.

Keywords: Covid-19 application; Analytics; Decision support.

Scientific sessions – Thursday, July 21st

Ambulance management: Ambulance location

Th1-A – *Lecture Hall* – 8:45-9:45

Chair: Metiani Nurtsaltsiyah

The repositioning game for ambulance services

Rudramoorthi Thangaraj
IIT Madras, rudramoorthithangaraj@gmail.com

R K Amit
IIT Madras, rkamit@iitm.ac.in

In Emergency medical service (EMS) management, placing the ambulance at the right location at the right time has a significant impact on the response time. The performance of an ambulance network is quantified in terms of coverage—the proportion of calls responded within a predefined response time threshold. In this study, we contribute to the literature of dynamic repositioning of ambulances using compliance table to improve coverage. We model the cooperation among base stations in the EMS network using game theory. We use a centrality measure—the Shapley value—a solution concept from coalitional game theory to quantify the importance of each base stations in the EMS network. Furthermore, we propose a compact representation of the model called repositioning game that includes the unavailability of ambulances and the variability in travel times. We show that the Shapley value of the repositioning game can be computed in polynomial time. Based on the Shapley value, we develop a compliance table for relocating the ambulances. Using the demand data of Chennai, we conduct the discrete event simulation, the simulation results shows that Shapley value based compliance table has better coverage when there are few available ambulances in the system.

Keywords: Emergency Medical Service; Ambulance management; Optimization algorithm.

Finding an optimal location for public health service ambulance in west java village of Rengasdengklok

Metiani Nurtsaltsiyah
Universitas Indonesia, mnurtsaltsiyah@gmail.com

Honora Smith
University of Southampton, honora.smith@soton.ac.uk

Rengasdengklok is a district on eastern border of Jakarta in West Java Province, Indonesia. A village included in district are shown in the map is available with shaded areas of population density. The problem, there is only one public ambulance serving Rengasdengklok district. Patients seeking transport by an ambulance to Proklamasi Hospital must first obtain referral notes in Primary Health Care. An ambulance goes into the local villages to pick up urgent patients and those without transport. However, given the geography of the villages in the area, public health services team believes that the location for an ambulance may be improved. The potential impact on project can advise on the best location of public health ambulance for the district, which can potentially save lives and improve health care for people in the poorest rural villages. Moreover, quantitative evidence can assist in taking decisions where alternatives be considered locally. Demand data of an ambulance usage is available from villages has taken. An ambulance goes out to villages on average 3 times a day. OR approach location analysis maximum cover approach has suggested. Available data on demand for the ambulance service. Then, comparisons made on best locations for maximum demand cover within 15–20–25–30 minutes travel time. Alternatively, 1-median type model is used to compare weighted total travel distances. A Python model can be written, even a spreadsheet used since only 1 location to be found.

Keywords: Ambulance management; Analytics; Data analysis and risk management.

Simheuristic approach to the ambulance location problem

Francesca Da Ros
University of Udine, daros.francesca001@spes.uniud.it

Luca Di Gaspero
University of Udine, luca.digaspero@uniud.it

David La Barbera
University of Udine, labarbera.david@spes.uniud.it

Vincenzo Della Mea
University of Udine, vincenzo.dellamea@uniud.it

Kevin Roitero
University of Udine, roitero.kevin@spes.uniud.it

Laura Deroma
Azienda Sanitaria Universitaria Friuli Centrale, laura.deroma@asufc.sanita.fvg.it

Sabrina Licata
Azienda Sanitaria Universitaria Friuli Centrale, sabrina.licata@uniud.it

Francesca Valent
Azienda Provinciale per i Servizi Sanitari di Trento, francesca.valent@apss.tn.it

Emergency Medical Services (EMS) are asked to provide the best possible service to the public. Consequently, a variety of planning problems arises. One of the notable examples is the optimal siting of emergency vehicles (i.e., ambulances), as the emergency response time (i.e., time incurring from the emergency call to the arrival moment of the rescue vehicle at the emergency time) is strictly related to ambulance location, dispatching policies, and the amount of vehicles available, thus not busy in serving other emergencies. We focus on solving the ambulance location problem using a multi-objective biased random key genetic algorithm. The objective functions consider the minimization of the average response time, the minimization of the 90th percentile of the response time, and the maximization of the municipalities served within a given time threshold (i.e., the maximum standard service time of 18 minutes). The algorithm evaluates the fitness of the solutions via a discrete event simulator. Finally, we also provide an experimental evaluation of the proposed solution by testing our method on real-life case studies from rural-mountainous areas of Italy. Preliminary results suggest that using a meta-heuristic approach integrated with simulation finds solutions to the problem that are able to decrease the response time indicators, as well as maximize the covered zone, with respect to the current ambulance locations.

Keywords: Ambulance management; Modelling and simulation; Emergency Medical Service.

Operating rooms scheduling: OR scheduling

Th1-B – *Room 6* – 8:45-9:45

Chair: Daniel Santos

Enhancing stakeholders' involvement in the scheduling of elective patients: a multi-methodology combining soft systems methodology with mathematical programming

Daniel Santos
University of Lisbon, daniel.rebelo.santos@tecnico.ulisboa.pt

Gonçalo Bico
University of Lisbon, goncalo.bico@tecnico.ulisboa.pt

Mariana Oliveira
University of Lisbon, mariana.m.oliveira@tecnico.ulisboa.pt

Monica Oliveira
University of Lisbon, monica.oliveira@tecnico.ulisboa.pt

Operating room planning and scheduling is a key aspect of hospital management that involves the coordination of different highly skilled human resources, as well as equipment, material, and other physical resources. In particular, elective patient scheduling, which is the problem of assigning resources and a date to a patient waiting for surgery, is a very complex recurrent task which has been extensively studied in the literature. However, many studies fail to be implemented since they seldom involve the tacit knowledge of the stakeholders within the model building process. This study aims to make a contribution to the area of patient scheduling by proposing a multi-methodology that technically combines Soft Systems Methodology (SSM) with Mathematical Programming (MP) and socially involves hospital stakeholders through interviews and workshops to inform the model building. Specifically, SSM methodology helps to acquire tacit knowledge from stakeholders that is used to inform a multi-objective mixed integer MP model. The multi-methodology was tested and validated in a real case of a private hospital in Lisbon, leading to a discussion of the managerial implications regarding its adoption and about which features the scheduling model should incorporate according to the stakeholders' views.

Keywords: Operating room planning and scheduling.

Flexible master surgery and outpatient clinic scheduling

Thomas Bovim
St. Olav's Hospital, thomas.reiten.bovim@stolav.no

Anders N. Gullhav
Norwegian University of Science and Technology, anders.gullhav@iot.ntnu.no

Henrik Andersson
Norwegian University of Science and Technology, henrik.andersson@ntnu.no

Atle Riise
SINTEF, atle.riise@sintef.no

In the Master Surgery Scheduling Problem, we generate a master surgery schedule where surgical specialties are assigned to operating rooms throughout a week in order to provide efficient services. Traditionally, the Master Surgery Schedule is cyclic, with a period of one or two weeks, and it covers a planning horizon of typically half a year. Downstream resources are often considered when generating the Master Surgery Schedule, but upstream activities are seldom included. In this paper we study the integrated master scheduling of the operating rooms and the outpatient clinic rooms. Leveling the activities between the two facilities is important as the patients require services in both facilities, and the surgeons perform all activities. Cyclic schedules are attractive because they offer predictability for the surgical staff and the personnel that are involved in up- and downstream activities. The major drawback of cyclic schedules is that they are inflexible in terms of handling variations in demand.

There is therefore a trade-off between predictability and flexibility in this case. Flexibility in the setting of master scheduling is related to postponing decisions. An example is to leave some slots unassigned until the operational scheduling. In this paper we evaluate the effect of imposing flexibility when generating master schedules. The problem is formulated as a two-stage stochastic program, and we apply simulation-optimization to generate the stochastic parameters.

Keywords: Operating room planning and scheduling; Modelling and simulation.

