ORAHS 2020

Program

July 21, 2020

TECHNICAL PROGRAM

Monday, 9:30-11:00

■ MA-01

Monday, 9:30-11:00 - 1

Opening Session Morning

Stream: Monday
Invited session
Chair: *Inês Marques*
Chair: *Roberto Aringhieri*
Chair: *Marion Rauner*
Chair: *Patrick Hirsch*
Chair: *Margit Sommersguter-Reichmann*

Monday, 11:00-12:00

■ MB-01

Monday, 11:00-12:00 - 1

Keynote Peter Zweifel

Stream: Monday
Keynote session
Chair: *Margit Sommersguter-Reichmann*

1 - Preference Measurement in Health Using Experiments
Peter Zweifel

This contribution seeks to attain the following objectives. (1) Understand what is "special" about health from an economic perspective; (2) See that this does not imply instability of valuation, in particular of willingness to pay (WTP) values; (3) Obtain insight into the estimation of WTP values in three studies: Managed Care attributes of health insurance, Adding a new drug to the benefit list, and End-of-life healthcare. through choice experiments; (4) Know the limitations of these studies.

Monday, 13:00-13:30

■ MC-01

Monday, 13:00-13:30 - 1

Opening Session Afternoon

Stream: Monday
Invited session
Chair: *Marion Rauner*
Chair: *Patrick Hirsch*
Chair: *Margit Sommersguter-Reichmann*
Chair: *Roberto Aringhieri*
Chair: *Inês Marques*

Monday, 13:30-15:30

■ MD-01

Monday, 13:30-15:30 - 1

Health Care Networks

Stream: Monday
Invited session
Chair: *Michael Carter*

1 - Embedding OR/systems modelling as decision support in health planning: establishing a Community of Practice
Sally Brailsford, *Steffen Bayer*, *Con Connell*, *Jonathan Klein*

Successive literature reviews over many decades have reported the paucity of examples of OR methods being routinely used to support decision-making in health and social care. Many studies have attempted to explain the reasons for this, and have produced "good practice" guidelines; nevertheless, the problem remains. In this talk we describe a project that set out to overcome some of these well-known barriers to implementation, reflect on the approach taken, and conclude with some insights gained. The project, funded by The Health Foundation, was undertaken entirely by practitioners (local authority and NHS staff, and a small modelling consultancy specialising in healthcare) and had two main aims, capacity building and awareness raising. The role of the authors was solely to evaluate the project through interviews with participants and stakeholders, and a critical review of the models that were produced. These findings largely supported the findings of previous studies in the academic literature, but also raised some interesting issues about the style of training delivery and the selection of problems to be modelled. It was clear that the project leaders fully understood all the barriers to projects aimed at embedding OR modelling skills in public sector organizations, and made considerable efforts to avoid them. Nevertheless the main barrier, pressures on very busy people's time, remained a major obstacle. We conclude with some general reflections and advice for others.

2 - Evaluating the Effectiveness and Efficiency of a Wales-wide public health initiative.
Mark Tuson, *Paul Harper*, *Daniel Gartner*

Adverse Childhood Experiences (ACE's) in the form of abuse, neglect and household dysfunction are strongly correlated with health harming behaviours. Compared with those who experienced no ACE's, adults who experienced four or more in their childhood are 6 time more likely to smoke, 16 times more likely to have used crack cocaine or heroin and 20 times more likely to experience incarceration. Working with the 4 police forces in Wales, 22 local authorities and a range of 3rd sector organisations, Public Health Wales (PHW) has instituted a national programme both to reduce the incidence of ACE's in the child population of Wales, and to mitigate their impact. The OR research team at Cardiff University were asked to evaluate the efficiency (cost and resources) and impact of a number of the initiatives that were used to drive the programme. A second phase focused on developing a methodology to review the impact of the programme as a whole. In the initial stages this encompassed a series of projects involving simulation, statistical analysis and estimating social return on investment. The latter stages involved synthesising the output from those projects into a single systems model with which to examine their combined impact. The results and learning from each of the projects are discussed along with those from the systems model.

3 - Sim.Pro.Flow - Automating Simulation Build
Emma Aspland, *Paul Harper*, *Daniel Gartner*, *Edilson Arruda*, *Geraint Palmer*, *Phil Webb*, *Peter Barrett-Lee*

Introducing Sim.Pro.Flow - The open source decision support tool that can: automatically extract clinical pathways, visualise the system, build the simulation, investigate capacity levels and allow for

flexibility, all within an easy to use Graphical User Interface (GUI). Sim.Pro.Flow is the product produced from research in partnership with Velindre Cancer Centre, the largest specialist cancer centre in Wales, which has the overall goal to improve patient care and outcomes by reducing time to diagnosis and treatment, for those with lung cancer. Using Sim.Pro.Flow allows for mapping, modelling and improving the clinical pathway and enables Velindre Cancer Centre to better align capacity and demand in an effective and efficient manner. Clinical pathway mining typically produces large and complex spaghetti diagrams with high levels of variation. Utilising a combination of data and expert information inputted to the tool and applying k-medoids clustering reduces the complexity. The tool then allows for the pathway, along with arrival rates, service times and capacity estimates, to be fed through to automatically build a discrete event simulation using Ciw. To allow for flexibility, users can choose different levels of data to explore, along with post simulation build alterations, and optimising capacity levels based on desired percentage time targets. Automating visualisation of the pathway and producing an easy to use GUI are two key features which enable clinical staff to engage with the simulation build process. Further facilitated by the automated build feature, which significantly reduces the time taken to build the initial simulation. The usability of Sim.Pro.Flow has been evaluated by the staff at Velindre Cancer Centre through a number of small workshops.

4 - Analyst-driven development of an open-source simulation tool to address poor uptake of O.R. in healthcare
Christos Vasilakis, Richard Wood

Computer simulation studies of health and care problems have been reported extensively in the academic literature, but the one-off research projects typically undertaken have failed to create an enduring legacy of widespread use by healthcare practitioners. Simulation and other modelling tools designed and developed to be used routinely have not fared much better either. Following a review of the literature and a survey of frontline analysts in the UK NHS, we found that one reason for this is because simulation tools have, to date, not been developed with the requirements of the end-user in the heart of the development process. Starting with a thorough needs assessment of NHS based healthcare analysts, this study outlines a set of practical design principles to guide development of simulation software tool for conducting patient flow simulation studies. The overall requirement is that patient flow be modelled over a number of inter-connected points of delivery while capturing the stochastic nature of patient arrivals and hospital length of stay, as well as the dynamic delays to patient discharge and transfer of care between different points of care delivery. In ensuring a cost-free solution that is both versatile and user-friendly, and coded in an increasingly popular language among the envisaged end users, the tool was implemented is the R programming language and software environment, with the user interface implemented in the interactive R-Shiny application. The talk will provide an overview of the project lifecycle including an illustrative example of an empirical simulation study concerning the centralisation of an acute stroke pathway.

■ MD-02

Monday, 13:30-15:30 - 2

Health Care Workforce Scheduling I

Stream: Monday
Invited session
Chair: *Inês Marques*

1 - The Value of Information in Multi-Skilled Nurse Scheduling
Jan Schoenfelder

The typically high variability of demand for nursing care in individual medical units has driven many hospitals to install pools of multi-skilled flexible nurses. These nurses can be (re-)assigned to a selection of different departments on short notice, e.g. at the beginning of their shift, to assist in meeting patient demand.

An effective nurse scheduling process needs to incorporate the availability of such flexible nurses as well as patient demand information beyond the typically used single-point expected demand estimations along with workforce-related factors such as nurse availability, shift preferences, and qualifications.

We model the described problem as a multi-stage stochastic problem and translate it into the deterministic equivalent formulation. We decompose the problem into a master problem and a set of subproblems according to Dantzig-Wolfe to cope with the size of the resulting MIP. A multifactorial numerical experiment with data from our practice partner allows us to tackle the following research questions: How much improvement can be gained from the proposed scheduling process over traditional scheduling, and how does the improvement depend on the included level of demand information? What is the relationship between the size of the float pool and the resulting cost, patient care, and nurse-experience-related performance measures?

2 - Need-based Workforce Planning for Healthcare Services Delivered by Teams
Majid Taghavi, Nader Azad

Collaborative care is emerging as the preferred way of providing high-quality, cost-efficient, and coordinated health care services for patients. Collaborative care is provided through interdisciplinary teams of several health care professionals who work together to provide high-quality care to the patients. Patients, health care professionals, and healthcare organizations can benefit from effective teamwork in healthcare delivery, including better health outcomes for patients, reducing workloads and staff shortage for healthcare providers, and stimulating learning from other professionals for healthcare organizations. In this research, we develop a general linear programming model to address healthcare workforce planning for health care delivery through collaborative multidisciplinary teams. The model helps decision-makers to find the structure and composition of the teams which is identified as one of the key factors determining the quality of team-based health care delivery. Then, we present a case study for specialist palliative care workforce planning in Nova Scotia, Canada and show that the introduced model can capture the characteristics of the problem identified in the case study. We also show how the historical and projected data are used to find high-quality forecasts for the parameters used in the model.

3 - Physician Staffing and Shift Scheduling at Emergency Departments with Time Varying Productivity
Negar Ganjouhaghighi, Marco Bijvank, Alireza Sabouri

In this study, we formulate a new staffing and shift scheduling problem for physicians at emergency departments. Two important characteristics that we include are (i) the demand for emergency care is random and time inhomogeneous, and (ii) the productivity of emergency physicians is random and it varies during the shift (in particular, the productivity decreases). We measure a physician's productivity as the patient-per-hour rate (or PPH rate). Due to the stochastic nature of both the number of patient arrivals to the system (i.e., demand) and the service rate of treating new patients (i.e., supply), we formulate the problem as a two-stage stochastic program with the objective of minimizing the unmet demand during a planning horizon. We solve the problem using benders decomposition. Numerical experiments are then performed with data from a Canadian emergency department. The staffing levels and scheduled shifts that we obtain are compared against the schedules that we obtain from a problem that doesn't consider stochastic nature of both the supply and demand (i.e., a deterministic problem) as well as the current schedule used the emergency department under study. Based on a simulation study we conclude that our schedule results in a reduction of the average waiting times for patients to receive an initial assessment.

4 - Nurse rescheduling with a fair distribution of shift changes
Lena Wolbeck, Natalia Kliewer, Inês Marques

Nurses organize their private lives according to their schedules, which is why scheduling as well as changes to the initial schedule have a major impact on their job satisfaction. If a disruption such as a short-term nurse absence during schedule operation invalidates the current schedule, rescheduling is needed. Rescheduling refers to the problem

of changing shift assignments in order to cover the specified staff demand. Doing this, scheduling rules must be adhered to as in initial scheduling. In nurse scheduling, more recent attention has focused on the conception of solution methods taking into account fairness aspects. Nevertheless, most rescheduling approaches aim at minimizing the number of shift changes which may lead to a disparate distribution of shift changes among nurses and thus increased dissatisfaction. This study therefore analyzes a penalization scheme to fairly distribute shift changes based on an individual dynamic accumulated penalty score considering previous reschedulings. Using a general optimization model, we are able to obtain schedules in a short computational time for different instances (real-world based instances from literature and a Portuguese hospital as well as real instances from a German care facility). The results show a significantly fairer distribution of shift changes. This effect is particularly noticeable in several consecutive planning periods, for which up to 12 periods (corresponding to one year) are examined. This work provides a rescheduling approach aiming at fairness while simultaneously demonstrating that the number of shift changes does not significantly deviate from the minimum number.

■ MD-03

Monday, 13:30-15:30 - 3

Infectious Disease Policy Modelling

Stream: Monday
Invited session
Chair: *Daniel Gartner*

1 - A Rule-based Digital Vaccination Decision Support for Child Immigrants Immunization Coordination in Sweden - The VacSam Digital Service
Odd Steen, Nicklas Holmberg

VacSam is a digital vaccination coordination service developed together with the Swedish Infectious Decease Control agency. It is a rule-based decision support for Swedish healthcare professionals to manage immigrant children's vaccination status to level their immunization status with the national Swedish vaccination schedule. The background to the service were: The people mobility in the world was and still is increasing; Only a few experts in Sweden were capable of quick vaccination recommendations of foreign children; Vaccination coverage must not sink below certain thresholds to maintain societal level immunization; Informal estimates by Swedish vaccination experts suggested that 70-80 percent of the inoculations are redundant. The heart of the VacSam digital service is the international vaccination schedules turned into business rules executing in a Business Rules Management System. Using only the child's birthdate, immigration date, emigration country, and sex VacSam compiles the child's ideal vaccination status, compares that to the Swedish national vaccination schedule, and infers both the vaccination status and the needed vaccinations to comply with the Swedish national vaccination schedule. Since the decision logic of VacSam is based on natural language business rules, vaccination experts would be able to maintain and manage the rules to keep them current and correct. The VacSam service could also be further developed to cater for e.g. score-based calculations of geographical risk areas and immunization quality. In these days of continuously increased people migration because of e.g. war and global warming a service like VacSam might have an important role to play to help keep immunity levels high and using vaccines more efficiently.

2 - Childhood Vaccination in Vienna: A Cross-Sectional Survey Conducted in 4th Grades of Public Primary Schools
Marion Rauner, Simone Schnedlitz, Sabine Blaschke

The World Health Organization accounts vaccine hesitancy as one of the ten biggest threats to global health. Thus, Austria made the childhood vaccination program for free to overcome monetary constraints of legal guardians. However, this program is on a voluntary basis. To understand why potentially eradicable infectious childhood diseases are still endemic and even on the rise, a survey on decision-making regarding childhood vaccination among parents of 4th graders in public primary schools in Vienna, Austria was conducted. We chose this sample since at that age group of children several important vaccination decisions had already been made, including the measles-mumps-rubella vaccination and the newly established human papillomavirus vaccination. Our survey consisted of the following three parts: 1) questions related to the score for "Parents Attitude about Childhood Vaccines", 2) questions related to childhood vaccination, and 3) questions related to socio-demographic factors of the respondents. We performed descriptive statistics to analyse sample characteristics, while IBM SPSS was utilized to perform bivariate and multivariate statistical analyses.

3 - Modeling HIV incidence and prevalence in Turkey, 2018-2030
Emine Yaylali, Zikriye Melisa Erdoğan

Background: There were 3,800 new HIV diagnoses in 2018 and a total of 21,988 cases of HIV infection reported until the end of 2018 in Turkey. Although the prevalence rate of Turkey could be considered as low (0.1 - 0.3%), the number of diagnosed HIV cases in the last five years has been rapidly increasing with a particularly high rate of infection for men who have sex with men (MSM). New HIV diagnoses have been tripled in the last decade and the number of new diagnoses in the last five years constituted 63% of total cases reported so far. Objective: To develop a mathematical model for determining HIV incidence and prevalence in Turkey in the next 10 years while assessing the current continuum of care and to evaluate impact of HIV prevention methods Methods: We developed a dynamic compartmental model of HIV transmission and progression among persons aged 18-65 in Turkey. The model population is stratified into subpopulations by transmission group and sex. Model compartments are categorized based on disease status, disease progression by CD4 count and continuum-of-care stage (from unaware of infection to viral suppression). We estimated HIV incidence, diagnoses and deaths by CD4 levels and transmission group from 2018 to 2030. Results: If continuum-of-care are maintained, we estimated that HIV incidence would increase approximately 3,150 cases in 2018 to 8,700 cases in 2030. Our model predicted similar increasing trajectories in the number of HIV diagnosis and HIV deaths as well. We estimated that HIV prevalence would reach 77,000 cases by 2030. Conclusions: HIV incidence and prevalence would increase significantly if current trend continues and no additional HIV prevention measures are are taken in Turkey.

Monday, 16:00-18:00

■ ME-01

Monday, 16:00-18:00 - 1

Elderly and Mental Health Care Planning

Stream: Monday
Invited session
Chair: *Leslie Anne Campbell*

1 - Informing the Transformation of Mental Health and Addictions Service: A Realist Evaluation
Leslie Anne Campbell, *Jill Chorney*, *Sharon Clark*, *Debbie Emberly*, *Julie MacDonald*

Creating an accessible and accountable mental health and addictions (MHA) care system requires a major shift in the philosophy and organization of health care to replace a traditional system that has little ability to measure patient-centred outcomes, tailor care, or actively engage patients and families in the care process. Selected to guide transformation of child and adolescent MHA services, the Choice and Partnership Approach (CAPA) is a continuous improvement service model based on collaborative and participatory practice and Lean principles and informed through outcome measurement to enhance the effectiveness of care and manage capacity and demand for services. While CAPA has been implemented to varying degrees internationally, progress has often been slower than desired and achieving 'scale-up' has proven problematic. Fidelity to the model and implementation of all 11 key components are fundamental to its effectiveness, however, little is known about their relative importance. The literature is sparse on these efforts. Intended to be adaptable to local contexts, there is little guidance regarding the key ingredients to support success, resulting in failed efforts or distilled down implementation. Transformational changes needed to improve patient and system outcomes are challenged by the highly complex nature of health care systems. Even when a new technology or model of care delivery is well supported by evidence and has been locally pilot tested, full implementation is a challenge due to important differences in context within and across health care systems. Using a Realist approach to elucidate the impact of context on the implementation of CAPA, we aim to describe, "To what degree does CAPA work, for whom, and under what circumstances?".

2 - Network-based operational modelling of healthcare systems to support service improvement
Sean Manzi

Healthcare systems are large and difficult to comprehend in their entirety with many different services which interface with multiple services producing highly complex systems. Due to this inherent complexity, service improvement projects in healthcare often struggle to account for the wider impact of a change made to one aspect of the system on the function of the wider system. System Dynamics is one approach that has been used to understanding large scale healthcare systems, however this approach requires the manual mapping of the system and considerable amounts of data to parameterise a quantitative model making the creation of such a whole system model time resource intensive and renders the model temporally static. A network based approach to the operational modelling of healthcare systems offers a way to comprehend, monitor and explore large healthcare systems at the strategic and operational levels in a real-time, data driven and temporally dynamic way.

A project to develop a platform enabling real-time, scalable, data-driven network based operational modelling of healthcare systems using a network based approach to support service improvement is currently being undertaken. This project has been preceded by pilot research examining the provision of care for people with complex relational disturbances in the regions of Devon and West London, United Kingdom. The development of a formal approach and platform for network-based operational modelling (NOM) of healthcare systems will be presented and its potential exemplified using examples from the pilot research.

3 - Regionalization in perinatal mental health in Ile de France
Catherine Crenn-hebert

Background Mental health disorders becomes first cause of maternal mortality; all teenagers with suicide attempt have a mother who had postpartum depression. France belongs to Maternal Mental Health Global Alliance. In IDF region, health authority with perinatal professionals and patients representatives of the regional perinatal commission decided to build an integrated system of mental health perinatal regionalization. Method Literature shows that disorders frequencies are universal. To build our pyramid as did Dr Gregoire in UK, we used a regional Perinatal health Information System data (hospital discharge summaries with residence place) to estimate how many women are involved in each district. Perinatal psychiatrists, psychologists, obstetricians, midwives, GP, public health doctor, user representatives, community workers inventoried existing structures and usage criteria. Results At the base of pyramid, 172897 women living in IDF region delivered 174 195 living births in 2018, 24% of Metropolitan France births. They all need mental health promotion from perinatal teams trained in respect of good treatment. Maternal difficulties may occur in 15 to 30% and should be cared by midwives or GP with psychologist help and community workers. Moderate disease and multiple vulnerabilities may occur in 10% and should require coordinated pathways and specialist advices. Major disease affect 3%, they will require ambulatory specialized team or day care hospital. Severe or High risk disorders will occur in about 1050 dyads who need joint care in mother and baby units. Discussion Conclusion Adaptation from existing structures to the needs is to be achieved in each territory. Clinical pathways have to be written from preconception consultation to postnatal care.

■ ME-02

Monday, 16:00-18:00 - 2

Emergency Care Planning I

Stream: Monday
Invited session
Chair: *Mario Jorge Ferreira de Oliveira*

1 - Characterization of Care Complexity in Emergency Departments
Marco Bijvank, *Seung-Yup Lee*

While the Canadian Triage and Acuity Scale (CTAS) has been a well-established triage tool developed and applied for Canadian Emergency Departments (EDs), it does not involve any consideration of the level of care complexity. To many healthcare providers, the notions of urgency and complexity are mixed and sometimes used interchangeably. In this presentation, two types of complexities are studied in the healthcare setting: case complexity (characteristics of a patient such as age, vital signs, main complaint, previous hospital visits) and care complexity (aspects of the process of care delivery including the need for resources such as diagnostic imaging, laboratory tests, consultations and procedures). We try to explain the influence of case complexity and urgency on care complexity, which ultimately can be used for early detection of complex patients. Besides the previously mentioned two types of complexities, we also investigate the moderating effect of the system's operational status on the case-to-care relationship.

2 - Managing Emergency Department Patient Flow and Nurse Staffing using Fluid Approximations for Multi-Class Pooled Service Queues
Maria Mayorga, *Siddhartha Nambiar*

Efficient patient flow through an emergency department (ED) is a critical factor that contributes to a hospital's performance, which in-turn influences overall patient health outcomes. In this work, we model a multi-class many-server pooled queueing system where patients of different acuity levels receive care from one of several nurse pools, each

comprising an ED unit. We assume that a patient's time in service is a function of the nurse workload (for which nurse-patient ratio is used as a proxy) in their unit. Our objective is to reduce patient Length-of-Stay (LOS) and to control nurse workload by optimizing routing and nurse allocation decisions between units. First, we address the complexity of the queueing model control equations due to patients of multiple acuity levels present in the same ED unit with service rates that depend on patient acuity and unit workload. To do this we approximate the queueing system via a deterministic fluid model to describe the control equations via their first order behaviors. Next, we formulate the optimization model using the control equations obtained from the fluid approximation. The results of the fluid optimization problem are input to a simulation developed with AnyLogic software to obtain performance measures of interest for the non-approximated system, such as patient LOS and unit workload. We use data from a hospital in North Carolina, USA, to estimate parameters such as arrival rates, unit capacity, and service rates. Our results (1) highlight the importance of accounting for nurse workload and service behavior in developing routing/staffing policies and (2) show that small changes to patient routing policies could lead to reduced patient LOS and better-balanced nurse workloads.

3 - A Simulation-Optimization approach for parameter calibration of Emergency Department discrete event simulation model
Massimo Roma, Alberto De Santis, Laura De Vito, Tommaso Giovannelli, Stefano Lucidi, Mauro Messedaglia, Federico Petitti, Ferdinando Romano

Discrete Events Simulation (DES) is the most widely used tool for studying Emergency Department (ED) operation. There are plenty of scientific papers devoted to analyze the patient flow through an ED via DES models, mainly aiming at tackling the worldwide phenomenon of overcrowding. However, data needed for building such models are usually incomplete due to the difficulty in collecting timestamps related to some activities. In particular, visit and treatment duration, which represent key service time, often cannot directly gained. Therefore, to achieve high reliability of a DES model for an ED, an accurate calibration procedure is firstly required in order to determine a good estimate of the model input parameters. Indeed, calibration along with validation is essential in the model building phase to avoid invalid simulation output. In this work we propose a simulation-optimization approach integrating DES simulation with an optimization algorithm in order to determine the best values of such input parameters. In particular, we adopt an algorithm belonging to a class of Derivative-Free Optimization (DFO) methods recently introduced in Continuous Optimization literature. The approach we propose, has been largely experimented on the ED of the Policlinico Umberto I, the biggest hospital ED in Rome, in terms of patient arrivals per year. The obtained results show that the use of the DFO algorithm enable to efficiently determine the optimal values of the input parameters needed to construct a high-fidelity model.

4 - Modelling the use of ICU beds in the State of Rio de Janeiro using big data, Simulation and Artificial Intelligence
Mario Jorge Ferreira de Oliveira

Brazil has undergone profound social, economic, political and demographic changes in recent decades and one of the most important aspects of these changes remains access to health. The difficulty in accessing emergency services is an increasing problem for society due to the complexity of planning and the lack of adequate investments in the face of increased demand. Among so many services essential to the well-being of the population, access to beds in the Intensive Care Unit (ICU) is essential for maintaining life in extreme cases, when the patient often cannot wait for the availability of places. This article offers a basis for dimensioning the offer of ICU beds according to regions of the State of Rio de Janeiro. The objective is to model and simulate different scenarios, increasing the number of monthly hospitalizations and the number of ICU beds available and recording information about the ICU bed utilization rate, average and maximum waiting time for hospitalization and the number of hospitalizations processed at the end of a simulation period. This study is based upon a big national database, constantly updated, enabling access to key information and artificial intelligency concepts to build simulation models for several hospitals, at different levels of geographic coverage. This study contributes to future planning in the provision of ICU beds for the entire Brazilian population as well as assist in the assessment of the current offer, allowing the identification of deficiencies and needs that exist today.

■ ME-03

Monday, 16:00-18:00 - 3

Machine Learning Approaches in Health Care

Stream: Monday
Invited session
Chair: *Evrim Didem Gunes*

1 - A personalized approach to the allocation of complex care delivery under parameter uncertainty
Onur Demiray, Evrim Didem Gunes, E. Lerzan Ormeci

Patients suffering from chronic diseases tend to experience comorbidities, which cause them to experience problems in their physical, mental and social lives more frequently. This also poses a threat to society since it constitutes a great economic burden in healthcare expenditures. As a result, the concept of care delivery for polychronic patients has been evolving to a more integrated and comprehensive paradigm called complex care. However, it is not feasible to include all patients in this paradigm due to scarce resources. This study proposes a Markov Decision Process (MDP) model to decide which patients should benefit from complex care at each decision epoch based on their physical and behavioral conditions. However, it is difficult to generate reliable estimates for the transition probabilities due to large amount of possibilities constituted by multimorbidity. Hence, a robust version of the MDP model is considered, which is known to favor conservative decisions. Then, we develop a framework in which a machine learning algorithm is employed to facilitate the transition from robust optimization to stochastic programming in order to abstain from conservatism. Through computational experiments, we compare our approach with other studies in the literature and evaluate the value of our approach.

2 - Improvement of patients outcome through the optimization of pre-surgical times and Length of Stay (LOS)
Santamaria-Acevedo Gustavo

Emergency departments and Emergency Surgery Theaters (EST) are facing increasing challenges due to a sustained increase in the amount of patients demanding their services. The rise in the demand, coupled with practices such as not operating patients at night unless absolutely necessary, and decisions made by surgeons and anesthesiologists, has led to longer waiting times, and to very stochastic pre-surgical waiting times.

Our hypothesis is that most of the surgical patients stay in the hospital a longer time than required, which can be harmful for them and reduce the access of other patients to surgical services. Therefore, the optimization of pre-surgical waiting times may reduce the lenght of the post surgical stay.

To address this issue we will use Predictive Analytics and Machine Learning (ML) techniques, that will take into consideration the occupancy rate of the ER, if the surgical specialty has any effects on the delay, as well as elements like the age of the patients, the severity of their condition, and their location in the hospital. In the proposed framework, patient and surgery theater data are used to create predictive models that will calculate the risk of a patient's decease or having severe complications due to pre and post surgical delays. The methods are tested in the Parisian Hospital of La Pitié Salpetriere.