Implementation of statistical learning techniques for the prediction of surgical times in highly complex health services

Valery F. Quiroga-Pedroza
University of Antioquia, valery.quiroga@udea.edu.co

Alma Karina Rodriguez Quintero
IPS Universitaria Antioquia, alma.rodriguezq@ipsuniversitaria.com.co

David Barrera Ferro
University of Southampton, o.d.barrera@soton.ac.uk

Juan G. Villegas
University of Antioquia, juan.villegas@udea.edu.co

Paula Andrea Velasquez Restrepo
University of Antioquia, paula.velasquezr@ipsuniversitaria.com.co

In this work, we study the prediction of surgical time in a high complexity hospital located in Medellín Colombia. This hospital performs approximately 1100 surgeries a month. Currently, the personnel planning and the scheduling of their operating rooms is done using times based on the experience of the surgeons, anesthesiologists, and the surgery scheduler. However, large forecasting errors have generated some problems. On the one hand, when a surgery takes longer than predicted, subsequent surgical procedures may need to be deferred or even canceled. On the other hand, when the real-time is shorter, idle time is generated. For example, between 2020 and 2021, 9.1% of canceled surgeries were due to failures in time estimation. Therefore, we propose the use of statistical learning techniques (linear regression, lasso regression, random forest, and support vector machines) to predict surgical times based on socio-demographic variables of the patient, the characteristics of the procedure, and the existing human-predicted times. We use data from 17776 surgeries performed in the last two years. The resulting predictions have been generated using exact times and time slots of 15 minutes that can be easily handled and used in the subsequent decision-making processes. So far, the best prediction is obtained using a random forest that almost halves the average absolute percentage error of the human-predicted times. Currently, we are working on the interpretability of the models.

Keywords: Operating room planning and scheduling; Forecasting; Analytics.

Clinical pathways

Th1-C – *Room 8* – 8:45-9:45

Chair: Elena Tànfani

Supporting pathway improvement for patients with common mental health problems using process mining

Elizabeth Yardley
University of Bath, egmy20@bath.ac.uk

Alice Davis
Mayden, alice.davis@mayden.co.uk

Christos Vasilakis
University of Bath, c.vasilakis@bath.ac.uk

Common mental health disorders such as anxiety and depression are cited as the largest cause of disability in England and their prevalence is increasing. The Improving Access to Psychological Therapies (IAPT) programme was established to support the delivery of such therapies in England. This evidence-based programme is based on the principle of stepped care, where effective but less resource intensive treatments are delivered to patients first. IAPT received nearly 1.7 million referrals between April 2019 and March 2020, and the NHS aims for 1.9 million people to be able to access IAPT services by 2023/24. In the challenging environment of limited resources and waiting time targets, effectively managing waiting lists and minimising preventable patient drop-outs from the care pathway are central to the success of the programme. Our research is part of a 3-year project which aims to develop innovative, advanced, analytical tools to help support decisions around IAPT service improvements. Our plans include using process mining and other data-driven methods, augmented by simulation modelling and a comprehensive programme of engaging with end-users. We present the early findings of applying process mining methods to routinely collected data from a number of IAPT services using Iaptus, a specialised electronic patient record management system. The focus of our analysis is on mapping the care pathway and identifying potential bottlenecks.

Keywords: Analytics; Patient flow; Access and waiting list.

Drivers of costs of care and disease trajectory for patients with neurocognitive disorders: a machine learning approach

Alice Martin
IAC Partners, alice.martin@iacpartners.com

Victor Manach
IAC Partners, victor.manach@iacpartners.com

Virginie Dauphinot
CHU Lyon, virginie.dauphinot@chu-lyon.Fr

Pauline Desnavailles
CHU Lyon, pauline.desnavailles@chu-lyon.fr

Frederic Gervais
CHU Lyon, frederic.gervais@chu-lyon.fr

Antoine Garnier-Crussard
CHU Lyon, antoine.garnier-crussard@chu-lyon.fr

Jean-Baptiste Guillaume
IAC Partners, jean-baptiste.guillaume@iacpartners.com

Julien Fondrevelle
INSA Lyon, julien.fondrevelle@insa-lyon.fr

Alain Guinet
INSA Lyon, a.guinet@insa-lyon.fr
Pierre Krolak-salmon
CHU Lyon, pierre.krolak-salmon@chu-lyon.fr

In 2019, it was estimated that 57.4 million people were living with neurocognitive disorders worldwide, a disease which remains incurable today. The prevalence is forecasted to grow to 152.8 million cases by 2050. The consequences of the symptoms reflect on the patient and their relatives, with a mental and economic burden related to care and dependency. In France alone, the medical costs of care borne by the health system to diagnose and manage patients with Alzheimer's disease are assessed at 5.3 billion euros per year. In the meantime, the French National Institute of Statistics and Economic Studies (INSEE) estimates that the growth of older patients requiring daily support will be much higher than the one of available informal caregivers. Being able to anticipate the entry into dependency is becoming a public health challenge. We aim to predict the patient journey based on their clinical characteristics, including disease progression, and using the cost of care as an indicator of resource consumption. The analysis has been conducted on the MEMORA study, a cohort of patients attending a memory center in Lyon, matched with the claims database of the French Primary Health Insurance Fund. Our methodology is built on time-series clustering and Markov chains to stratify patient groups by resource consumption and evaluate the probability of transition from one patient group to another over time. Our model allows to cover up to 89% of costs and consultations.

Keywords: Care Pathway; Artificial Intelligence; Cost effectiveness and health economics.

Benefits and limitations of business process model notation in modelling patient healthcare trajectory: a scoping review

Kassim Said Abasse
Université Laval, kassim.said-abasse@fsa.ulaval.ca
Jean-Baptiste Gartner
Université Laval, jean-baptiste.gartner.1@ulaval.ca
Paolo Landa
Université Laval, paolo.landa@fsa.ulaval.ca
Catherine Paquet
Université Laval, catherine.paquet@fsa.ulaval.ca
Elena Tànfani
University of Genoa, elena.tanfani@unige.it
André Côté
Université Laval, andre.cote@fsa.ulaval.ca

The adoption of business process model notation (BPMN) in modelling healthcare trajectory can enhance the efficiency and efficacy of healthcare organizations, improve patient outcomes while restraining costs.Existing systematic reviews have been inconclusive regarding the effectiveness of BPMN in modelling healthcare trajectory.The aims of this scoping review are to map and aggregate existing evidence on the benefits and limitations associated with BPMN, highlighted areas of improvement on its' ability to support clinical activities and decision-making processes.Based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews, we conducted a scoping review of the literature reporting the use of the BPMN approach for optimising healthcare trajectories.A total of 46 studies met the pre-established requirements.The findings support the use of BPMN as a feasible and useful methodology to design and optimize clinical processes, as well as to automate tasks. However, the complexity of the healthcare domain makes process modeling such as BPMN a challenging task. Based in our analysis, we identified a set of relevant modeling challenges, which we categorized into three main categories:patient-related challenges, medical practice-specific challenges, and medical resource-related challenges.Additionally,a large number of BPMN extensions are proposed in the literature, as an alternative solution to address the respective challenges.

Keywords: Clinical modelling; Care Pathway; Process optimisation.

Humanitarian logistics

Th2-A – *Lecture Hall* – 11:15-12:15

Chair: Derya Demirtas

Why resilience in health care systems is more than coping with disasters: implications for health care policy

– ONLINE PRESENTATION via MS Teams –

Marion Rauner
University of Vienna, marion.rauner@univie.ac.at

Doris Behrens
Donau-Universität Krems, doris.behrens@donau-uni.ac.at

Margit Sommersguter-Reichmann
University of Graz, margit.sommersguter@uni-graz.at

Health care systems need to be resilient to deal with disasters like the global spread of the Severe Acute Respiratory Syndrome Coronavirus (SARS-CoV-2) on top of serving the changing needs of a multi-morbid, ageing and often dispersed population. This paper identifies, discusses and augments critical dimensions of resilience retrieved from the academic literature. It pulls together an integrated concept of resilience characterised by organisational capabilities. Our concept does not focus on the micro-level like most resilience literature in health care but addresses the system level with many stakeholders involved. Distinguishing exogenous shocks to the health care system into adverse events and planned innovations provides the basis for our conclusions and insights. It becomes apparent only when dealing with planned interventions that transformative capabilities are indispensable to cope with sudden increases in health care pressures. Due to the current focus on absorptive and adaptive resilience, organisations over-rely on management capabilities that cannot generate a lasting increase in functionality. Therefore, reducing the resilience discussion to bouncing back from adverse events could deceive organisations into cultivating a suboptimal mix of organisational capabilities lacking transformative capabilities, which pave the way for a structural change that aims at a sustainably higher functionality.

Keywords: Decision support; Strategic and operational planning; Disaster management.

Service delivery planning for effective management of chronic dialysis patients after a disaster

Evrim Didem Gunes
Koç University, egunes@ku.edu.tr

Burcu Balcik
Özyeğin University, burcu.balcik@ozyegin.edu.tr

Cem Deniz Caglar Bozkir
Özyeğin University, cem.bozkir@ozu.edu.tr

Ali Kaan Kurbanzade
Özyeğin University, kaan.kurbanzade@ozu.edu.tr

Cagri Ozmemis
Özyeğin University, cagri.ozmemis@ozu.edu.tr

We consider service planning for dialysis patients after a disaster, which reduces the available capacity of the dialysis facilities. In the first part, we model the decisions of assignment of patients to available facilities and scheduling the dialysis sessions. We consider the last time a patient received dialysis before the disaster and allow a limited number of short dialysis sessions for each patient. An integer programming model is developed to maximize the number of patients served within the system, which also ensures the minimum amount of decrease in the quality of dialysis services offered to patients kept in the system. Solution algorithms are developed and

a decision support system to prepare for an earthquake in Istanbul is presented. We also consider the resource planning and scheduling in a dialysis clinic serving to infected and non-infected patients during the COVID-19 pandemic. A mathematical minimizes the overlaps of infected and non-infected patients in the clinic to prevent further infections. We present a case study that shows the benefits of the model, using data from a public hospital in Istanbul.