3 - Predicting and Improving Patient-Level Antibiotic Adherence
Margaret L. Brandeau

Low antibiotic adherence causes substantial health and economic burden. We analyzed primary data from electronic medical records of 250,000 random patients from Israel's Maccabi Healthcare services from 2007-2017 to predict whether a patient will purchase a prescribed antibiotic. We developed a decision model to evaluate whether an intervention to improve purchasing adherence is warranted for the patient, considering the cost of the intervention and the cost of non-adherence. The best performing prediction model achieved an average AUC of 0.684, with 82% accuracy in detecting individuals who had less than 50% chance of purchasing a prescribed drug. Using the decision model, an adherence intervention targeted to patients whose predicted purchasing probability is below a specified threshold can increase the number of prescriptions filled while generating significant savings compared to no intervention - on the order of 6.4% savings and 4.0% more prescriptions filled for our dataset. We conclude that analysis of large-scale patient data can help predict the probability that a patient will purchase a prescribed antibiotic and can provide real-time predictions to physicians, who can then counsel the patient about medication importance. More broadly, in-depth analysis of patient-level data can help shape the next generation of personalized interventions.

Monday, 18:30-19:00

■ MF-01

Monday, 18:30-19:00 - 1

e-Vienna City Tour

Stream: Monday
Invited session
Chair: *Marion Rauner*
Chair: *Nurcan Cakan*

Tuesday, 9:30-11:30

■ TA-01

Tuesday, 9:30-11:30 - 1

Emergency Services - Ambulance Location

Stream: Tuesday
Invited session
Chair: *Maria Eugénia Captivo*

1 - The challenge of dispatching the right ambulance: A simulation-optimization approach
David Olave-Rojas, Stefan Nickel

Healthcare is one of the most important disciplines to ensure life quality for human beings, specially in critical situations such as accidents, natural disasters, terrorism or when acute ailments exist. In these cases, Emergency Medical Services (EMS) face big challenges due the complex nature of pre-hospital events. Complementary, Agent-based and Discrete Event Simulation are excellent approaches to find new strategies for facing this complexity. In this presentation, we implement a hybrid simulation model which is integrated with an optimization approach for deciding a dispatch ambulance strategy. The goal of this methodology is to improve response time, service level, fairness and robustness in real time scenarios. Furthermore, we present some challenges found during modelling process and an analysis related to the results. Finally, we give some guidelines for future research work.

2 - Overcoming modeling flaws in ambulance location models
Pieter van den Berg

In many state-of-the-art ambulance location models that use the busy fraction to account for ambulance unavailability as a result of simultaneous calls, we encounter the following three modeling flaws. Flaw 1: The busy fraction of ambulances is used as input, whereas this changes with the location of the ambulances. Flaw 2: A constant busy fraction over the entire region is considered, whereas this varies with both the location of the ambulances as the demand of the various demand points. Flaw 3: It is assumed that ambulances operate independently, whereas this is not the case in practice.

To overcome these deficits, we compare eight different iterative ambulance location models. To overcome Flaw 1, we use an iterative procedure where the resulting busy fraction of one iteration is used as input for the next iteration. This resulting busy fraction is either calculated using the hypercube approximation model or simulation. To overcome Flaw 2, we either consider a system-wide busy fraction or demand point specific busy fraction. And finally, to overcome Flaw 3, we use the base model of MEXCPDD, which incorporates the correction factors of the hypercube approximation model and compare this to the classical MEXCLP model.

Since we have two modelling options for each of the three flaws, this leads to a total of eight different iterative ambulance location models, which we compare on data from ambulance regions in the Netherlands.

3 - An investigation into 'optimal service hours' for the operation of response vehicles for the North West Air Ambulance Charity (NWAA)
Dave Worthington, Roger Brooks, Lucy Morgan, David Briggs

North West Air Ambulance (NWAA) are a charity funded organisation in the UK that provides Enhanced Pre-Hospital Care (EPHC) throughout the Northwest of England. NWAA provide advanced medical expertise and equipment that can be utilised at the scene of an emergency. They can also facilitate conveyance of patients to hospital when required. At the time of this work the Charity had up to three advanced healthcare teams available at any time, each of which can respond using its air ambulance (helicopter) or its rapid response vehicle (RRV). They attend over 2,000 missions each year. Currently NWAA complete missions during daylight hours only. Their interest for this project, undertaken during Autumn 2019, was whether to extend operational hours beyond this. The results from the consultancy-style project enabled NWAA to justify trialling a night-time RRV-based service in the Spring of 2020; with the expectation that the trial combined with the modelling results might then justify a more extensive night-time service. This talk will describe how a mixture of consultancy skills, data analytics, simulation modelling and queueing theory contributed to this project.

4 - Integrating ambulance dispatching and relocation problems: the Portuguese case
Ana Sofia Carvalho, Maria Eugénia Captivo, Inês Marques

Ambulance dispatching and relocation problems are crucial for the decision-making process in an Emergency Medical Service (EMS) context. Dispatching decisions assign ambulances to emergencies and the relocation problem decides to which base available ambulances should be (re)assigned. These decisions are highly complex as there is a huge level of uncertainty involved. Thus, having an effective and efficient EMS response is of the utmost importance to help EMS managers in the decision process. The proposed strategy maximizes system's preparedness to achieve a good service level and increase the number of emergencies served within the maximum response time. This strategy is used for both dispatching and relocation decisions. A mathematical model and a pilot-method heuristic are developed to solve these problems. This study considers the Portuguese EMS case where these decisions are still expert based. Tests consider real data on the Lisbon area and real travel times on roads. The proposed strategy is compared with the current Portuguese EMS strategy which dispatches the closest available ambulance and relocates ambulances to their home bases. Results highlight the potential of the proposed strategy and solution approaches in a real-time context.

■ TA-02

Tuesday, 9:30-11:30 - 2

Home Health Care Planning

Stream: Tuesday
Invited session
Chair: *Patrick Hirsch*

1 - A study of integer programming formulations on traveling salesman problem with flexible coloring: models and application in home healthcare service
Haibo Wang, Bahram Alidaee

The traveling salesman problem with flexible coloring (FCTSP) has recently been introduced in the literature. FCTSP has the clustered traveling salesman problem (CTSP) as a special case. In the real world applications such as home healthcare service, if a given patient is assigned to a unique caregiver, we consider it as the CTSP. If one of multiple caregivers could visit some patients, then we formulate it as the FCTSP. We present several new alternative IP formulations for CTSP. Some of our formulations provided improved bounds of objective function compared to some existing ones. In this paper for FCTSP we show: (1) the IP formulation presented by the recent paper, in general, will not enforce nodes of the same assigned color in the graph to be visited contiguously. We will provide several IP formulations for the problem in the general case. Some of our proposed IP formulations significantly reduce the number of variables, and the number of constraints compared to the existing formulation while other proposed formulations provide much-improved bounds. (2) Finding an appropriate number of colors used in the final solution may not be trivial, but a major problem because it is a strong NP-hard problem by itself. (3) Our proposed IP formulations have advantages of linear, even super-linear, speedup on large-sized instances solved by Gurobi solver

under a parallel computing environment, which could be alternative on solving large-sized instances directly instead of developing problem-specific heuristics. Finally, we assess our formulations with randomly generated test instances, and home healthcare service using available commercial solvers.

2 - Evaluation of an integrated mobility concept for home care staff and ambulant patients
Lorena Reyes-Rubiano, Jana Voegl, Patrick Hirsch

Efficient transport of home care staff and ambulant patients is crucial for health care service providers. Due to the increase in demand, limited availability of resources and environmental regulations, service providers are starting to integrate trip sharing strategies as a sustainable solution to mobility problems. Sustainability is a complex concept that involves the economic, environmental and social dimensions of a process. This work investigates the sustainability impact of an integrated trip sharing system combined with the additional option of walking for home care staff and ambulant patients. A transport service delivers home care staff of different qualification levels to clients and picks them up after completion of their services. Ambulant patients are transported from their homes to hospitals or other medical facilities and then picked up after the end of their treatment. To determine a routing and scheduling plan for the mobility of home care staff and ambulant patients, a matheuristic algorithm is developed and implemented. A simulation model that depicts dynamic events during the planning period is designed to evaluate the feasibility of the generated operational plan. Subsequently, an online algorithm is implemented to adjust the operational plan and provide a suitable solution considering the simulated events. Different geographic regions and demographic characteristics are tested and analyzed. Consequently, decision-makers can use this model to determine operational plans considering dynamic events during the planning period concerning the sustainability impact.

3 - The impact of synchronization in home health and social care services
Helena Ramalhinho Lourenco, Jesica de Armas, Marcelus Lima

Home Health Care (HHC) is defined as medical and paramedical services delivered to patients at home. A patient in a hospital has a high cost for the community, so the main benefit of the HCC service is the significant decrease in the hospitalization rate, as well as, the improvement on the quality of patient recovery. The current trend is to send medical personal to visit patients in their home in order to reduce costs for the community and increase quality of life of the patients. Home Social Care (HSC) refers to provide social work, personal care, protection or social support services to a population in need or at risk, or adults with needs arising from illness, disability, old age or poverty with the objective to meet their specific needs. The providers of these services are a set of different professionals, that need to be coordinate by a central, usually, public organization. Frequently, a large set of the population needs both HHC and HSC services. Therefore, the closer integration of the HHC and HSC is a policy goal for many government institutions. This integration has had a limited implementation due several reasons as cultural, ways of working, regimes and logistics complexity. In this work, we propose optimization models to optimize to solve the Integrated Home Care (IHC) and evaluate the cost and quality service impact of introducing synchronization in the full system. The work is done taken into account the reality at the city of Barcelona, Spain.

■ TA-03

Tuesday, 9:30-11:30 - 3

Chronic Care Policy Modelling

Stream: Tuesday
Invited session
Chair: *Eric Silverman*

1 - Simulating the interaction of social and child care demand with an agent-based model
Eric Silverman, Umberto Gostoli

In the UK, adult social care and child care are provided through both formal and informal means, and is therefore governed by complex policies that interact in non-obvious ways with other areas of policy-making. Within affected households, families must make difficult choices as they give their time and energy to vulnerable members who need support. As the UK population continues to age and care need levels rise, supporting these carers becomes ever more critical.

In this model, we simulate care-giving agents who can provide informal care or pay for private care for their relatives. Agents make care decisions as part of complex negotiations taking place in their kinship networks, where they consider numerous factors, including their health status, employment status, financial situation, and social and physical distance. Providing care significantly impacts carers, and can cause them to reduce their working hours, sacrifice educational opportunities, and fall behind in career advancement. Care need also can generate additional health care demand, as prolonged unmet care need can lead to agents requiring hospitalisation.

The ABM reproduces the population dynamics and economic characteristics of the UK, including gender inequalities in care provision, and is able to generate plausible patterns of care need and availability. The results also demonstrate that the interrelationship of child care and adult social care means that targeting just one or the other can lead to unexpected consequences. This suggests that reducing unmet care need most effectively may require some challenging and innovative policy-making, and in this context this kind of comprehensive modelling of the interactions of multiple varieties of care will be advantageous.

2 - An Evaluation of Funding Reform for Cerebrovascular Stroke in Ontario, Canada
Felipe Rodrigues, Salar Ghamat, Norine Foley, David Barrett, Matthew Meyer

Acute care, followed by rehabilitation, are two of the most significant stages of the Cerebrovascular stroke care pathway. In Ontario, Canada, acute care hospitals are currently funded by "quality based procedures", which is a form of fee for service tied to key performance indicators. On the other hand, rehabilitation funding is mostly based on bed occupancy, with no regard to throughput.

As such, there is empirical evidence that stroke patients experience very long wait-times for rehabilitation services and decreased health outcomes. Furthermore, there is also an increased use of costly Alternate level of care (ALC) options, such as using the acute care resources as makeshift rehabilitation.

Using a queuing game-theoretical model, we investigate the performance of the current funding and admission policies and propose new policies/contracts based on treatment intensity, cost sharing and vertical integration.

We are able to derive closed form solutions and boundary conditions for such policies. Moreover, we utilize aggregate secondary data for numerical analysis and simulation, validating the potential efficiency gains and cost savings of our proposed policies.

3 - Designing Cancer Care through Patients Experiences: A Perspective of Self-Determination Theory
Jiun-Yu Yu

Cancer patients are experiencing a number of pain points in their current journey through the cancer care continuum. In order to understand thoroughly the root causes of the pain points, multiple research methods are applied. In-depth interviews are conducted with cancer patients and medical professionals and are analyzed using Grounded Theory. In addition, text mining technique, Latent Dirichlet allocation (LDA) is employed to investigate the post and comments downloaded from a number of Facebook Group particularly for cancer patients. The integrated qualitative analysis generates unique insights about the underlying causal loop structure that creates those pain points. To fundamentally and effectively solve the problems, the theory of basic psychological needs, Self-Determination Theory, is incorporated. It has been

found that both information and psychological supports from other experienced patients play an important role. Thus the design guidelines for a new care model for cancer patients are developed accordingly.

4 - Evaluating service innovations to alleviate pressures in the management of patients with long term conditions through system dynamics modelling
Gozdem Dural-Selcuk, *Christos Vasilakis*

Developed countries are struggling with an ageing population and its effects on healthcare services. One of the reasons is that changes in population structure as well as other contributing factors such as changes in peoples' lifestyles tend to increase the number of people with long term conditions. The management of long term conditions necessitates periodical and frequent visits to a specialist, which generates additional demand for healthcare services. Partly as a result, healthcare professionals and managers have been looking into different ways of expanding capacity in innovative and more efficient manner. One such service innovation is the introduction of remote-review or virtual clinics, primarily for those patients with long term conditions who are deemed to be stable or low risk. The idea is to increase capacity for outpatient appointments while avoiding the high costs associated with setting up and running a full consultant led clinic. There are plenty of empirical studies in the literature addressing different aspects of virtual clinics: e.g. the false negative/positive rates for patient risk group classification, the patient experience during and after implementation, their use in different diseases and conditions, etc. There are fewer examples in the literature that consider the problem from an operations research/systems modelling perspective. The modelling is not trivial given the need to capture the relevant population dynamics including notions of disease progression in the patients. In this paper we describe a system dynamics model that is designed to evaluate the likely impact of the implementation of virtual clinics under changing population dynamics and dynamic disease progression of the patients.