Keywords: Disaster management; Patient scheduling; Covid-19 application.

Evaluating medical disaster planning exercises using mathematical programming

Derya Demirtas
University of Twente, d.demirtas@utwente.nl

Gelbrich Holsbrink
University of Twente, g.holsbrink@gmail.com

Patricia Rogetzer
University of Twente, p.b.rogetzer@utwente.nl

Nancy Ter Bogt
Acute Zorg Euregio, n.terbogt@mst.nl

During a mass casualties incident (MCI), treatment capabilities of the regional hospitals are overwhelmed. In the Netherlands, emergency care networks prepare their regions for an MCI by organizing analog simulation exercises called Emergo Train System (ETS) exercises. In 2019, two separate emergency medical teams simulated the allocation process of casualties to ambulances and hospitals using ETS. The results differed significantly between the teams. Although the ETS exercises are widely used in the world, the optimal solutions are not known before or after, leaving how much better a team could perform a mystery. In this research, we propose an ILP that allocates each casualty of an MCI to an ambulance and a hospital. We demonstrate the effectiveness of our models by comparing our results to the outputs of the ETS exercises of 2019 and provide sensitivity analysis.

Keywords: Disaster management; Humanitarian logistics; Healthcare logistics.

Operating rooms scheduling: OR scheduling with uncertainty

Th2-B – *Room 6* – 11:15-12:15

Chair: Erik Demeulemeester

Data-driven operation room planning and scheduling under uncertainty

Ricardo Otero-Caicedo
KU Leuven / Pontificia Universidad Javeriana, ricardo.otero@kuleuven.be

Erik Demeulemeester
KU Leuven, erik.demeulemeester@kuleuven.be

Due to its relevance and complexity, the operation research community has extensively studied the operation room planning and scheduling problem. In a real-world setting, planning and scheduling depend on usually unknown inputs such as surgeries duration. Researchers have demonstrated that surgery duration uncertainty can severely affect the performance of traditional deterministic approaches. Nonetheless, surgery duration is often only characterized by surgery type, which could drop relevant patient data correlated to surgery duration. In this sense, we propose using side data and machine learning to describe surgery duration uncertainty. In particular, we use different regression algorithms such as neuronal networks, random forests, decision trees, and linear regression to predict a surgery duration given some patient features. Then we use local predictions to estimate the conditional probability distribution for a given patient in a purely data-driven approach with no assumptions about any probability distribution or parameters. To optimize the schedule, we implemented a genetic algorithm driven by a Monte Carlo simulation. We tested our approach using real data from a reference hospital in Bogota, Colombia. The results suggest that incorporating side data improves solutions' quality and robustness.

Keywords: Operating room planning and scheduling; Analytics; Optimization algorithm.

Stochastic optimization of inpatient and outpatient surgery scheduling

Davide Duma
University of Pavia, davide.duma@unipv.it

Ambrogio Maria Bernardelli
University of Pavia, ambrogiomaria.bernardelli01@universitadipavia.it

Lorenzo Bonasera
University of Pavia, lorenzo.bonasera01@universitadipavia.it

Eleonora Vercesi
University of Pavia, eleonora.vercesi01@universitadipavia.it

With the advancement of surgery and anesthesiology in recent years, surgical clinical pathways have changed significantly, with an increase in outpatient surgeries. Since inpatients and outpatients have different characteristics in terms of variability, resources, and needs, the management of Operating Rooms (ORs) is challenging when the same resources are shared. In this talk, we present two stochastic mixed-integer programming models for scheduling decisions at the operational level under a block-scheduling strategy. Different types of surgeries are taken into consideration (i.e., inpatient and outpatient, elective and non-elective), and multiple uncertainty components are included in our study. Furthermore, several patient-centered and facility-centered objectives are defined, that is direct and indirect waiting times, cancellations, OR utilization, and overtime. Computational issues arise solving the introduced models with the sample average approximation (SAA) method as combinatorial complexity and uncertainty increase. Then heuristic approaches that guarantee good solutions in reasonable computational times are proposed and compared with the SAA. Finally, a quantitative analysis is performed to analyze the trade-off between schedule robustness and average performance, and between the defined objectives in different scenarios. Such an analysis allows us to provide general insights for ORs dealing with inpatients, outpatients, and emergencies.

Keywords: Operating room planning and scheduling; Decision support; Patient scheduling.

On the use of partitioning in the inpatient surgical department: robust surgery scheduling

Lien Wang
KU Leuven, lien.wang@kuleuven.be

Erik Demeulemeester
KU Leuven, erik.demeulemeester@kuleuven.be

Nancy Vansteenkiste
University Hospital Leuven, nancy.vansteenkiste@uzleuven.be

Rademakers Frank
University Hospital Leuven, frank.rademakers@kuleuven.be

In hospitals, efficiently scheduling ORs is challenging especially for an inpatient surgical department where complex and long surgeries from different surgical disciplines are often performed in combination with surgeries on emergency patients. To deal with the complexity along with various uncertainties, this paper develops a robust scheduling approach, in which we consider partitioning the elective surgeries into the more predictable surgeries (MPS) and the less predictable surgeries (LPS) groups based on surgery duration characteristics. The MPS group is scheduled in separate ORs from the LPS and emergency surgeries. The partitioning is solved for each discipline by heuristics as well as simulation. Using data from a university hospital, we report important insights. First, the partitioning can considerably reduce the cancellation rate by 14.8% relative to the existing practice and can fairly reduce the elective access times. However, the option must be allowed to schedule patients across OR subgroups rather than completely partitioning. Second, partitioning slightly worsens the waiting times of emergency patients, while the slightly negative impact decreases when the number of accessible ORs is higher. Third, the benefit of partitioning to elective patients increases with an increased patient demand. Finally, to better perform partitioning, OR practitioners should pay attention to both an effective use of available OR capacity and a high efficiency in the MPS group.

Keywords: Operating room planning and scheduling; Modelling and simulation; Patient scheduling.

Ambulance management: Ambulance fleet management

Th2-C – *Room 8* – 11:15-12:15

Chair: Mark Tuson

Emergency vehicle fleet and network configuration

Juan Carlos Espinoza
Tecnologico de Monterrey, jcespinog@tec.mx

In this paper we study the response times of ambulances to traffic incidents in Mexico City. We strive to design a fleet of emergency vehicles to meet the city's response time goals. Furthermore, we test the limits of the proposed network for different configurations and conditions through simulation. We collected historical data from the city's transparency system, to study the geographical distribution of events through time. We analyze this data and identify patterns and rates of occurrence for the events. Using this information, we propose a fleet and network configuration of emergency vehicles to meet the city's response time goal for traffic incidents. We use simulation to test the response time of the proposed network to different stress scenarios: increased traffic, global rates of occurrence, local rates of occurrence, etc. With the results of the simulation we evaluate the robustness of the network configuration to respond to extreme events. The simulation model could be used to reconfigure the city's emergency network to respond to disaster events as needed. Furthermore, the use of heterogeneous vehicles can be studied to improve the performance of the network.

Keywords: Ambulance management; Capacity and network planning; Modelling and simulation.

Ambulance allocations for maximising survival within a heterogeneous population using a heterogeneous fleet

Mark Tuson
Cardiff University, tusonm@cardiff.ac.uk

For medical emergencies, an ambulance service has a duty of care to the clinical outcomes of the population it serves. The geographical locations of emergency medical services (EMS) can directly impact on the probability of patient survival and the overall quality of care provided. The ambulance location-allocation problem has been widely studied but has predominantly focused on minimising response times or maximising coverage, and not explicitly for maximising patient outcomes. In this paper we propose a model to consider where to optimally locate different types of EMS vehicles in order to maximise patient outcomes within a heterogeneous population. Using real-world data from ambulance services working in Jakarta, the model is shown to provide more favourable outcomes for different patient groups and the research helps to demonstrate the importance of considering clinical outcomes when making ambulance location-allocation decisions.

Keywords: Ambulance management; Optimization algorithm; Strategic and operational planning.