Tuesday, 12:00-14:00

■ TB-01

Tuesday, 12:00-14:00 - 1

Emergency Care Planning II

Stream: Tuesday
Invited session
Chair: *Melanie Reuter-Oppermann*

1 - Designing an Emergency Navigator for Assigning Emergency Patients to Hospitals
Melanie Reuter-Oppermann, *Clemens Wolff*

Emergency services in countries such as Germany are defined by a complex service network and a multitude of planning problems and necessary decisions. In case of an emergency, emergency medical service (EMS) providers send an ambulance to the patient, perform first treatment and then transport most patients to a hospital. Due to the comparably high number of hospitals in Germany, often more than one hospital is available. Therefore, an EMS provider must decide to which hospital, more specifically, to which emergency department (ED), the patient is taken, without knowing the current workload of the EDs. Applying the Design Science Research paradigm, we propose a concept for a decision support system (DSS) called the "Emergency Navigator" that connects the EMS provider with the EDs and allows for an informed decision making that not only considers the patient's, but also the EMS provider's and the EDs' objectives. Therefore, by applying system thinking, the decision support system enables customer-centric care. A first prototype of the system in form of a mock-up was developed and evaluated with emergency service providers who would be the main users of the system. For the DSS, the applicability of a discrete-event simulation of the ED as well as of machine learning models for predicting the treatment time for an individual patient are investigated. A research outline for fully designing and developing the system is presented. The idea of the "Emergency Navigator" was developed at a series of healthcare hackathons together with practitioners from related fields.

2 - Triage algorithms for mass casualty incidents: Comparison, analysis and new systems.
Christina Bartenschlager

Traffic accidents, terrorist attacks or natural disasters regularly lead to mass casualty incidents (MCI), which significantly exceed the supply capacities of the rescue service. In order to ensure the survival of as many patients as possible, it is particularly important to classify the injured persons according to urgency of treatment. Various algorithms are available for this triage. The systems suggest a sequence of defined processes (e.g. checking vital signs), at the end of which each patient is assigned a category. The aim of the work is to present and analyze different algorithms, compare them based on a simulation and suggest new triage systems based on our results.

3 - When to Switch? Index Policies for Resource Scheduling in Emergency Response
Dong Li, *Li Ding*, *Stephen Connor*

We consider the scheduling of limited resources to a large number of jobs (e.g., medical treatment) with uncertain lifetimes and service times, in the aftermath of a mass casualty incident. Jobs are subject to triage at time zero, and placed into a number of classes. Our goal is to maximise the expected number of job completions. We propose an effective yet simple index policy based on Whittle's restless bandits approach. The problem concerned features a finite and uncertain time horizon that is dependent upon the service policy, which also determines the decision epochs. Moreover, the number of job classes still competing for service diminishes over time. To the best of our knowledge, this is the first application of Whittle's index policies to such problems. Two versions of Lagrangian relaxation are proposed in order

to decompose the problem. The first is a direct extension of the standard Whittle's restless bandits approach, while in the second the total number of job classes still competing for service is taken into account; the latter is shown to generalise the former. We prove the indexability of all job classes in the Markovian case, and develop closed-form indices. Extensive numerical experiments show that the second proposal outperforms the first one (that fails to capture the dynamics in the number of surviving job classes, or bandits) and produces more robust and consistent results as compared to alternative heuristics suggested from the literature, even in non-Markovian settings.

4 - Fairness in ambulance routing for post disaster management
Sara Bigharaz, *Roberto Aringhieri*

Although many researches concerning humanitarian relief services highlight the importance of demand satisfaction and equity, the few articles focus on fairness as an objective in disaster optimization problems. The concept of fairness has been varied in definition according to the context of problems. Regarding relief operations, fairness can be defined as equity and impartiality in service level for people who are in need. In humanitarian relief operations one of the major concern is transportation of patients by ambulances. Efficient post disaster management strongly are entwined with decrease in possibility of death and human suffering. When a disaster occurs initial data about the damages and injuries is collected without delay. The dispatcher classifies patients' requests according to their severity and locations. According to [1], two groups of patients based on triage system can be considered in affected area. Different types of ambulances staffed by medical crew are dispatched to affected areas immediately in order to treat wounded people and transport patients to hospitals as needed. We present a realistic problem statement and a new formulation based on the depicted by the team orienteering framework: given a set of requested services the class of orienteering problems seeks routing solutions with respect to a given time threshold maximizing the scores of the collected services. We consider different approaches to include the concept of fairness in the model in accordance with [2]. Preliminary computational results and insights are also reported. [1] L. Talarico et. al., Ambulance routing for disaster response with patient groups, C&OR 2015 [2] G. Nicosia et al., Price of Fairness for allocating a bounded resource. EJOR, 2016

■ TB-02

Tuesday, 12:00-14:00 - 2

Health Care Appointment Planning I

Stream: Tuesday
Invited session
Chair: *Jens Brunner*

1 - Empirical Analysis of the Impact of Operational Factors On Clinical Decision Making in a Chronic Care Clinic
Zehra Önen Dumlu, *Evrim Didem Gunes*, *Raj Sengupta*, *Tolga Tezcan*

The rising number of patients with chronic conditions brings an imperative to find ways to improve efficiency of chronic care without compromising quality. In this research, we investigate how non-clinical operational factors affect clinical decisions of health professionals using 61,335 patient visit data from a rheumatology outpatient clinic. At each appointment, the clinician gives the decision of either to discharge the patient from care or to recommend a follow up appointment to be scheduled. Patients who are discharged may then ask for an appointment and reattend with similar complaints, if needed. We analyse the effect of three important factors namely workload, continuity of care and patient waitlist size on these decisions. Using econometric models, we show that increasing workload decreases probability of discharge. By contrast, patient waitlist size and continuity of care increase probability of discharge. On the other hand, higher patient list size at time of discharge increases reattendance probability while continuity of care decreases it. We discuss managerial implications of our results and give suggestions supported by counterfactual analysis on outpatient scheduling policy to show how to improve delivery of care in a chronic care clinic with the possible impact of these suggestions.

2 - Chemotherapy planning and clinicians rostering in an outpatient cancer centre
Elena Tanfani, *Giuliana Carello*, *Paolo Landa*, *Angela Testi*

In the past years, the number of patients needing chemotherapy treatments has been constantly increasing and the chemotherapy treatments must be carefully planned so as to provide suitable and timely cure. Chemotherapy treatments are often provided within a day hospital setting, where clinicians and nurses staff must face the increasing demand for treatment, with limited resources, such as outpatients rooms, beds and seats for the chemotherapy infusion.

In this work we focus on the oncologist visit each patient must undergo before treatment to check if his/her conditions can bear the drug infusion. We consider the problem of planning the weekly assignment of outpatient rooms and time slots to the pathologies in a cancer center where the area dedicated to treatment is shared among different oncologist specialties, as suggested by the Organisation of European Cancer Institutes. The problem asks to decide when and where each pathology is treated: the week is divided into time slots and a pathology must be assigned, in each time slot, to each of the outpatient rooms. Further, the clinicians' availability on a monthly basis is given and we must select a clinician with suitable skills to cover each time slot assigned to a pathology along the weekly schedule.

We formulated the problem as an ILP model and we considered different objectives, such as the amount of satisfied demand and clinicians workload balance.

We applied the models to real data from an Italian hospital and we analysed the resulting solutions, in terms of scalability and maximum handled demands.

3 - Minimizing Tardy Appointments in Physiotherapy Under Consideration of Continuity of Care and Therapist Preferences
Jens Brunner, *Sebastian Kling*, *Sebastian Kraul*

Physical therapy in hospitals plays an important role for the rehabilitation of patients. Similar to nursing, the profession often has to deal with staff shortages due to lack of potential employees and absenteeism caused by high physical and mental workload. The therapist shortage negatively affects the number of appointments, which can take place each day. Furthermore, continuity of care with the same therapist, highly important for the quality of care as well as an influencing factor on employee stress, cannot be guaranteed for individual patients. This presentation shows a multi- criteria optimization model for the daily therapy appointment-scheduling problem. We minimize the number of unfulfilled appointments weighted by patient priority. In order to improve patient rehabilitation, we also penalize missing continuity of care and consider employee preference violations for therapy tasks. We present preliminary results using real-world data of our cooperation hospital.

■ TB-03

Tuesday, 12:00-14:00 - 3

Operating Room Planning

Stream: Tuesday
Invited session
Chair: *Erik Demeulemeester*

1 - Designing master surgery schedules with downstream unit integration via stochastic optimization
Daniel Santos, Inês Marques

Surgical activity has a substantial impact in hospitals, generating most of their funding, comprising most of their costs and directly influencing all other areas of the hospital. Additionally, social concerns arise, namely related to equity and speed of access, especially given that demand for health care continues to increase and resources are scarce. Improving the efficiency and quality of operating room management is therefore paramount in the modern society.

This work studies the (cyclic) master surgery scheduling problem which assigns surgical specialties to operating room blocks (i.e., a shift of an operating room). For a master surgery schedule to be applicable in practice, multiple considerations must be taken into account. The most common bottlenecks to the construction of a master surgery schedule are the available human resources, namely surgeons, anesthetists and nurses, and non-human resources, particularly beds. The focus of this work is in the integration of downstream units, i.e., beds. Overutilization of beds originates canceled surgeries. Conversely, underutilization of beds leads to a waste of hospital capacity. For this reason, it is important that the master surgery schedule is such that it produces an overall leveled utilization of beds. Although in a tactical planning scenario, operational bed requirements are unknown, these may be estimated based on historical data.

We propose a stochastic optimization model that captures uncertainty in bed requirements, with a recourse function that reduces the overutilization of beds. A solution approach based on Benders decomposition is developed and results for instances based on real-life data are presented.

2 - Operating room planning and scheduling for outpatients and inpatients under uncertainty: A literature review and a simulation study
Lien Wang, Erik Demeulemeester, Vansteenkiste Nancy, Rademakers Frank

In hospitals, the efficient planning of the operating rooms (ORs) is difficult due to the uncertainty inherent to surgical services. This paper aims to analyze the similarities and differences between the outpatient surgery scheduling and the inpatient surgery scheduling in order to provide valuable insights for an efficient scheduling of the inpatient OR department. First, we review the literature from three perspectives, i.e., the uncertainty, the strategies and methodologies, and a performance comparison between the two scheduling settings. Based on this review, we propose that a promising practice to schedule inpatient surgeries consists of partitioning inpatient surgeries into two homogeneous groups, namely one group with more predictable surgeries (MPS) and another one with less predictable surgeries (LPS). Next, we suggest how to partition, and discuss whether to pool OR capacity and patients or not. Finally, through an extended simulation study that quantifies the trade-off between pooling and partitioning regarding various performance measures (PMs), we report a number of findings and insights. First, when contemplating the partitioning of ORs and surgeries, the surgery duration uncertainty should be considered as it substantially affects most PMs. Second, the partitioning policy tends to be harmful for the OR-related and the non-elective patient-related PMs, while it might improve the elective patient-related PMs if an additional overflow is allowed. Specifically, the partitioning policy increases the difference in the PMs between both groups. Furthermore, these results are robust to hospital and patient attributes, but the magnitude of the impact brought by the partitioning policy depends on some of these attributes.

3 - Stochastic Scheduling of Operating Rooms And Reusable Medical Devices Under Dynamic Rescheduling
Enis Kayis, Elvin Coban, Seyyed Kian Farajkhah

Health care expenditures are expected to grow every year, and more than 40% of a hospital's total expenses and revenues are generated by surgical operations. One of the major resources required during surgeries is reusable medical devices (RMDs). RMDs are surgical instruments used during surgeries which have to be reprocessed by thorough cleaning followed by sterilization after each use. RMDs have to be planned with operating rooms (ORs) concurrently since insufficient RMDs may cause delays in operation starting times. However, the management of RMD sterilization stage is nontrivial. First, RMDs are sent to sterilization service at different times due to different finishing times of surgeries during a day. Second, the decision of how to load the sterilization machines, i.e., how to batch RMDs, is a complicated one. Lastly, time spent during sterilization has to be considered during the scheduling of ORs since a surgery cannot start without the required number of RMDs. In this paper, we study the integrated scheduling of ORs and sterilization of RMDs under stochastic surgery durations with the possibility of dynamic rescheduling, if needed, during the day. We propose a simulation-optimization approach to tackle this problem, quantify the value of incorporating uncertainty and dynamic rescheduling and create managerial insights for the OR managers.

4 - A mathematical programming framework to manage extended operating room hours
Mariana Oliveira, Valérie Bélanger, Angel Ruiz, Daniel Santos, Inês Marques

One of the strategic objectives of the Portuguese National Health Plan is to provide an adequate, equitable and timely access to health services. A maximum guaranteed response time, according to a clinical priority, is assigned to each surgical patient. Passed that time, a voucher is issued for the patient to receive surgery in any other (public or private) hospital. Besides not being reimbursed for the surgery, the hospital of origin must pay an additional fee. Thus, to avoid this double jeopardy, every hospital intends to maximize the number of surgeries that are performed in due time. Frequently, hospitals need to rely on a different strategy to increase surgical capacity. To face the high surgical demand and low capacity resources, an additional production program was created in Portugal in 2004 to complement normal production. Two surgical production types are simultaneously performed in the hospitals: normal production uses regular operating room time and is part of the salary of staff; additional production uses operating room and staff's extra time and is paid under a fee-for-service system. Additional production is often imperative to avoid surgery vouchers emission and guarantee economic stability of the hospitals. However, surgical staff is not obliged to perform additional production. Based in a collaboration with a public Portuguese hospital, this work combines two different financing systems (salary and fee-for-service) for surgery activity and develops a mathematical model to schedule patients for additional production. Moreover, a framework on normal and additional production is proposed to assess the results obtained with the model. The ultimate goal is to avoid surgical vouchers emission and balance effort towards normal and additional production.