A semi-online ambulance routing and scheduling problem with complex patient-vehicle relations

Julia Resch
University of Graz, julia.resch@uni-graz.at

We consider a new complex variant of a dial-a-ride problem arising from the daily operations of the Austrian Red Cross. This non-profit organization faces the challenge that its vehicles not only provide emergency services, but also a patient transfer service for non-emergency medical appointments. For the latter, some transportation requests are known well in advance, while others arrive at relatively short notice during the day. In addition to this semi-online scheduling setting, practical constraints and operational features are considered. The main aspects are multiple depots, short and long time windows, a heterogeneous vehicle fleet allowing various loading patterns, and patients with different transportation mode requirements. We seek routes and schedules to serve all transportation requests of a day with a given vehicle fleet. Contrary to most standard dial-a-ride problems, our goal is not to minimize costs or driving distances but to maximize the overall service level associated with the deviations of patients' actual arrival and/or departure times from their desired ones. For this problem, an exact ILP model based on a time expanded network is proposed. As a more practical approach we present a constructive heuristic that follows a selective insertion procedure. Computational results on real-world data show that our proposed heuristic is well suited for coping with the difficulties of the problem in practice, both in terms of solution quality and computation time.

Keywords: Ambulance management; Healthcare logistics; Optimization algorithm.

Home care services

Th3-A – *Lecture Hall* – 13:15-14:45

Chair: Semih Yalçındağ

Modelling decisions in home health care at multiple planning levels

Luca Grieco
University College London, l.grieco@ucl.ac.uk

Martin Utley
University College London, m.utley@ucl.ac.uk

Sonya Crowe
University College London, sonya.crowe@ucl.ac.uk

Efficient deployment of resources to deliver home-based care is critical for the sustainability of health care systems, particularly given the trend towards ageing populations with more complex needs. Recent literature reviews of OR applied to Home Health Care reported an abundance of work focusing on operational decisions and less work at strategic and tactical levels, with little explicit recognition of the hierarchical nature of these decisions which undermines the potential of OR approaches to support real-life decisions. We developed a modelling framework, consisting of a synthetic data generator and an optimisation environment, to enable coherent analysis of Home Health Care decisions made at different planning levels in a given hierarchical order and affecting each other. We tested our approach on case studies built upon challenges currently faced by an organisation serving two boroughs in London (population sizes: 200-300K). We selected decision hierarchies of interest and formulated the corresponding optimisation models, which we implemented according to our modelling framework. We built reference synthetic datasets using parameters estimated from data gathered from the two boroughs. We will illustrate the potential benefits and challenges of informing decisions at higher planning levels while accounting for their effects at lower planning levels and vice versa, in particular depending on whether the aims of those decisions are aligned or in conflict with each other.

Keywords: Home care and Long Term Care; Strategic and operational planning; Workforce planning and scheduling.

A unified approach for planning home blood donations

Sara Mattia
CNR-IASI, sara.mattia@iasi.cnr.it

Tiziano Bacci
CNR-IASI, tiziano.bacci@iasi.cnr.it

Ettore Lanzarone
University of Bergamo, ettore.lanzarone@unibg.it

Paolo Ventura
CNR-IASI, paolo.ventura@iasi.cnr.it

The availability of a sufficient blood supply is crucial for ensuring high-quality and fully-functional health services. Unfortunately, blood and its components are highly perishable: this forbids long term conservation and requires continuous donations by unpaid volunteers. We consider the problem of planning blood donation services, where the donors are reached at home. The scope is to minimize the penalty for the unserved donors, while guaranteeing that a budget constraint is respected and that the preferences of the donors for the appointments are met. Contrary to previous contributions in the literature, we present an over comprehensive offline model for this setting, where the produced solution must be robust with respect to the availability of the donors, which is not known in advance and it is modeled using a set of scenarios. A Benders decomposition approach to solve this model is developed. The proposed algorithm is tested on real-life instances coming from the Milan department of the Associazione Volontari Italiani Sangue (AVIS). AVIS is not offering home blood donations at the moment, then

the purpose is to propose a framework that supports an innovative service. The results show that the algorithm is effective is solving this kind of problems. Statistics showing how the results change when the budget is modified are presented, providing interesting managerial insights in designing home blood donation services.

Keywords: Healthcare logistics; Optimization algorithm.

Home healthcare service assignment, routing, and appointment scheduling with uncertainties

Syu-Ning Johnn
University of Edinburgh, s1722740@ed.ac.uk

Andres Miniguano-Trujillo
University of Edinburgh, andres.miniguano-trujillo@ed.ac.uk

Yiran Zhu
University of Edinburgh, y.zhu-95@sms.ed.ac.uk

Akshay Gupte
University of Edinburgh, akshay.gupte@ed.ac.uk

Home healthcare (HHC), often called hospital-at-home services, is a growing sector within the home service industry that has attracted rising attention. The typical requirements for the HHC providers are to decide on the number of teams to deliver services, their assignments to customers, the visiting sequences, and the scheduling of customer appointments. These four specific decisions form the Home Service Assignment, Routing, and Appointment scheduling (H-SARA) problem, presented for the 13th AIMMS-MOPTA Optimization Modeling Competition. This work also assumes three typical uncertainties (stochasticity), the service durations, travel times, and last-minute customer cancellations to better resemble reality. We propose a stochastic MILP model for the H-SARA problem, which is solved using two self-implemented acceleration approaches in CPLEX to tackle small-scale instances. Realising the natural partition of our stochastic model, we also develop an exact solution method using Benders Decomposition. For larger instances, we design a tailored two-stage heuristic approach with an embedded Adaptive Large Neighbourhood Search metaheuristic that provides time and cost-effective solutions based on information revealed at different stages.

Keywords: Home care and Long Term Care; Workforce planning and scheduling; Decision support.

Integrating short-term and long-term planning problems in home health care systems under continuity of care

Semih Yalçındağ
Yeditepe University, semih.yalcindag@yeditepe.edu.tr

Ettore Lanzarone
University of Bergamo, ettore.lanzarone@unibg.it

Home Health Care (HHC) human resource management is a complex process where patients are assisted for a long time during which their demand for care evolves in terms of type and frequency of visits. Under continuity of care, this uncertain evolution must be considered even when scheduling the visits in the short-term, as the corresponding operator-to-patient assignments could generate overtimes and unbalanced workloads in the long-term, which must be fixed by reassigning some patients and deteriorating the continuity of care. On the other hand, the operator-to-patient assignment problem under continuity of care over a long time period could generate solutions that are infeasible when the scheduling constraints are considered. Hence, we analyze the trade-offs between the two problems, to determine the conditions in which they can be solved sequentially, or an integration is required. To do this, we take an assignment and scheduling model for short-term planning, an operator-to patient assignment model over a long-time horizon, and we merge them into a new combined model. Results on a set of realistic instances show that the combined model is necessary when the number of patterns is limited and the variability of patients' demands is high, whereas simpler models deserve to be applied in less critical situations.

Keywords: Home care and Long Term Care; Patient scheduling.

Operating rooms scheduling: OR scheduling optimization

Th3-B – *Room 6* – 13:15-14:45

Chair: Nadia Lahrichi

Integrating patient length of stay in the master surgical schedule planning

Nadia Lahrichi
Polytechnique Montréal, nadia.lahrichi@polymtl.ca

Adam Lebrigui
Polytechnique Montréal, adam.lebrigui@polymtl.ca

In this project, we aim to generate a master surgery schedule for a university hospital that considers patient wait time in the wait lists, priority and length of stay in the wards and the ICU units. The goal is to avoid surgery cancellations due to a lack of downstream resources and to limit the need to move patients between the wards on the one side, and to offer the best access to patients while maximizing efficiency in terms of beds and rooms utilization. We propose an approach to model length of stay based on patients' diagnosis. We have used a clustering algorithm for each specialty on one year data to build these groups. The Master Surgery Scheduling is then created for a one month period. We are then able to provide insights regarding elective patient scheduling. We also investigate how to include emergency patients in the schedule.

Keywords: Operating room planning and scheduling.

Operating room scheduling considering reusable medical devices with preventive maintenance

Elvin Coban
Özyeğin University, elvin.coban@ozyegin.edu.tr

Seyyed Kian Farajkhah
Özyeğin University, kian.farajkhan@ozu.edu.tr

Hospital expenditures keep growing and operating rooms are one of the major causes for these expenditures. To reduce the costs, efficient operating room scheduling should be targeted. However, operating room problems are complex as they also include scheduling of several resources, such as reusable medical devices (RMDs). RMDs are resources utilized during surgeries and after each use they have to go through cleaning followed by high-level disinfection or sterilization. In this work, we study an integrated scheduling problem of operating rooms and RMDs while considering RMDs' preventive maintenance via a mixed integer linear programming model. However, the proposed model's size may increase a lot preventing to compute a solution. Thus, heuristics and a rule-of-thumb are proposed to overcome this computational problem. We analyzed more than 500 instances and report our solutions based on computation time, optimality gap, average number of surgery cancellations and delays. We also quantify the effect of preventive maintenance while varying the probability of unavailable RMDs.