Tuesday, 15:00-16:00

■ TC-01

Tuesday, 15:00-16:00 - 1

Keynote Greg Zaric

Stream: Tuesday
Invited session
Chair: *Marion Rauner*

1 - Incentives and Coordination in Healthcare
Greg Zaric

The healthcare system involves the actions and decisions of multiple parties, including patients, doctors, hospitals, payers, and regulators. The different parties may have different information and different objectives, resulting in decisions that are sub-optimal from the perspective of the entire system. In this talk I present several examples of research on contracts to coordinate the actions of independent decision makers in health care. In particular, I will discuss principal-agent models of pharmaceutical risk sharing contracts and hospital gain-sharing agreements; and empirical studies of the impact of incentive payments to physicians.

Tuesday, 16:30-18:00

■ TD-01

Tuesday, 16:30-18:00 - 1

Round Table on Prevention

Stream: Tuesday
Invited session
Chair: *Bernhard Schwarz*

1 - Round Table on Challenges in Health Care Prevention
Sally Brailsford, Margaret L. Brandeau, Alexandra Schosser, Bernhard Schwarz

International experts from practice and research discuss current and challenging issues of health care preventions strategies from Austria, Great Britain, and United States of America.

Tuesday, 18:30-19:00

■ TE-01

Tuesday, 18:30-19:00 - 1

e-Tour Sky Lounge

Stream: Tuesday
Invited session
Chair: *Marion Rauner*
Chair: *Nurcan Cakan*

Wednesday, 13:30-15:30

■ WA-01

Wednesday, 13:30-15:30 - 1

Poster Session

Stream: Wednesday
Invited session
Chair: *Roberto Aringhieri*
Chair: *Inês Marques*
Chair: *Sally Brailsford*
Chair: *Michael Carter*

1 - Application of forecasting techniques to predict the volume of EMS calls
Paulo Abreu, Ana Paula Barbosa-Póvoa, Inês Marques

Emergency medical services (EMS) are present in most cities around the world. Attention for such services is increasing, as demand is also growing due to the aging population, population growth and contemporary problems such as alcohol abuse, which can lead to potential emergencies, for instance, car accidents. Tighter budgets, demand coverage, and population equity are the usual aspects that lead to the efficient use of resources, since there is no place for mistakes or inefficiency because human lives depend on it. The efficiency of these operations is critical and demand forecasts can contribute to such goal as reliable forecasts are important inputs for EMS planners to better allocate scarce resources. Hence, attention is needed due to fluctuations throughout the month, week, day and hour of each day. The aim of this work is to forecast the volume of EMS calls. Time series models proposed in the literature are compared with a new radial basis function (RBF) network in a dataset of the Portuguese EMS provider. As far as we are aware, despite previous applications of artificial neural networks to forecast the volume of EMS calls (e.g. multilayer feedforward neural network with backpropagation learning in Charlotte-Mecklenburg, North Carolina), this is the first attempt to apply a RBF approach to generate EMS call volume predictions.

2 - Variability in hospital treatment costs: A time-driven activity-based costing approach for early stage invasive breast cancer patients
Erin Roman

Objectives: Using generic treatment pathways for breast cancer, and molecular subtype perspective, we aim to measure the impact of several patient and disease characteristics on the overall treatment cost for patients. Additionally, we aim to generate insights into the drivers of cost variability within one medical domain. Design, setting and participants: We conducted a retrospective study at a breast clinic in Belgium. We utilized time-driven activity-based costing to measure costs within the hospital and used 15 anonymous patient files to conduct our analysis. Results: Significant cost variations within each molecular subtype and across molecular subtypes were found. Luminal A had a cost differential of 166%, with the greatest treatment cost amounting to $29,780 relative to $11,208 for patients. The main driver of cost variations related to disease characteristics. Luminal B classification was impacted by both patient and disease characteristics resulting in a cost differential of 242%. Triple negative patients treatment costs amounted to $26,923, this sub-group is considered more aggressive in nature, thus costs are driven by disease characteristics. Given the inclusion of Herceptin, the HER2-enriched subtype is impacted by disease characteristics. Conclusion: Given the cost crisis in health care, the need for greater cost transparency has become imperative. We generate initial insights into the drivers of cost variability for breast cancer. We found evidence that disease characteristics such as severity and more aggressive cancer forms have a significant impact on treatment cost across the different subtypes. Similarly, patient factors such as age and presence of gene mutation contribute to differences in treatment cost variability within molecular subtypes.

3 - Multi-site Pathology Service Optimisation
Daniel Gartner, Daniel Tolley, Trish Chalk

Transportation services in healthcare are under intense pressure to meet specific target transit times. This is especially the case when considering specimen transportation from Primary and Secondary Health Care locations to specimen testing laboratories, as well as inter-hospital specimen transportation. This paper explores the use of mathematical modelling for specimen transportation in a multi-hospital, multi-clinic and multi-pathology laboratory setting in the U.K. We formulate the model as a vehicle routing problem and show that a far more efficient transport setting can be produced as compared to current transport services. We propose a new configuration of van routes using meta-heuristic optimisation and geographical modelling. Our results reveal that a fleet of vehicles can be reduced by two vans while, at the same time, reducing average specimen transit time. Our results will be used to inform a new service model around the opening of a new critical care centre hospital site.

4 - Patient adherence in healthcare problems: A systematic literature review of OR/MS approach
Hakan Kılıç, Evrim Didem Gunes

Patient non-adherence is a major obstacle to desired health outcomes. This study presents a systematic literature review of studies that apply Operations Management/Management Science (OR/MS) methods, excluding statistics, for tackling healthcare decision-making problems involving patient adherence. PubMed, Scopus and Web of Science databases were searched with the following keywords until May 2020: OR/MS methodology, patient adherence terms and healthcare operations management problems. The literature is then classified to report what is the healthcare problem setting, what is the objective, what type of patient adherence is considered, how patient adherence is incorporated and which OR/MS modelling technique is used.

5 - Multi-site and multi-service modelling for elderly and frail patients
Elizabeth Williams, Paul Harper, Daniel Gartner

Baby boomers born in and around the 1950's are now beginning to turn 70 years old, causing a rising elderly population within the UK. With 50% of elderly (over 65) patients having some degree of frailty, their care requires attention and careful planning. Frailty often results in patients being admitted into hospital, with difficulties being discharged due to ill health or unsuitable care residences, becoming very consuming of time and resources, even if they are medically fit to be discharged. Within our research, a systematic literature review has been conducted, analysing papers from 2000 to 2020 (March) from five Thomson-Reuters Journal Citation Report categories, specifically focusing on those primarily using healthcare and operational research (OR) methods. The search criteria was used to collate papers focusing on care pathways for the frail and elderly. Initial results from the original, forward and backward search produced over 900 publications, however further analysis reduced this result to 46 papers of relevance. Research within this field has been increasing over the last 20 years, with 40% of papers having been published since 2016. The main OR method discussed tends to be variations on Markov modelling, i.e. Coxian-phase type distributions. Our preliminary analysis reveals that most studies consider the complex challenge of demand forecasting, with two papers aiming to improve patient care. The body of literature does not model the pathway in a holistic way and tends to focus on a specific department or ailment. The research also highlights the need for more work in combining patient flow modelling with patient outcomes. The research leaves scope to develop a tool which will analyse the elderly and frail pathway among both hospital and community care.

6 - Reducing Waiting Time for MRI Services Using Discrete Event Simulation
Sara Ketabi, Michael Carter

There is an increasing demand for MRI imaging everywhere due to many reasons including MRI advantages over other imaging modalities. This high demand has resulted in system inefficiencies such as increased patient wait times. Interventions ranging from changing the process flow to adding additional servers could improve the process with different costs but unknown impacts. The medical imaging department of Sunnybrook Health Sciences Centre has an MRI division

with three machines available. Patients are scheduled in 55-minute slots during normal hours. The aim of this study was to investigate reducing the average in/out-patient waiting time while keeping the average emergency wait time and average resource utilization within acceptable intervals. A Discrete Event Simulation model was created based on the data for patient arrivals and service times for two months, October and November 2019. Several scenarios were tested to see whether they could improve the performance measure of the system. Using simulation optimization, the best scenarios among the proposed ones, which was changing the strategy of MRI machine allocations to different patient types, were chosen.

7 - Developing and Benchmarking a Scatter Search for Markov Blanket Attribute Selection and Classification for Healthcare Data Sets
John Threlfall

In healthcare, datasets with many discrete variables and relatively few observations are generated every day. Learning which variables are re-levant and non-redundant effectively and efficiently is a challenge. Moreover, achieving high accuracies for making predictions is difficult. In this paper, we develop a novel Scatter Search improvement heuristic to efficiently learn which variables are relevant and non-redundant in a probabilistic graphical model. Our algorithm learns a graphical Markov Blanket-based classifier from data which can be used to predict, for example, whether a patient has a specific diagnosis or not. We combine our algorithm with a construction heuristic and evaluate it on different performance metrics and level of detail based on benchmark data sets. Computational results reveal that the our algorithm leads to competitive classification results. Another observation is that the graphical models learned from the data can be inferred within less than 5 minutes time. Furthermore, some models have substantially less predictor variables as compared to the variables in the full data set. In conclusion, our algorithm can be used in practice to classify patients effectively and efficiently.

8 - Hybrid modelling of spread of anxiety due to virus infection
Leonidas Sakalauskas

The study aims to develop a hybrid model of pandemic anxiety and panic dynamics, calibrated through indirect social anxiety and emotion level indicators, and apply it to the analysis, forecasting and management of anxiety and related panic scenarios. The developed model combines agent modeling, dynamic systems modeling with differential equations and machine learning methods. The spread of anxiety and panic associated with fear of contracting a viral disease is a characteristic feature of pandemics (Blakey & Abramovitz, 2017). From the point of view of cognitive anxiety theory (Clark and Beck, 2010), an important part of the anxiety mechanism is the stimuli that trigger it, which become negative information that spreads in the social space. Because direct investigation of the prevalence and spread of anxiety and related panic is a complex task, coronavirus morbidity data and indirect anxiety indicator data will be used to calibrate and verify the developed model, which will be processed by machine learning algorithms. One of the possible reflections of public anxiety is the web content The sentiment analysis will identify and extract subjective information about anxiety and emotional level from the web media content.In this way, the application of machine learning methods would help to identify additional variables and their properties in the development of a hybrid model.

Wednesday, 16:00-18:00

■ WB-01

Wednesday, 16:00-18:00 - 1

Covid-19 Policy Modelling

Stream: Wednesday
Invited session
Chair: *Alexander Rutherford*

1 - Discrete Event Simulation Model to support decision-making concerning COVID-19 patients' admissions in hospitals and Intensive Care Units
Daniel García de Vicuña, Laida Esparza Artanga, Fermin Mallor

The disease COVID-19 presents an important threat to global health. This outbreak leads to an important increase in the demand for hospital beds, especially the Intensive Care Unit (ICU) beds, which involve highly specialized personnel and expensive technical sanitary material. An efficient prognosis of the necessary resources is needed to provide the best possible care to patients to report to public health authorities. The accuracy of the predictions allows preparing the response and helping to save lives. This paper reports the construction of a simulation model used to support the decision-making concerned with the short-term planning of the necessary hospital beds to face the COVID-19 in the Spanish Autonomous Community of Navarre. The simulation model focusses on estimating the health system's transitory state. It reproduces the outbreak dynamics by using the Gompertz growth model and the patient flow through the hospital, including the possible admission in the ICU. The output of the simulator estimates the number of the necessary ward and ICU beds to provide healthcare to all patients in the region for the next days. The simulation model uses expert opinions at the first stages of the outbreak, but as more data are collected the necessary parameters are fitted by statistical analysis or combining both. Every day, the research team informed the regional logistic team in charge of planning the health resources. Based on these predictions the authorities plan the necessary resources. Furthermore, the structural simplicity of the simulation model makes it appropriate for general use, i.e., it can be adapted to estimate the bed needs in any geographic area. The model was adapted to be used in other Spanish regions.

2 - A Queue Network Model of Ventilator Access during the COVID-19 Epidemic
Alexander Rutherford, Samantha Zimmerman, Peter Dodek, Monica Norena, Alexa van der Waall

The COVID-19 pandemic has placed considerable strain on healthcare systems in many countries, and particularly on intensive care units. Approximately 60% of COVID-19 patients admitted to intensive care units require mechanical ventilation within 24 hours. Although many hospitals have the ability to expand intensive care capacity to meet surge demand, mechanical ventilators are a more constrained resource. Planning for access to mechanical ventilators was of key concern for providing sufficient care during the peak of the epidemic. We developed a two-stage queue network model to support planning requirements for access to mechanical ventilators by both COVID-19 and non-COVID-19 patients in British Columbia, Canada. The first stage models stochastically the delay from onset of COVID-19 symptoms to respiratory failure and need for mechanical ventilation. The second stage is a time-dependent M/G/c/c Erlang loss model of the pool of mechanical ventilators. Input was provided by COVID-19 case projections from epidemiological modelling by the BC Centre for Disease Control. Our model produced time series projections of the number of ventilators required by health authorities in British Columbia under a range of social distancing assumptions and scenarios for reductions in elective surgeries. Analysis using our model during the initial stages of the epidemic forecasted that without social distancing the number of COVID-19 patients requiring mechanical ventilation would likely

have exceeded the number of available ventilators. Our modelling projected that public health measures such as social distancing, reductions in the number of elective surgeries, and purchasing additional ventilators would ensure that there would be sufficient ventilator capacity during the epidemic.

3 - Optimising the daily swab test collection to identify new cases of Covid-19

Davide Duma, *Roberto Aringhieri*, *Sara Bigharaz*, *Alessandro Druetto*, *Andrea Grosso*

The explosion of the new Coronavirus (Covid-19) pandemic has suddenly challenged our economics and health care systems, placing us in front of new management issues. One of these is the daily swab test collection (DSTC) problem, which plays a crucial role in identifying infected individuals to contrast the spread of the virus.