Keywords: Operating room planning and scheduling.

Operating room scheduling and outpatient surgery: a review

Lydia Bouchlaghem
Université de Reims Champagne-Ardenne, lydia.bouchlaghem@univ-reims.fr

Fatima Ghedjati
Université de Reims Champagne-Ardenne, fatima.ghedjati@univ-reims.fr

Alexandre Philippot
Université de Reims Champagne-Ardenne, alexandre.philippot@univ-reims.fr

The world had witnessed during the last three years a major health crisis caused by the spread of the Covid-19 virus. To cope with this pandemic, hospitals had to both manage the infected patients and the regular cases among which those requiring surgery. The latter have been neglected due to the lack of human and material resources such as nurses, beds, respiratory devices. The challenge was to optimally allocate hospital resources without altering the regular flow of operating rooms. Thus, the interest of the development of outpatient surgery unities seems to be nowadays a sustainable and effective solution to be considered by hospital managers. Ambulatory surgery aims primarily to improve patient safety and health. It is also a policy chosen to cut costs by reducing the length of hospital stay and take care of an optimal number of patients not requiring a long stay at the discretion of the doctors. However, these objectives can only be achieved with effective planning and scheduling. The Operating Room (OR) scheduling problem has aroused the interest of several researchers. They investigated multiple techniques to solve it but were mainly focused on inpatient cases. Our study deals with an ambulatory surgery scheduling problem of the outpatient unit of the Robert Debré hospital in Reims-France. In this work, we present a survey on the question of how a hospital can best use its ORs to balance efficiency and optimize resources when performing ambulatory surgery cases.

Keywords: Operating room planning and scheduling; Resource scheduling; Staffing and capacity planning.

An iterative optimization approach for surgery department management

Andrea Mancuso
University of Napoles Federico II, andrea.mancuso@unina.it

Maurizio Boccia
University of Naples Federico II, maurizio.boccia@unina.it

Adriano Masone
University of Napoles Federico II, adriano.masone@unina.it

Claudio Sterle
University of Napoles Federico II, claudio.sterle@unina.it

Surgery department with its operating rooms represents the financial backbone of modern hospitals accounting the main part of a hospital cost and revenue. Therefore, maximizing its efficiency is of vital importance since it can have important implications on cost saving. In this context, Operations Research methodologies can play a relevant role supporting hospital executives in operating room management and surgery scheduling issues. In particular, great relevance has been given in literature to the Surgery Scheduling Problem. In its more general form, it consists in determining a day, an operating room and a starting time of a set of surgeries. In this work, we address the Surgery Scheduling Problem faced by a local hospital of Naples. The aim of the hospital is to determine a weekly surgery schedule capable of handling unforeseeable events while maximizing the number of performed surgeries, according to some medical guidelines. In addition, the schedule needs to be adjusted when a deviation occurs. To this aim, the problem has been tackled by an iterative optimization approach, drawing up a first surgery schedule by an original integer linear programming formulation and re-optimizing it whenever it is needed. The proposed formulation has been tested and validated on several instances derived from real data provided by the hospital. The results of this experimentation can be used to provide useful managerial insights for an efficient management of the hospital surgeries.

Keywords: Operating room planning and scheduling; Strategic and operational planning; Decision support.

Health care systems: Decision making

Th3-C – *Room 8* – 13:15-14:45

Chair: Margaret L. Brandeau

A mathematical tool to inform decision making in South Australia's emergency medical retrieval service

Laura Boyle
Queen's University Belfast, lboyle12@qub.ac.uk

South Australia's emergency medical retrieval service, MedSTAR, provides 24-hour rapid clinical response for patients who need critical care and transport using emergency vehicles, including helicopters and other aircraft. MedSTAR collects information on a large set of variables for each patient encounter. In this research, we utilise the MedSTAR database to develop a mathematical model which can predict the on-scene and total turnaround time of the crew for each emergency mission. The model is embedded in an R Shiny application so that it can easily be used by MedSTAR staff. This tool will assist MedSTAR in planning and allocation of resources. It will further allow them to benchmark turnaround times against previous missions to reflect on improvements which could be made to their operations.

Keywords: Ambulance management; Emergency Medical Service.

Fairness and balancing: a comparison of different modelling techniques in operations research in health care

Martina Doneda
Politecnico di Milano, martina.doneda@polimi.it

Ettore Lanzarone
University of Bergamo, ettore.lanzarone@unibg.it

Giuliana Carello
Politecnico di Milano, giuliana.carello@polimi.it

The concepts of fairness or balancing-related metrics can be formalized and modelled in several ways. In this work we consider proportional fairness, as defined by Bertsimas et al. (2011). Under a Nash equilibrium, a change of resource allocation between two (or more) players is considered fair if the percentage increase in the utility of one player is larger than the (sum of) percentage decrease(s) in utility of the other player(s). This definition can be extended to a set of problems in which a decision maker needs to allocate resources/workloads to competing actors, by ensuring a fair balance among them, a rather common requirement in health care. For example, problems with fair assignment constraints can be found in personnel rostering (e.g. allocating the number of less desirable shifts), production planning (in blood donation, producing a balanced number of units for each blood type every day), or when dealing with indivisible quantities (such as ward space occupation). Solving this problem is not trivial, because quantities may not be divisible by the number of actors, additional constraints must be considered (e.g., maximum capacities), or perturbations are added (e.g., stochastic demands). In this work, we compare several approaches to represent fair assignment problems and we discuss their relevance for common health care service management problems. Moreover, we test them on benchmark instances to derive insights on their performance.

Keywords: Strategic and operational planning; Staffing and capacity planning; Decision support.

New metrics for the analysis of sequential decision-making in the ICU-bed management

Daniel García de Vicuña
Public University of Navarre, daniel.garciadevicuna@unavarra.es

Laida Esparza Artanga
Complejo Hospitalario de Navarra, lesparza@navarra.es

Fermin Mallor
Public University of Navarre, mallor@unavarra.es

This work presents new metrics developed for the analysis of the decisions recorded by an interactive ICU simulator used by ICU professionals, as well as other types of users. The simulator records all the admission/discharge decisions made by users on every patient. Bed-management decisions are categorized into three types: shortening the stay of admitted patients, canceling scheduled surgeries, and diverting unscheduled emergency patients to another facility. The sequences of all decisions made by users in a simulation run are analyzed using four metrics. The first metric focuses on how much each control action is used during the management. The second one measures how much these actions are used taking into account the pressure level of the ICU. The third metric accounts for the patient-level decisions. The fourth one aims to measure the combined effect of the three tools over time-related to the bed-occupancy level. The main purpose of the data analysis is to detect similarities and discrepancies of physicians in their ICU bed management. Some tables and figures obtained from real data illustrate the methodology developed here.

Keywords: Decision support; Analytics; Performance evaluation.

Replacing complex models for health decision making with metamodels: three examples

Margaret L. Brandeau
Stanford University, brandeau@stanford.edu

Models used to inform decisions in health are often complex, data- and computation-intensive, and difficult to interpret. For this reason, many models developed by operations researchers to support clinical, operational, and public health decision making are never used by decision makers. This talk focuses on the use of metamodels – that is, a statistical approximation of an original model – to replace complex models for health-related decision making. Metamodeling is an important tool for making results from complex models accessible to decision makers. In addition to the development of simple decision rules, common methods for developing metamodels include linear and logistic regression, generalized linear and additive models, random forest and tree methods, and neural networks. The typical trade-off in metamodeling is between reducing computational burden versus potentially introducing new sources of error relative to the real-world system and losing interpretability with advanced machine learning methods. We describe three metamodels focused, respectively, on personalization of drug treatment for schizophrenia, control of hepatitis C in prisons, and use of mass prophylaxis for controlling disease outbreaks. Although each metamodel is specific to the original model, these examples illustrate general principles for creating simple yet useful models to support health decision making.

Keywords: Modelling and simulation; Healthcare policy modelling; Clinical modelling.

Poster session

Sant'Agostino Cloister – 16:30-18:00

Chair: Ettore Lanzarone

Modelling the recovery of an elective care orthopaedic pathway impacted by COVID-19

Matthew Howells
Cardiff University, howellsma@cardiff.ac.uk

Paul Harper
Cardiff University, harper@cardiff.ac.uk

Daniel Gartner
Cardiff University, gartnerd@cardff.ac.uk

Geraint Palmer
Cardiff University, palmergi1@cardiff.ac.uk

Elective care waiting lists are faced with incredibly strenuous backlogs following the disruption caused by the COVID-19 pandemic. Orthopaedics is one such area faced with these pressures, and with an ageing population at greater risk of these disorders, it is imperative that the pressures can be alleviated. We present the results of a proposed taxonomic classification of the research literature of operational research modelling techniques applied to orthopaedic settings. The results identify the research trends of the literature, as well as gaps that could be explored in future research. Further to this, we propose a simulation model of the patient flow through an orthopaedic pathway in the U.K.'s National Health Service, with the aim to help relieve the elective care backlog in the service and support recovery from the pandemic.