The DSTC consists in organizing the daily collection of swab tests reaching the house of the contact(s) of a positive case detected the day(s) before through a digital contact tracing system [1]. A set of medical teams are in charge of collecting the swab tests. In a pandemic scenario the number of test could be larger than the daily capacity of all teams in terms of working time. Further, they could have different priorities due to the proximity and the duration of the contact with the positive case(s).

This problem could be modelled as a variant of the Team Orienteering Problem (TOP) [2], that is a routing problem on a graph with durations (travelling times) associated to the arcs and profits (patient priorities) assigned to visiting the vertices. We propose an integer linear programming model for the DSTC problem, providing a quantitative analysis based on realistic instances generated for the city of Turin, Italy.

[1] Ferretti, L., Wymant, C., Kendall, M., Zhao, L., Nurtay, A., Abeler-Dörner, L., Parker, M., Bonsall, D., & Fraser, C. (2020). Quantifying sars-cov-2 transmission suggests epidemic control with digital contact tracing. Science.

[2] Gunawan, A., Lau, H. C., & Vansteenwegen, P. (2016). Orienteering problem: A survey of recent variants, solution approaches and applications. European Journal of Operational Research.

Wednesday, 18:30-19:00

■ WC-01

Wednesday, 18:30-19:00 - 1

e-Tour Schönbrunn

Stream: Wednesday
Invited session
Chair: *Marion Rauner*
Chair: *Nurcan Cakan*

Thursday, 9:30-11:30

■ HA-01

Thursday, 9:30-11:30 - 1

Behavioral OR & Policies in Health Care

Stream: Thursday
Invited session
Chair: *Sally Brailsford*

1 - Designing Delphi knowledge construction processes to enable OR behavioural research and extend stakeholders' analyses in health settings
Monica Oliveira, Liliana Freitas, Ana Vieira, Klára Dimitrovová, Carlos Bana e Costa

Stakeholder involvement is crucial for developing operational research tools to assist health policy- and decision-makers. The Delphi process is widely used for involving large and geographically dispersed groups, with its recent use for collaborative value modelling being enhanced by new web platforms that allow for collecting vast amounts of data. However, as humans, stakeholders' interaction within Delphi may be influenced by their characteristics and advice-taking attitude, and by selected features of the Delphi design. Such aspects are critical for interpreting and using the information generated. In this study we design novel features for collaborative value modelling Web-Delphi processes to enable behavioural research and group analyses. Namely, we build an experimental design to explore if health stakeholders' willingness to take advice is influenced by their knowledge about the stakeholder group who gives the advice, with social network analysis used to draw the stakeholders' advice network; we propose various Delphi designs entailing homogeneous and heterogeneous panels suitable for distinct contexts; and we suggest metrics to understand group influences. We show results from testing distinct Delphi designs and performing behavioural research in the context of collecting stakeholders' views to inform the evaluation of medicines and medical devices, within the scope of the H2020 IMPACT HTA and FCT MEDI-VALUE research projects. We reflect about the need and scope to develop new approaches and experimental research in the area enabled by new technologies.

2 - Using a hybrid system dynamics and agent-based simulation to evaluate the External Reference Pricing regulation effect on access, affordability and availability
R Kazakov, Susan Howick, Alec Morton

External reference pricing (ERP) regulation and its effect on drug access, affordability and availability in the EU has only previously been explored by dynamic simulation methods through a single study using a discrete event simulation approach. However, this study paid limited attention to the adaptive behaviour of market actors. The authors have developed a hybrid agent based and system dynamics simulation model to explore the aforementioned effects of the ERP regulation including its impact on agents' decision making. Key to the simulation modelling approach is the conceptualization of the pharmaceutical market as an anticipatory adaptive socio-economic system. The system involves agents' heuristic rules and forward-looking behaviour, competing for control over limited internal and external resources in an imperfect regulatory and competitive environment. The development of the hybrid simulation model was supported by the use of Resource Agent Maps, a novel qualitative modelling technique designed to analyse the interactive behaviour of agents and resources in a complex adaptive systems environment. The Resource Agent Maps provided a theoretically sound and methodologically robust procedure for the hybridization of the both simulations, and helped to support confidence in the simulation model building process.

3 - Should I stay or should I go? Understanding no-show behaviour among low-income patients in Bogotá, Colombia
David Barrera Ferro, Sally Brailsford, Honora Smith, Steffen Bayer

In Colombia, cervical cancer is the first cause of cancer mortality among women between 30 and 59 years old. Despite having reached healthcare universal coverage and implemented a free screening program, low-income patients show low adherence levels and high incidence rates. In this context, the District Secretary of Health designed an outreach program to increase early diagnosis. A group of community workers visit patients at their homes and schedule a screening appointment at the nearest healthcare facility. However, over the last three years, no-show rates for these appointments have reached levels of 35%.

In previous work we have used machine learning techniques to predict individual no-show probabilities. In this paper, we explore the use of the Health Belief Model (HBM) to understand the reasons for no-show behaviour among low-income patients. Using data collected through a survey, our analysis of their perceptions of susceptibility, severity, benefits and barriers - the four key constructs of the HBM - informs a simulation model designed to improve the impact of the outreach program.

■ HA-02

Thursday, 9:30-11:30 - 2

Emergency Care Planning III

Stream: Thursday
Invited session
Chair: *Roberto Aringhieri*

1 - Analysing the impact of workload-based patient to physician assignment on emergency department performance by use of discrete-event simulation
Lien Vanbrabant, Kris Braekers, Katrien Ramaekers

Emergency departments (EDs) worldwide are confronted with crowding. In order to overcome the negative consequences of crowding, hospital managers are constantly looking for opportunities to improve ED performance. Because of the strict healthcare budgets, the main focus is on improving operational efficiency while preserving a high quality of care. One of the main bottlenecks in an ED are physicians. Physicians are confronted with a high and imbalanced workload, which may negatively impact ED performance through, e.g., a lower quality of care, reduced physician productivity, high stress levels among physicians, high waiting and treatment times, etc. Firstly, physicians are confronted with a (too) high workload caused by excessive multitasking. Because they are a costly resource, multiple patients are assigned to the same physician simultaneously, as multitasking has the advantage to reduce unproductive idle time. However, cognitive limitations of physicians, and patient switching costs, cause productivity losses if the number of patients assigned to a physician increases. Secondly, most EDs use a rotational patient assignment rule to assign patients to physicians. As workload is patient- and physician-dependent, an equal distribution of the number of patients among physicians can imply an imbalance in workload. Therefore, an interesting opportunity to improve ED performance entails the revision of the patient-physician assignment process by (1) taking the workload of a patient into account when assigning patients to physicians, and (2) placing a limit on the workload per physician. This way, ED performance can be improved in terms of door-to-doctor time and length-of-stay through simultaneously reducing the level of multitasking and balancing workload among physicians.

2 - Minimizing travel time in a neonatal care network by reassigning general hospitals to Neonatal Intensive Care Units
Robin Buter, Gréanne Leeftink, Erwin W. Hans, Maarten Blanken, Willem de Vries

Current shortage of qualified nurses and increasing healthcare costs force many healthcare organizations to review the organization of their processes. Neonatal Intensive Care Units (NICUs) are responsible for providing care for critically ill newborns. A NICU bed is a scarce and expensive resource, but required for survival for these newborns. In the Netherlands, NICU staff spends much time on transporting newborns in their catchment area, but also on transporting newborns to other NICUs if at full capacity. The organization of Neonatal Intensive Care (NIC) has evolved over time, and the question has now arisen if the current assignment of general hospitals to NICUs is optimal regarding travel time and available local capacity. In this paper we analyze how transfers within a network are affected by the allocation of demand to single queues. In this network there are no waiting rooms, so rejected arrivals must be served by another queue in the network. Only when the network is fully occupied, will new arrivals leave unserved. An exact Markov Chain based algorithm is formulated that could be used for smaller networks with limited state space. For larger networks however, a Discrete Event Simulation model is used. Improvements to the current assignment are found using a local search heuristic. Results from our case study show that time spent on transferring patients could be reduced by up to 25%, while also decreasing the number of transports by approximately 15%.

3 - A Review on Initiatives for Management of Daily Emergencies Prior to Arrival of Emergency Medical Services
Niki Matinrad, Melanie Reuter-Oppermann

As statistics provided by organizations such as WHO show, the number of people that are killed every year by daily emergencies worldwide is more than those killed by natural disasters. Emergency services that are responsible organizations for managing these emergencies, however, face increasing cost pressure that potentially limits existing resources. In many countries, these organizations also face the issues of staff shortage and long distances to sparsely populated areas resulting in longer response times. To overcome these issues and potentially reduce consequences of daily emergencies, several countries, e.g. Sweden, Germany, and the Netherlands, have started initiatives in which new types of resources, human resources as well as equipment, are employed in response to daily (medical) emergencies. New types of human resources include volunteers and semi-professionals, and examples for new equipment are automated external defibrillator (AED) and drones. These resources are considered new not because of their identities or features, but because they have not been part of the existing emergency systems before. In these initiatives, the resources are employed in medical emergency cases if they can arrive or be used earlier than the professional emergency medical services (EMS) to potentially increase the patients' chance of survival. There is a good number of works that have studied the use of these new types of resources in medical emergency systems, from medical, technical and logistical aspects. This paper presents a review of these studies. Our objective is to give an application based and methodological overview of these papers, to provide insights to this important field and to bring it to the attention of researchers and emergency managers and administrators.

4 - A simulation-based dss for ed process management
Cristiano Fabbri, Vincenzo Bua, Enrico Malaguti, Michele Monaci, Paolo Tubertini

Overcrowding is a very common and increasing problem within an Emergency Department (ED), both at regional, national and international level in Italy. Overcrowding get to the point where the normal operation of the service is limited by the disproportion between demand and available resources. In order to solve the problem, Emilia-Romagna Region proposed the "ED access improvement plan", where different strategies to face overcrowding are suggested. Moreover, the Region established that 90% of patients treated within an ED should have a length of stay smaller than 6 hours (+1 additional hour for complex cases).

We present simulation-based decision support system applied to Bologna Maggiore Hospital ED, aimed at implementing the best strategy in order to guarantee the 6 hours constraint.

First, we introduce a machine learning algorithm which, based on patients' information (such as age, sex, clinical data, nursing diary etc...), tries to predict patients' pathways patterns within the ED In addition, we propose a model to forecast patients' arrival rate during the day.

Second, we present a simulation model that integrates the patients' pathways patterns algorithm and the patients' arrival rate. The model, based on patients within the ED and on the forecast of new arrivals, returns the most likely ED state in the next three hour.

Finally, we show how the simulation model is going to be used to automatically suggest the best strategy in order to improve the ED performance and to satisfy the 6-hour constraint.

■ HA-03

Thursday, 9:30-11:30 - 3

Health Economics I

Stream: Thursday
Invited session
Chair: *Alec Morton*

1 - Multi-objective optimization of a Colorectal Cancer Screening Programme
Lauri Neuvonen, Mary Dillon

Cancer screening can be an effective way to reduce mortality and incidence rates in a population. However, screening the whole population is often infeasible due to e.g. heavy costs and, when performed on low risk populations, screening can incur unjustified discomfort and costs for participants and society. This raises the questions "who and when to screen?".

We propose a newly developed methodology named Decision Programming to optimize a colorectal cancer screening program. Decision Programming is a novel approach to modeling discrete multi-stage decision problems under uncertainty, and allows the use of various kind of risk measures, such as conditional value at risk (CVaR), as objectives or constraints.

We optimise the faecal immunochemical test (FIT) cut-off level for specified target populations with regard to direct costs minimization and maximization of the reduction of incidence and mortality rates. The results present optimal cut-off levels for Finnish target groups with colonoscopy capacity constraints. Additionally, CVaR type risk measures are included as constraints to account for different risk profiles of Pareto-optimal decision strategies and enforce a risk level.

Finally, we present a case study modeled after the newly implemented Finnish CRC Screening Programme, and report estimated expected costs and health effects for the case study programme.

2 - Investigating a Subscription Payment Model for Antibiotic Purchasing
Euan Barlow, Alec Morton, Itamar Megiddo, Abigail Colson

Novel subscription payment schemes are one of the approaches being investigated to tackle the threat of antimicrobial resistance. One example is the scheme currently being piloted by the UK government separating overall payment of an antibiotic into a fixed lump-sum component and a component dependent on sales-volume. Intended to incentivise investment in development of new antibiotics, this scheme will enable the government to consider societal benefits when determining payments for antibiotic treatment. This payment scheme significantly increases the complexity of decision making for HTA bodies, ensuring that sufficient incentive can be provided to the pharmaceutical industry to encourage innovation, whilst managing the responsible use of the antibiotics developed, and maximising the benefits to society from investment in this innovation.

We present a mathematical model of subscription payment schemes, explicitly featuring fixed and volume-based payment components. Total welfare returned at a societal level can then be estimated (incorporating financial costs and monetised health benefits). The model can represent scenarios where decisions to allocate antibiotic treatment and subsequent measurement of treatment benefits are each driven by different value functions (for example, using individual-based and

societal-based valuations, respectively). We interrogate the mathematical model under different parameterisations of the payment scheme, to demonstrate the impact of pricing decisions on the optimality of the total societal welfare. To conclude we discuss the insights this work presents on the nature of these payment schemes, and how this can enable HTA bodies to take the first steps in determining how subscription payment schemes can be effectively structured.

3 - Prepare or react? Integrating large health shocks into life-cycle models
Michael Freiberger, *Michael Kuhn*, *Stefan Wrzaczek*

The majority of models describing life-cycle health investments assume that individuals are able to foresee the development of their health perfectly. However health shocks with significant impacts on the individual life (severe life-threatening diseases, accidents, chronic diseases) should not be averaged into a mean value, as they have the potential to put the life-course on a different trajectory. In this paper we introduce a dynamic optimal control framework incorporating a stochastic health shock with individuals allocating their resources to consumption and different kinds of health care over their life-cycle. We distinguish between general health care and shock specific prevention, acute and chronic care. This set-up enables us e.g. to analyse how the health risk shapes individual behaviour with respect to the different types of health care and how health shocks change the trajectories of consumption and savings. Newly developed transformation techniques allow us to investigate the optimal decisions made in anticipation of a potential health shock and the optimal reaction to all possible shock scenarios. We are able to obtain analytic expressions for the consumption and health investment profiles before and after the shock and identify the driving forces. Furthermore, we extend the value of life concept to other aspects of individual health. Finally we illustrate our findings by calculating a numerical solution calibrated to an individual facing a potential cancer diagnosis in the US.