Keywords: Modelling and simulation; Access and waiting list; Patient flow.

Mathematical programming for scheduling telemedicine appointments

Charlotte Marshall
Cardiff University, marshallcl@cardiff.ac.uk

Daniel Gartner
Cardiff University, gartnerd@cardff.ac.uk

Paul Harper
Cardiff University, harper@cardiff.ac.uk

Geraint Palmer
Cardiff University, palmergi1@cardiff.ac.uk

With telemedicine coming to the forefront during the COVID-19 pandemic, flexibility in terms of modes of care delivery has emerged. In this paper, we consider the scheduling of patients' GP and hospital follow-up clinic appointments via four different modes of delivery: traditional face-to-face appointments, video conferencing platforms, telephone, and home visits. The solution of the model not only has an impact on satisfying patients and clinicians' preferences, but also could potentially reduce travel for patients and staff. We present a multi-mode resource constrained project scheduling problem formulation to solve the problem. Our aim is to schedule appointments while maximising how often the patients' delivery method preferences are met. We also consider uncertainty in the number of emergency appointments which are added to the set of planned appointments to be scheduled with no associated patient preference. This model will then be evaluated with data from a partner organisation in the UK.

Keywords: Patient scheduling; e-Health.

An implementor-adversary robust optimization approach for the nurse rostering problem

Rafael A. M. Gomes
Federal University of Ouro Preto, rafael.amgomes@gmail.com
Túlio A. M. Toffolo
Federal University of Ouro Preto, tulio@toffolo.com.br
Greet Vanden Berghe
KU Leuven, greet.vandenberghe@cs.kuleuven.be
Ettore Lanzarone
University of Bergamo, ettore.lanzarone@unibg.it

The Nurse Rostering Problem (NRP) is an optimization problem in which nurses with specific skills have to be assigned to working shifts during a planning horizon. This assignment must take into account the demands for nurses in addition to several soft and hard constraints. The objective is to obtain a solution that minimizes soft constraint violations while maximizing coverage and respecting all hard constraints. Most approaches for the NRP in the literature consider the hospital's demands to be fixed and given a priori. However, in the real world there are many situations that may interfere and change these demands. Such variations on the demands represent a great challenge for planners. In this context, this study investigates the robust counterpart of the Second International Nurse Rostering Competition (INRC-II) problem in which the demands are uncertain. A Robust Method with two phases is presented to solve the problem. The first phase consists of solving the NRP problem with fixed demands (called the Implementor problem), thereby finding the best solution over a particular realization of demands. The second phase consists of obtaining the valid realization of demands that deteriorates the current solution the most (called the Adversarial problem). The demands are then updated and the two problems are solved iteratively until the Adversarial is no longer capable of finding critical realizations for the Implementor. Computational experiments assess the potential of the approach for the IRNC-II problem instances. To further evaluate the impact of the approach in highly uncertain scenarios, additional problem instances based on the INRC-II data are also investigated. It is shown that the proposed Robust Method outperforms deterministic approaches for problem instances with high demand variation.

Keywords: Second International Nurse Rostering Competition; Correlated Demands; Robust Optimization; Implementor-Adversary Approach

Posters of the Gallivan award finalists

- Hannah Bakker: *Logistics for diagnostic testing: an adaptive decision-support framework*
- Carolin Bauerhenne: *Robust appointment scheduling with waiting time guarantees*
- Robin Buter: *Spatial risk analysis of out-of-hospital cardiac arrests*
- Joseph Farrington: *Deep reinforcement learning for platelet inventory management*
- Syu-Ning Johnn: *Home healthcare service assignment, routing, and appointment scheduling with uncertainties*
- Vinicius Martins Ton: *Real-time management of patients' transport requests*
- Simon Moulard: *Minimizing outpatients' waiting time in same-day multi-appointment settings*
- Mariana Oliveira: *Creating and evaluating joint waiting lists in a hospital network using stochastic optimization and discrete event simulation*
- Valery Fernanda Quiroga Pedroza: *Implementation of statistical learning techniques for the prediction of surgical times in highly complex health services*
- Julia Resch: *A semi-online ambulance routing and scheduling problem with complex patient-vehicle relations*

Scientific sessions – Friday, July 22nd

Circular Health for Industry (CH4I): Process mining and optimization in healthcare

Fr1-A – *Lecture Hall* – 9:15-10:45

Chair: Roberto Aringhieri

Mining workshifts: an exercise combining sequence pattern mining and process discovery

Emilio Sulis
University of Turin, emilio.sulis@unito.it

Stefano Branchi
Fondazione Bruno Kessler, sbranchi@fbk.eu

The present work concerns the analysis of workshifts starting from the extraction of patterns from event logs, using methods from the discipline of process mining. We deal with staff rostering, which represents a complex problem difficult to manage for any organization. In particular, we focus on a healthcare dataset including information personnel in a hospital. A sequence pattern mining algorithm is applied to mine frequent contiguous sequential patterns from data, that is to identify constraints that are possibly not explicitly reported as domain knowledge. We specifically look at the frequency of a pattern in terms of number of employees who followed the pattern at least once. The model reveals that the most frequent work shifts are the ones carried out in the morning, followed by the rest workshifts and by the afternoon ones. Moreover, the model also shows that very often the morning workshift is iterated and preceded by a rest workshift. Moreover, process discovery techniques allow for a diagram representation. Employee workshift process of the hospital extracted with Disco can be discussed with the medical staff management. Their positive evaluation revealed the validity of the exercise, which is useful for designing workshifts in the future. This research has been partially carried out within the Circular Health for Industry project, funded by *Compagnia di San Paolo* under the call *Intelligenza Artificiale, uomo e società*.

Keywords: Healthcare Information System; Workforce planning and scheduling; Artificial Intelligence.

Leveraging textual data in predictive process monitoring for the home hospitalization service

Massimiliano Ronzani
Fondazione Bruno Kessler, mronzani@fbk.eu

Chiara Di Francescomarino
Fondazione Bruno Kessler, dfmchiara@fbk.eu

Roger Ferrod
University of Turin, roger.ferrod@unito.it

Chiara Ghidini
Fondazione Bruno Kessler, ghidini@fbk.eu

Predictive Process Monitoring is a branch of Process Mining which uses data about historical execution of a process to make predictions about incomplete case executions. In this work we apply Predictive Process Monitoring to a real healthcare scenario, leveraging on administrative and clinical hospital data. We focus on the Home Hospitalization Service of the City of Health and Science in Turin. We aim in supporting the decision team about the home hospitalization of a patient, by predicting whether it is likely that the patient will successfully undergo home hospitalization. We notice that important information is contained in natural language text and we claim that to obtain more accurate predictions this information should be transformed into structured data. To

this aim we devise a Natural Language Processing approach to convert textual diagnosis, written by the doctor in Emergency Department, into structured data, supplied by the ICD-9-CM classification of diseases, and we compare the performance of the predictions obtained. This research has been partially carried out within the Circular Health for Industry project, funded by *Compagnia di San Paolo* under the call *Intelligenza Artificiale, uomo e società*.

Keywords: Artificial Intelligence; Forecasting; Screening and prevention.

Workshift optimization exploiting process mining's shift patterns

Alberto Guastalla
University of Turin, alberto.guastalla@unito.it

Roberto Aringhieri
University of Turin, roberto.aringhieri@unito.it

Dealing with the management of staff rostering is always been a hard problem to be treated in many sectors. When planning shifts, it is necessary to take into account multiple factors like the operative and contractual constraints, the personal needs and the often unspoken habits of the staff. All of these points are usually considered explicitly or implicitly by the personnel management who often manually prepares shift schedules. Generally, in a work context, the planning shifts is done using human effort and therefore could not be the best realizable plan. In the present talk we aim to provide support to healthcare organizations in automatically generating rostering plans by combining optimization and process mining approaches. The underlying idea of our work is subdivided into three steps: (i) take the optimal, and therefore feasible solution given in output by solving the corresponding optimization model, (ii) detect of personal needs and unspoken habits from the input files through a pattern mining procedure, and (iii) adapt the current solution using a post-optimization algorithm to include as many patterns as possible collected in the previous step while maintaining its feasibility and optimality. Finally, we applied this idea in a real application context using input data that coming from the Cottolengo Hospital in Turin, partner of the Circular Health for Industry (CH4I) research project.