Thursday, 12:00-14:00

■ HB-01

Thursday, 12:00-14:00 - 1

Strategic Health Care Modelling

Stream: Thursday
Invited session
Chair: *Anders N. Gullhav*

1 - Forecasting the bed census for surgical and internal departments
Nicky Schuermans, *Richard Boucherie*, *Aleida Braaksma*, *Paul Joustra*, *Elise Van Zandbrink*

Forecasting the bed census is of utmost importance for hospitals to optimally assign nurses to wards, especially in light of the considerable shortage of nurses in Dutch hospitals. We develop a tactical model for both surgical and internal departments that allows us to forecast the bed census three months ahead, which enables rostering of nurses to follow the predicted workload at the nursing wards. The characteristics of the flow of patients in the surgical and internal chain differ considerably. The majority of patients in the surgical chain have an elective surgery and are scheduled in operating room sessions that are scheduled three months ahead and may therefore be used as input for the bed census predictions. In contrast, the majority of patients in the internal chain do not undergo surgery, but originate from the emergency department or are admitted due to an appointment at the outpatient clinic. Our model considers the combined flow of surgical and internal patients. This research is done in collaboration with Rijnstate, a large hospital in the Netherlands, where the results are incorporated in the planning environment.

2 - Policy design for selection of alternatives and physicians'consideration choice sets
Christine Huttin

This paper continues the development of an economic model on physicians'choice sets on diabetic patients (Huttin,2017;2018;Huttin et Hausman (Ispor 2019)); it aims to discuss from a policy decision aiding perspective, the design of alternatives (Ferreti, Pluchinotta, Tsoukias,2019; Alexander, 1982) for drug choice sets in Diabetes type II. For treatments'alterantives (types of pharmacotherapies, including no treatment), the guidance of clinical guidelines is not always sufficient, facing different priority settings between professions (e.g. physicians and pharmacists'opinions on the use of oral agents in prediabetes cases). In addition, findings using recent advances of machine learning for diagnostic support in diabetic care, also demonstrate better outcomes than professions'knowledge using big datasets (Bertsimas,Interpretable AI, 2018); conventional pharmacologic recommendations are then challenged. It re-opens needs to explore ways to design or influence the selection of choice sets and discuss the reliability of alternatives; the collaboration with Prof J Hausman on the US market for diabetes will help with applications of new specification tests (Hausman, Lustig, Hahn,2017) and Prof Huttin and Hausman' mixed logit models on diabetes; the new specification tests are in development and used for reliability of results with and without Independence of Irrelevant Alternatives assumption on the data (Huttin, Lustig, Hausman, Liu, 2020); this helps the decision making process on a reliable selection of alternatives; it may provide additional guidance to algorithms used for medical and health policies.

3 - Emergency Department Layout Planning Using Simulation and Optimization
Anders N. Gullhav, *Tore Bjørseth Berdal*, *Erlend Nydal*, *Henrik Andersson*, *Bjørn Nygreen*

Several factors affect the functioning of an emergency department (ED), such as sufficient staff capacity, reasonable distribution of work, and plans to handle a variety of urgent situations. However, without a

satisfactory internal layout, various challenges, like overcrowding and long waiting times, may still exist. The internal layout have a significant influence on efficient working procedures, operational costs, reduced walking-distances for patients and staff, and improved patient flow. This work studies the Emergency Department Layout Problem (EDLP), which solution proposes a placement of the functions of the ED, such as care rooms, triage halls, and medical imaging scanners. Herein, the total area and footprint of the ED are considered known, including the placement of hallways. The quality of the solution is measured by various performance metrics, including the patients' length of stay. A simulation-optimization framework is developed to solve the EDLP. In this framework, a simulation model, which captures the dynamic and stochastic setting of the ED, evaluates layouts, and produces values on performance metrics and flows of staff and patients. Based on the output of the simulation, an optimization model creates a new and improved layout by minimizing a weighted sum of walking distances of the patients and staff. The simulation and optimization models are run iteratively until a convergence criterion is reached. The simulation-optimization framework is tested both on artificial cases and a real Norwegian hospital ED handling roughly 40,000 patients each year. The tests on the latter produce three different layouts for the ED, which, compared to today's situation, show significant improvements in the performance metrics.

■ HB-02

Thursday, 12:00-14:00 - 2

Health Care Operations Management I

Stream: Thursday
Invited session
Chair: *Christos Vasilakis*

1 - Combined master surgery and outpatient clinic scheduling
Thomas Bovim, Anita Abdullahu, Lars Hellemo, Anders N. Gullhav

Two of the most important activities that surgeons at a surgical department must perform are surgeries in the operating theatre and serving the outpatient clinic. At the outpatient clinic, the surgeons decide which patients to admit for surgery, and perform post-surgery follow-up of patients. There are three separate, but dependent, queues of patients related to the two activities. The first queue consists of patients waiting to be examined at the outpatient clinic and potentially admitted for surgery. Those patients that are admitted for surgery constitute the second queue, while the patients that need a post-surgery follow-up session join the third queue. Traditionally, the tactical master surgery schedule and the outpatient clinic schedule are planned separately, ignoring the dependency between them. By including the scheduling of both activities in a joint model, we find the optimal flows of patients. The surgeons belong to different specialties and the patients are separated into diagnostic categories. Each surgeon specialty can treat a subset of the patient categories. The operating rooms (ORs) and outpatient clinic rooms serve as a shared capacity among the specialties. The joint scheduling problem is solved as a mixed integer program (MIP). The MIP finds a tactical schedule that allocates surgeon specialties to time slots in the ORs and the outpatient clinic rooms based on the available resources and the different queue lengths. Simulation is used to evaluate the tactical schedule in a dynamic setting with uncertain patient arrivals. We present results from a case study of the orthopedic department at St. Olav's hospital in Norway. Our results indicate a potential improvement in the patient throughput when planning the joint schedule.

2 - The Prisoner's Dilemma in healthcare scheduling
Marion Penn

While examining simulation scenario data for chemotherapy scheduling, we noticed that after a point as the number of patients listed as being the most urgent patients increased, the waiting time for all patients increased. This is due to the restrictions on when urgent patients can be scheduled adding constraints to the scheduling process which result in it becoming less efficient. This talk will explore how this is an example of the Prisoner's Dilemma in healthcare scheduling and in what other circumstances the Prisoner's Dilemma may be occurring in healthcare. We will also consider what action can be taken in these circumstances to avoid the negative consequences for patients. This will include our ongoing work with the local chemotherapy team and the impact for their patients.

3 - An optimal non-uniform piecewise constant approximation of the patient arrival rate for a more efficient representation of the Emergency Department arrival process
Tommaso Giovannelli, Alberto De Santis, Stefano Lucidi, Mauro Messedaglia, Massimo Roma

All over the world Emergency Departments (ED) are afflicted by the increasing and well-studied phenomenon of overcrowding. Insufficient staff, flu season and unavailability of hospital beds are among the possible causes. As consequence, the enlargement of waiting times lead to threatening the life of critical patients. Among the tools used by ED managers to improve performance of healthcare services, Discrete Event Simulation is one of the most widely applied. In order to achieve a high reliability of the simulation model, arrival process must be accurately represented being the first step of patient flow within the ED. Indeed, Key Performance Indicators related to all the ED activities are significantly affected by the number of arrivals across the day. Moreover, since the arrival rate is time-dependent, suitable nonstationary process models must be considered, such as the non-homogeneous Poisson process. In this work we focus on this arrival process, in order to determine the best piecewise-constant approximation of the arrival rate function. Non-equally spaced intervals are used aiming at accurately representing the time-varying arrival rate. To this aim, a proper derivative-free algorithm is applied to solve the resulting integer nonlinear black-box constrained optimization problem. To prove the effectiveness of the proposed approach, data from a large Italian hospital ED are used.

■ HB-03

Thursday, 12:00-14:00 - 3

Health Economics II

Stream: Thursday
Invited session
Chair: *Margit Sommersguter-Reichmann*

1 - Changes in hospital efficiency and size in the age of city hospital investments: An integrated propensity score matching with data envelopment analysis
Songul Cinaroglu

Turkey has made massive investments in city hospitals. The distinguishing feature of these hospitals is that they are physically large. While many research efforts have investigated the efficiency of public hospitals, there is a scarcity of knowledge about the effect of classes of hospital size with respect to efficiency. This study examines changes in public hospital efficiencies by considering hospital sizes. The analysis includes three steps: First, through the use of a bootstrap data envelopment analysis (DEA), pure efficiency scores were calculated for each hospital. Second, propensity score matching (PSM) were used to ensure that any differences observed could be attributed to size classes and were not due to differences in sample characteristics between groups. To shed light on a potential time differences, efficiencies were examined for the years between 2014 and 2017. Third, the Mann Whitney-U test was employed for a robustness check of the DEA and PSM results. Fourth, logistic regression was used to examine determinants of public hospital efficiency on balanced data. The results highlight remarkable differences between before and after matching groups

in terms of the bed-occupancy rate for all the study years. Additionally, urban location is a key predictor for discriminating between efficient and inefficient hospitals. Health policy makers should consider efficiency advantages of high workload and service burden during the planning of public hospitals.

2 - Frontier efficiency studies in healthcare and quality: A review
Margit Sommersguter-Reichmann

There is broad consensus that health care providers' efficiency assessments should take into account the quality of service delivery to capture adequately any relationship between cost and quality. Given the multi-dimensional nature of quality, the ambiguous relationship between quality and cost, and the various ways in which quality can be included in the efficiency assessment, different findings may result from considering one or more quality dimensions in efficiency studies. This article systematically reviews articles, which use the frontier efficiency methods of data envelopment analysis and stochastic frontier analysis and include quality dimensions to assess the efficiency of service providers. The analysis is based on a Web of Science keywords search for articles published between 1978 and 2019 We identified 213 papers, of which 124 papers actually consider one or more quality dimen-sions to assess the efficiency of healthcare providers. Of these 124 contributions, 70% apply a DEA and 30% a SFA approach. Among the DEA studies, almost one third assumes that the quality of the service provided does not have an impact on the efficiency frontier, but on the distribution of inefficiency given the technology set. In contrast, SFA studies heavily rely on the assumption that quality indicators impact the efficiency frontier. Outcome and structural quality are frequently considered, while process quality is used less often. General statements about the association between quality and efficiency are hardly possible following the mix of different approaches, quality dimensions and dimension-specific quality indicators, so that the results seem to be valid in the respective context only.

3 - Methodology for Estimating the Private and Societal Values of Antimicrobials
Itamar Megiddo, Abigail Colson, Euan Barlow, Alec Morton

Current Health Technology Assessment (HTA) methods capture the private value and ignore the societal value associated with novel antimicrobial treatment, reducing manufacturers' incentive to invest in these technologies. As the failure of Achaogen exemplifies, pharmaceuticals that have invested in antimicrobials often struggle financially. HTA methods that ignore externalities such as the value of reducing transmission, cost of spreading antimicrobial resistance (AMR), and value of a diverse portfolio of drugs, do not provide a pull incentive to bring antimicrobials to market. Health systems considering new payment models for antimicrobials need methods to understand how much society should be will to pay.

We develop methodology to estimate the private and societal values of antimicrobials. Method inputs include information on costs of complications as well as projections of resistant cases for the possible indication scenarios. We describe our methodology through a test case that considers a novel antimicrobial to treat resistant gonorrhoea in the United Kingdom. We explore indication scenarios, scope the boundaries of externalities, and define the input variables the model requires.

HTA methods need to consider externalities associated with antimicrobial treatment to ensure society has effective treatment while also preventing overpayment and pharmaceuticals capturing the economic surplus. Our methodology can be used by HTA bodies to estimate the amount society should be willing to pay. This value will be particularly important in the next few years as countries such as the United Kingdom are testing a novel subscription payment model for antibiotics: government will pay pharmaceuticals for the right to use antibiotics instead of paying per use.

Thursday, 15:00-17:00

■ HC-01

Thursday, 15:00-17:00 - 1

Health Care Operations Management II

Stream: Thursday
Invited session
Chair: *Stefan Nickel*
Chair: *Brecht Cardoen*

1 - A board game to discuss fundamentals in operations management
Brecht Cardoen, Kris Meyers

This paper introduces a board game to let professionals, without core knowledge in the field of operations management, have a better understanding of the behavior of processes. The game discusses fundamental concepts and thoughts like process mapping, dealing with bottlenecks, identification of the critical path, lean management and the impact of variability, applied to a hospital's surgery changeover process. Therefore, the main operational learning stems from the field of both process management and project management. The game does not require participants to prepare on beforehand, nor to have a medical background although the game context describes a hospital's operating theater and the challenges the head anesthetist is facing. The game can be used as it stands or as an opening session to a broader course on operational management, taking less than 3 hours. Obviously, more time can be spent to the different concepts upon the need of the participants and aims of the instructor. The game is validated at a European triple-accredited Business School in the open program teaching portfolio (graduates with working experience), of which we share insights from participant's feedback.