Keywords: Workforce planning and scheduling; Optimization algorithm; Decision support.

The interventional radiology process scheduling problem

Roberto Aringhieri
University of Turin, roberto.aringhieri@unito.it

Matteo Di Cunzolo
University of Turin, matteo.dicunzolo@edu.unito.it

Alberto Guastalla
University of Turin, alberto.guastalla@unito.it

Interventional radiology (IR) is a medical speciality that performs various minimally-invasive procedures using medical imaging guidance. IR performs both diagnostic and therapeutic procedures through very small incisions or body orifices decreasing risks, pain, and recovery compared to open procedures. Although the operative context is quite similar to that of the operating room, our case study is characterised by two unusual aspects: (i) the anaesthetist must be present for the entire duration of the procedure (due to the Italian legislation), and (ii) the IR does not have its own ward but receives inpatients from different wards, and outpatients. Further, several other constraints should be considered. In this talk, we introduce IR process scheduling problem composed of two sub-problems. To the best of our knowledge, this problem never seems to be considered from a healthcare management perspective. The first one consists in selecting patients from the waiting list and assigning their procedure an IR session, that is an IR operating room in a certain day over the planning horizon. The second one consists in determining the precise sequence of IR procedures and the allocation of resources for each IR session. We provide different formulations and solutions approaches, and some preliminary results on real data provided by Molinette Hospital in Turin, partner of the Circular Health for Industry (CH4I) research project.

Keywords: Operating room planning and scheduling; Optimization algorithm; Healthcare logistics.

Therapy and treatment optimization

Fr1-B – *Room 6* – 9:15-10:45

Chair: Joana Matos Dias

Spatial risk analysis of out-of-hospital cardiac arrests

Robin Buter
University of Twente, r.buter@utwente.nl

Derya Demirtas
University of Twente, d.demirtas@utwente.nl

Erwin W. Hans
University of Twente, e.w.hans@utwente.nl

Erik Koffijberg
University of Twente, h.koffijberg@utwente.nl

Hans Van Schuppen
Amsterdam UMC, j.l.vanschuppen@amsterdamumc.nl

Remy Stieglis
Amsterdam UMC, r.stieglis@amsterdamumc.nl

Objectives: Obtaining a better understanding of the spatial out-of-hospital cardiac arrest (OHCA) distribution is not only relevant for strategically locating automated external defibrillators, but also for directing other interventions to improve health outcomes of OHCA. We aim to analyze spatial trends in OHCA incidence and mortality. Methods: We included OHCAs in Amsterdam, the Netherlands from 2006 to 2016 (the ARREST registry). We used Kernel Density Estimation (KDE) to estimate the spatial OHCA distribution. To analyze spatial trends in mortality, we estimated the spatial relative risk (RR) function of mortality to survival, i.e. the ratio of estimated probability density of mortality to estimated probability density of survival. Tolerance contours are used to identify areas that have significantly higher (or lower) risk of mortality. Results: We included 2582 OHCAs in Amsterdam, of which 507 survived and 2075 died after 30 days. Visualization of spatial OHCA incidence showed peaks in the city center and other densely populated areas. Tolerance contours on the spatial RR identified multiple areas that have significantly higher (or lower) risk of mortality ($p \leq 0.05$). Conclusions: Areas of statistically significant increased (and decreased) risk of OHCA mortality can be identified using KDE and spatial RR function. Further investigating the cause of disparities between areas may prove useful in determining effective interventions to improve health outcomes.

Keywords: Emergency Medical Service.

Improving volunteer response to out-of-hospital cardiac arrest using mobile automated external defibrillators

Niki Matinrad
Linköping University, niki.matinrad@liu.se

Derya Demirtas
University of Twente, d.demirtas@utwente.nl

Tobias Andersson Granberg
Linköping University, tobias.andersson.granberg@liu.se

In many countries (semi-)organized volunteers are used in systems for enabling a quick first response to cases of out-of-hospital cardiac arrest (OHCA). Mobile phones are used to notify volunteers in the proximity of the OHCA patient and to dispatch them to the patient. The volunteers are people who know how to perform cardiopulmonary resuscitation (CPR) and how to use an automatic external defibrillator (AED). The volunteers are selected and assigned tasks based on a predetermined set of rules. One recent development is the idea of using mobile AEDs, which means that instead of volunteers fetching an automatic external defibrillator (AED) on their way to the

patient, AEDs can be delivered to the location of the patient, and thus, saving time. In this work, we focus on a volunteer dispatch system in the Netherlands, with a pilot program in which a small set of volunteers own AED-equipped cars. Using simulation, we model the current task assignment strategy used in this system and evaluate the benefits of including mobile AEDs (i.e., privately owned cars equipped with AEDs) in terms of improving the AED delivery times and increasing the survival chance for patients. We investigate the potential benefits of including different numbers of mobile AEDs in the system. We also compare a new dispatch strategy for mobile AEDs to the existing strategy, showing an increase of survival probability.

Keywords: Healthcare logistics; Modelling and simulation; Performance evaluation.

Fluence map stochastic optimization for proton therapy treatment planning

Joana Matos Dias
University of Coimbra, joana@fe.uc.pt

Humberto Rocha
University of Coimbra, hrocha@fe.uc.pt

Joana Neves
University of Coimbra, joana.g.neves23@gmail.com

Brígida da Costa Ferreira
University of Aveiro, brigida@ua.pt

Intensity Modulated Proton Therapy (IMPT) can deliver highly conformal radiotherapy cancer treatments, taking advantage of the proton beam unique depth-dose characteristics. Protons slow down as they penetrate matter, their rate of energy transfer increases with depth, coming to an abrupt stop just beyond where energy deposition is maximum producing the so-called Bragg peak. It is possible to obtain excellent tumor dose conformity while adjacent organs at risk are significantly spared. However, IMPT is extremely vulnerable to different sources of uncertainty. It is thus crucial that uncertainty is explicitly considered when planning the treatment, otherwise it is not possible to guarantee the achievement of the desired prescription objectives. And this is where stochastic optimization can do the difference! We have developed a novel, totally automated stochastic approach for IMPT fluence map optimization (FMO). Our solution is calculated by representing uncertainty through a set of "structure clones". FMO considers the minimization of an unconstrained quadratic optimization objective function, with all optimization parameters automatically determined by a fuzzy inference system. This approach was tested considering a set of prostate cancer cases. The assessment of the optimized plans is done by Monte Carlo simulation taking also treatment fractionation into account. Computational experiments show the ability of this approach to produce high quality plans.

Keywords: Optimization algorithm; Modelling and simulation; Decision support.

New treatment plans for intensity modulated radiotherapy (IMRT)

Janosch Ortmann
Université du Québec à Montréal, janosch.ortmann@gmail.com

Ana María Anaya-Arenas
Université du Québec à Montréal, anaya-arenas.ana_maria@uqam.ca

María Camila Gómez López
EAFIT University, mcgomezl@eafit.edu.co

Radiation therapy is a form of cancer treatment that uses ionizing radiation to treat the disease. One of the most advanced forms of treatment is called Intensity modulated radiotherapy (IMRT) which is a technique that allows better dose conformation to the tumour while reducing the dose in healthy tissue. Treatment plans are designed using optimisation techniques and computational methods that allow the radiation dose to be calculated. To minimise the impact of errors in patient positioning that can potentially have a negative impact on the efficacy and safety of the treatment, robust optimisation methods have been proposed. Since some parts of the radiation will hit surrounding tissues, we are necessarily faced by a multi criteria problem: optimise the radiation dose delivered to the tumour while minimising the dose delivered to adjacent organs. Changing the weights of each

objective will give different solutions, and this adjustment is often done manually, with input from doctors. In this talk I will present a novel algorithm, inspired by ideas from machine learning, that guides this process and provides doctors with new treatment plans. Rather than displaying a single solution, multiple possible plans are offered and represented visually for radiologists and oncologists to choose from.

Keywords: Optimization algorithm; Artificial Intelligence; Clinical modelling.

https://www.overleaf.com/project/62a98f6ce99bf4d624f058c0

Emergency management systems: Analysis

Fr1-C – *Room 8* – 9:15-10:45

Chair: Caroline Jagtenberg

Modeling emergency medical service volunteer response

Caroline Jagtenberg
Vrije Universiteit Amsterdam, c.j.jagtenberg@vu.nl

Out of hospital cardiac arrest requires immediate treatment and patient survival can be improved by combining traditional ambulance response with the dispatch of volunteers alerted via an app. How many volunteers are needed, and from where should they be recruited? We model the presence of volunteers throughout a region as a Poisson point process. We compute the response-time distribution and, using known survival functions from literature, infer survival rates. Survival rates depend on the way volunteers are spread across a city, but it is challenging to estimate this distribution because of data-privacy issues. We consider both plausible volunteer location distributions and also an optimized volunteer location distribution that maximizes survival rates. All of the optimization problems are highly tractable. We include a case study for Auckland, New Zealand, where we show how the optimal allocation of volunteers over the region varies, depending on the number of available volunteers as well as the choice of objective function. We also show how ambulance locations affect the optimal distribution of volunteers. The optimal allocation of volunteers over the region provides guidance for recruitment of volunteers, both in terms of the number of volunteers needed to substantially increase survival rates and in city locations where additional recruitment would be most beneficial.

Keywords: Emergency Medical Service; Optimization algorithm; Healthcare logistics.

Collaboration in healthcare for resilience improvement during disasters

Danuphon Tippong
University of Nottingham, danuphon.tippong@nottingham.ac.uk
Sanja Petrovic
University of Nottingham, sanja.petrovic@nottingham.ac.uk
Vahid Akbari
University of Nottingham, vahid.akbari@nottingham.ac.uk

The study presents a simulation model for resilience improvement during disasters. Our contributions are as follows. We develop a first model that simulates collaborative care according to the real-world operations of emergency medical response. We collaborate with the health authorities in Thailand who experienced disasters to investigate real-world operations that take place in an emergency medical response and to define the potential disaster scenarios. In our study, we compare three strategies including non-collaborative, semi-collaborative and collaborative care. The model is validated and verified using common practices and performs well with respect to the available data. We demonstrate the impact of different strategies on resilience improvement during Tsunami in Thailand in 2004. We adopt the generic resilience metric presented in the literature and use it in the healthcare context. Our analysis yields the managerial insights into the emergency planning as follows. The collaborative care strategy has a greater impact on improving the resilience and returns to the pre-disaster state of the healthcare network quicker than others in defined scenarios. The semi-collaborative care strategy frequently provides the worst resilience in almost all the identified scenarios. However, it provides better resilience than the non-collaborative care strategy when the number of patients is relatively low.

Keywords: Emergency Medical Service; Humanitarian logistics; Modelling and simulation.

Optimization for queueing models with priority patients in emergency departments

Chesoong Kim
Sangji University, dowoo@sangji.ac.kr

Queueing theory is well-recognized mathematical tool for optimization of a restricted resource scheduling in many real-world systems. One of the important branches of queuing theory is the theory of priority systems. In such systems, customers are classified into different categories, depending on urgency of their service and importance, and service is provided according to a certain fixed priority scheme. That is, various priority schemes are used in hospital emergency departments during the sorting incoming patients according to the severity of the injury or disease and for ambulances scheduling. The optimization for healthcare systems in disruption situations as the COVID-19 pandemic is undeniable. It's true that even the slightest difference in service time or waiting time in medical systems can lead to saving or losing a person's life. Therefore, it makes sense to optimize the health care queueing system to minimize infection rate by prioritizing patients based on their health status so that patients with higher risk of infection can leave the queue sooner. In this paper, we analyze multi-server queuing system providing service to heterogeneous patients arriving in the Marked Markov Arrival Process and having different priorities. The expressions for calculating the key performance measures of the health care system are presented and numerical examples to solve optimization problem based on the obtained results is considered.

Keywords: Emergency Medical Service; Optimization algorithm; Performance evaluation.

Social program

SUNDAY – welcome party

Participants and accompanying persons will be welcomed in the Sant'Agostino cloister starting at 18:30. All participants will be served an aperitif and a bouffet dinner. Please, see the conference venue details (page 6) for information on how to access the cloister via the Sunday entrance.

MONDAY & TUESDAY – city tour

To allow a limited number of visitors in the hospital visit, participants will attend the city tour either on Monday or Tuesday (the day in which they do not visit the hospital) according to the letter on the badge and the preferred day (if a preference has been expressed in the online questionnaire). Group A and all accompanying persons will have the guided tour of the Upper Town on Monday, while group B on Tuesday. Please, **respect the day of the letter indicated on your badge**. Each day, the participants will be divided into 3 groups that will be assigned to as many touristic guides (who will do the tour in English). The guides will start the tour from Piazzale Sant'Agostino, in front of the Lecture Hall main entrance, at 16:15 immediately after the bus to the hospital leaves.

WEDNESDAY – boat trip to Como Lake

This is the traditional boat trip of the ORAHS conferences, which this year will be held in the beautiful location of Como Lake. Buses will depart at 9:00 from the Bergamo bus terminal (Piazzale Guglielmo Marconi 7) and will be back at about 19:45 in the same place. The day's program includes:

Trip from Bergamo to Carate Urio

Boat from Carate Urio to Bellagio with guide on board

Guided visit to the Italian style gardens of the Urio Castle

Free time in Bellagio

Lunch in a lake-view restaurant 3 minutes walk from the castle

Boat from Bellagio to Como, with short stop in Carate Urio

Trip from Como to Bergamo

THURSDAY - social dinner

The social dinner will be held at the Villa Maliana restaurant – Viale A. De Gasperi 4, 24030 Almenno San Bartolomeo (Bergamo):

www.villamalliana.com

Transfer will be organized by bus.

Buses will depart at 19:30 from the Bergamo bus terminal (Piazzale Guglielmo Marconi 7) and will be back at about 24:00 in the same place. It will be possible to ask the driver to make some additional stops in Bergamo (excluding the Upper Town).

Program for accompanying persons

MONDAY – Val Brembana

- Departure from Bergamo by bus at 9:30 (pick up at the Bergamo bus terminal in Piazzale Guglielmo Marconi 7).
- Arrival in Cornello dei Tasso at 10:15.
- Walk along the Medieval *Mercatorum* street as far as San Giovanni Bianco.
- Optional entrance to the house of Harlequin, the most famous carnival mask in the word, whose birthplace is in Bergamo and not in Venice as mistakenly believed.
- Organised lunch included.
- Bus transfer to San Pellegrino at 14:00.
- Guided tour of San Pellegrino, a typical Art Nouveau town. Between the end of the 19$^{\text{th}}$ and the beginning of the 20$^{\text{th}}$ century, it became the center of Bergamo's social life and at the same time the favourite holiday destination for the rich international middle class. It was called the "pearl of Val Brembana", for its Art Nouveau buildings, the Grand Hotel, the Casino, the thermal springs and the most famous water and soft drink factory in the word.
- Free time in San Pellegrino
- Return to Bergamo (departure at 15:15 and arrival close to Piazzale Sant'Agostino at 16:00).

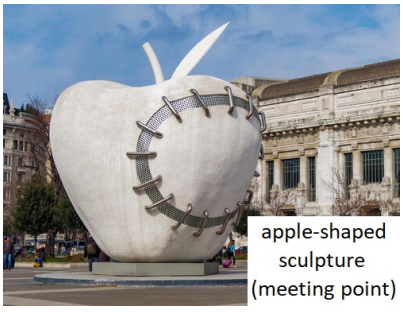
Being back to Piazzale Sant'Agostino at 16:00, accompanying persons can join the Bergamo city tour of the conference participants (see page 88).

TUESDAY – Iseo Lake

- Departure from Bergamo by bus at 9:30 (pick up at the Bergamo bus terminal in Piazzale Guglielmo Marconi 7).
- Arrival in Sulzano at 10:30 where you will be leaded to the beautiful Montisola island (boat trip around 10 minutes – tickets included).
- Lunch on the lakeside included.
- Arrival in Lovere at 15:00.
- Walk from Lovere, one of the "Most Beautiful Villages in Italy", to Valvendra, with its Basilica of Santa Maria.
- Departure from Valvendra at 17:00 and arrival in Bergamo at 18:00 (at the bus terminal in Piazzale Guglielmo Marconi 7).

THURSDAY – Milan

- Departure from Bergamo by train (meeting point at 10:00 at the fountain in front of the railway station in the center of Piazzale Guglielmo Marconi; a guide will accompany the participants on the train).
- Meeting with the tour guide at 11:30 at the train platform of Milan central station.
- Visit to: Central Station; Via Giovanni Battista Pirelli; Gioia/Porta Nuova and its new skyscrapers.
- Organised lunch included.
- Visit to: Corso Como and Corso Garibaldi; Moscova; Brera; Castello Sforzesco; Duomo di Milano.
- Free time
- Meeting point at 16:40 in Piazza Duca d'Aosta in front of the central station, near the apple-shaped sculpture.
- Departure by train (a guide will accompany the participants on the train from the meeting point), and arrival at Bergamo station at 17:50.



apple-shaped sculpture (meeting point)

Accompanying persons have free time in Bergamo before the departure of the buses for the social dinner (see page 90).

Author index

CONTACTS

Conference chairs and committee
orahs2022@unibg.it

Ettore
ettore.lanzarone@unibg.it

Giovanni
giovanni.righini@unimi.it

Organisational secretariat
orahs2022@promoest.com