2 - Bed Management - Hybrid simulation of a bed logistics flow at a Danish public hospital
Gaspard Hosteins, Allan Larsen, Dario Pacino, Christian Sørup

The population is aging; the patients' expectation for the quality of care is increasing, and, as a consequence, hospitals face a growing patient workload. Beds are an essential resource, which follows the patients, and must be adequately managed. Stock-outs could lead to severe consequences: delays, redirectionsor procedure cancellations. Therefore, reliable and robust bed management is fundamental for well-performing hospitals. Beds have their own internal flow. The whole bed cycle has two parts: in use with the patient and after usage, without, including cleaning, transport, and storage. Beds navigate with the patients through all the departments of the hospital and their specific and independent processes. The patients constitute a highly uncertain demand, as their number and characteristics (length of stay or pathology) make forecasting, planning, and execution more difficult. Bed management involves several disciplines and methods from Management Science. We conducted a literature review that highlights the cross-departmental aspects of bed management and the potential for holistic approaches. With the digital technologies, the quantity of hospital data has skyrocketed, giving the opportunity to devise new data-driven decision-support tools. In that optic, we work jointly with Rigshospitalet, a public hospital in Denmark, using their data in a bed management case study to build a simulation model that can help better understand, optimize, beds and patients flows. This model takes into account the entire bed flow of the hospital, which allows operating on the entire bed cycle and bed fleet and evaluate new policies and processes. The objectives are to smooth the demand, minimize the workload, and reduce the need for storage and resources.

3 - Investigating cooperative hospital supply chain operations
Lotte Verdonck, Lien Vanbrabant, Silia Mertens, An Caris

Hospitals are confronted with tight budgets and an increased demand for their services. As a result, they are looking for ways to reduce their costs and improve the efficiency of their processes, while ensuring a high quality of care. Logistics costs are the second largest cost for hospitals, so effectively managing the hospital supply chain (SC) provides significant opportunities for improvement. Hospitals receive and handle a wide range of materials that are directly linked to patient care, such as pharmaceuticals, medical consumables and sterile items. A hospital SC is typically designed as a multi-echelon inventory system, consisting of external suppliers, a central warehouse within the hospital, point-of-use locations (i.e. care units) and the patients as final users. Among the logistics activities in the hospital SC, inventory management is most frequently investigated as a way to improve efficiency and reduce costs without affecting the quality of care. A high amount of capital is tied up in hospital inventories because of the unpredictable demand and the severe consequences of a stock-out in critical materials. A way to reduce the amount of inventory while maintaining a high service level is inventory pooling. It requires re-engineering the traditional hospital SC into a cooperative SC consisting of a central warehouse that operates for multiple hospitals and replaces the central warehouse of each individual hospital. The aim of this research is to provide hospitals with new insights on how to improve the efficiency of their logistics processes, and on the optimal shaping and operational implementation of a cooperative hospital SC. More specifically, the focus is on the integration of location, inventory and routing decisions in a real-life (hospital) context.

4 - Healthy Supply Chains: How OR Inventories Can Save Millions
Tammi Hawa, Michael Carter

Operating room inventories typically manage thousands of surgical items. Currently, most inventory managers lack the data and software to automatically set periodic review (s, S) parameters to provide the desired service rate while minimizing costs. Instead, they rely on their intuition, potentially leading to overstocking and increased costs. Even when they have access to software that automatically sets inventory policies using classical methods, the methods rely on assumptions on lead time, usage, ordering and reviews that do not accurately represent typical operating room inventories. The inventory parameters proposed within the framework of these assumptions lead to policies which promote poor service rates and increased costs. We use discrete event simulation to analyze the cost effectiveness of automatically setting inventory control parameters when considering the real-world environment rather than relying on classical methods or an optimistic expert intuition. We assume inventory levels in all scenarios are automatically set and policies are always adhered to. We examine 42 scenarios in which usage is nonstationary, lead time is empirically represented, and lead time variance is minimized. We test these scenarios on ten items from an Ontario acute-care hospital, basing our simulations on the real environment and empirical data. We find tested scenarios outperform the classically proposed policies in two ways: the classically proposed policies overshoot the desired service level in 34% of tested scenarios and undershoot in 60% of scenarios, while achieving the best policy for a mere 6% of policies. Furthermore, the tested policies could reduce inventory control costs by 34%-62% compared to the experts' intuition.

■ HC-02

Thursday, 15:00-17:00 - 2

Blood Collection/Supply Planning

Stream: Thursday
Invited session
Chair: *John Blake*

1 - Optimization of blood inventory management - Portuguese Hospital Case Study
Maria Meneses, Inês Marques, Ana Paula Barbosa-Póvoa

Shortage and wastage are two important characteristics in blood supply chains. Shortage may cause postponement of scheduled transfusions or even complications for the health status of patients. Wastage is an unethical issue and generates high costs. In addition, blood is a unique resource that cannot be replaced by any other product. But managing blood inventory is a challenging problem due to several reasons. First, blood is a perishable product with a short lifespan. Second, there are several blood types with a certain level of substitutability. Finally, blood products demand and supply are stochastic. Thus, optimal decision making in the blood supply chains is important to meet high customer service level requirements while avoiding wastage. In this paper, red blood cells inventory management is studied from the perspective of the hospital blood banks. To this end, an optimization model that minimizes shortage and wastage of blood products, as well as total inventory costs is presented and applied to a Portuguese hospital. The model selects an inventory policy based on demand forecast aligned with the hospital's goals. The performance assessment is based on total inventory cost, service level, units wasted, quality and safety of the service provided. Tests compare different inventory policies with different (R, S) values. The analysis starts by comparing the policy currently used in the hospital against the inventory policies recommended by the Portuguese blood service. Then, a benchmark policy is compared to an optimized policy. This policy is then evaluated in more detail and a sensibility analysis is made. The main insight is that by reducing the inventory target level S, the wastage and total costs are minimized and the quality of the service provided improves.

2 - Modelling ferritin in Canadian blood donors
John Blake

While recipient safety has received much attention over the years, more recent focus on donor health suggest that frequent donation negatively impacts donor iron levels. One method for ensuring the health of donors is to monitor ferritin in repeat donors and provide information to individuals with low ferritin levels. Donors can be encouraged to consult their family physician and consider iron supplementation. In addition, donors may be temporarily deferred from blood donation until their iron reserves can be restored.

The purpose of this study is to estimate the impact of ferritin testing on the CBS donor population; specifically, the number of donations expected, the number of tests conducted, and the number of donors identified as having a low ferritin level, under varying potential ferritin testing and deferral policies.

■ HC-03

Thursday, 15:00-17:00 - 3

Health Care Appointment Planning II

Stream: Thursday
Invited session
Chair: *Fermin Mallor*

1 - Optimizing the invitation process of colon cancer screening
Jasmijn Manders, Richard Boucherie, Gréanne Leeftink, Hans Peter Lifmann

Each year 2.2 million clients are invited for the Dutch colon cancer screening program. An invitation consists of a self-test which results in either a positive or a negative result. In case of a positive (undesirable) result the client should get an intake-appointment in a nearby hospital within 15 days after submission of the result. Invitations are sent based on available capacity and hospital service areas such that a future intake-appointment can guaranteed. Until now these hospital service areas were constructed manually based on gut feeling and trial and error. As a result, linking clients in municipalities to capacity of hospitals was inefficient. In this research we develop a prototype algorithm that determines the optimal hospital service areas for the entire Netherlands, taking into account possible future intake-appointments

in case of a positive test result. Via a Mixed Integer Linear Program we maximize the number of clients linked to the nearest hospital and minimize the total travel time for clients, while satisfying the limited capacity constraints of the hospitals. With these optimal hospital service areas we can invite all clients of which 83% to the nearest hospital and 95% within a travel time of 30 minutes. The optimal hospital service areas for 2020 are currently used in practice where we anticipate to see a decrease in rescheduling of intake-appointments. We are developing a software architecture that can be added to the current IT-software of Bevolkingsonderzoek Nederland.

2 - Modeling Appointment Systems with Strategic Walk-ins
Feray Tuncalp, Evrim Didem Gunes, E. Lerzan Ormeci

We consider an outpatient clinic which allocates some slots to walk-in patients. We analyze equilibrium behavior of patients who can choose between waiting for the given appointment or applying to the clinic as a walk-in, with the risk of not being served. We compare the socially optimal and equilibrium behaviors.

3 - Comparison of percentage prolonged times to tracheal extubation between a Japanese teaching hospital and one in the United States
Franklin Dexter

Prolonged times to tracheal extubation are end of surgery to extubation >= 15 min. They are so long others in the operating room (OR) have exhausted whatever activities can be done. They cause delays in starts of to-follow cases and cause longer duration workdays. Physicians rate them as inferior quality. We compare prolonged times to extubation between a US teaching hospital with a phase I post-anesthesia care unit (PACU) and Japanese teaching hospital without PACU. This is important because in regions with substantive prevalence of COVID-19, many patients undergoing general anesthesia will have initial recovery in the OR where they had surgery not PACU.

Historical cohort study of all gynecological surgery patients at University of Iowa (N=785) or Kameda Medical Center (N=699) with time from room entrance to end of surgery >= 4 hr.

Mean times from end of surgery to OR exit were slightly longer at Iowa (mean difference 1.9 min, P < .0001). The mean from end of surgery to discharge to surgical ward at Iowa also was longer (P < .0001), mean 2.2 hr. The standard deviations of times from end of surgery to tracheal extubation was 40 min for Iowa vs 4 min at Kameda (P < .0001). Prolonged times to tracheal extubation were 39% of cases at Iowa versus 6% at Kameda; relative risk 6.40, 99% confidence interval 4.28-9.56. Neither patient demographics, case characteristics, surgeon, anesthesiologist, nor anesthesia provider significantly revised the risk ratio. Using integer programming, we isolated the effect to use of 2 expensive anesthetic drugs at Kameda.

There are dramatic differences in anesthetic practice between countries. Understanding them can be useful when (eg, pandemic) patients will recover initially in the OR or PACU nurses are caring for other patients.

Thursday, 18:00-19:30

■ HD-01

Thursday, 18:00-19:30 - 1

e-Conference Dinner

Stream: Thursday
Invited session
Chair: *Margit Sommersguter-Reichmann*
Chair: *Marion Rauner*
Chair: *Patrick Hirsch*
Chair: *Inês Marques*
Chair: *Roberto Aringhieri*

Friday, 9:30-11:30

■ FA-01

Friday, 9:30-11:30 - 1

ÖGOR Health Session

Stream: Friday
Invited session
Chair: *Margit Sommersguter-Reichmann*
Chair: *Marion Rauner*

1 - An integrated framework to combine blood collection planning and inventory management
Ettore Lanzarone, Semih Yalçındağ, Inês Marques, Luís Miguel Barros Dias Sousa

Blood supply chain oversees providing an adequate amount of blood units to satisfy the demand from hospitals and transfusion centers. Blood is withdrawn from volunteer donors in many countries, and it must be transfused within a limited time period. After this period, blood cannot be transfused and is wasted. Therefore, picking out the right number of blood units to be collected each day for each blood type is fundamental to reduce wastage and shortage. The number of blood units available in the system results from consumption and the balance between two steps of the blood supply chain: collection planning and inventory management. Therefore, these two steps need to be aligned to avoid blood wastage and shortage. However, in the literature, they are separately addressed, which can create suboptimal solutions with associated shortage and wastage. We too have studied the appointment scheduling for blood collection and the blood inventory management problem, but in separate works, with reference to the Italian and Portuguese blood systems. In this work, we combine both problems in an integrated framework. In particular, we consider a small network in which a collection center serves a central storage unit, which in its turn supplies blood to several local users, e.g., departments of a hospital, emergency services or transfusion centers, each one characterized by a specific demand. The integrated framework allows us to define the optimal amount of collected blood units for each type and day based on the demand to serve, the requirements of the collection center and the availability of donors.

2 - The power of motivation: Co-production of an m-health application for patients with obesity
Doris Behrens, Daniel Gartner

Aneurin Bevan University Health Board (ABUHB) established its Adult Weight Management Service (AWMS) in 2014 in Gwent, South Wales. This area is home for 650,000 people and has some of the highest obesity rates in the United Kingdom (approx. 29%). The service aims to support people to achieve clinically meaningful weight-loss (i.e. above 5%). However, many patients have more immediate weight-loss expectations, and these unrealistic expectations often hinder motivation because patients do not achieve the weight-loss they desire, become frustrated and drop-out from the service. A key challenge is keeping patients engaged and motivated. The focus towards health gains, as opposed to aesthetic weight loss, has been reported to enhance 'intrinsic motivation' (i.e. acting for the inherent satisfaction of the activity itself) which is associated with weight-loss maintenance. The project, we seek to present, tackles obesity and obesity-related illnesses by explaining the health benefits of small weight loss through a digital app. A Monte-Carlo simulation runs in the background and accounts for all effects of "diabesity" (=lifestyle-related type 2 diabetes) progression. While designed to motivate users about the impressive impact of tiny wait losses (to keep the person going), it can also be used by a healthcare provider to determine a cost-effectiveness analysis of AWMS interventions.

3 - A duration-distributed model of COVID-19 epidemics
Raimund Kovacevic, Nikolaos Stilianakis, Vladimir Veliov

Infection by asymptomatic and presymptomatic infected individuals play an important role in the spread of COVID-19. We use a duration-distributed model in order to deal with timing effects of incubation, infectiousness and the serial interval, which can be formulated based on an integral equation that describes the underlying dynamics. We also demonstrate a related optimal control problem with decisions on social distancing.

■ FA-02

Friday, 9:30-11:30 - 2

Clinical Pathways

Stream: Friday
Invited session
Chair: *Elena Tanfani*

1 - A perishable inventory approach for capacity planning in cancer pathways
Edilson Arruda, Paul Harper, Tracey England, Daniel Gartner, Emma Aspland, Fabrício Ourique

This work is part of an ongoing project funded by Cancer Research UK aimed to model and evaluate the diagnostic phases of single cancer pathways in Wales. Single cancer pathways are part of a nationwide effort to improve the delivery of cancer care, as well as patient's experiences and outcomes. We introduce an innovative framework for the assessment of the required capacity for individual diagnostic tests, with a focus on the diagnosis and staging of cancer. The approach views the problem as a perishable inventory model in which daily appointment slots for a given test are made available and perish at the end of the day if not utilised. We firstly evaluate the compounded demand for a given diagnostic test by convoluting the probability distribution of incoming referrals with the distribution of the total number of tests required by an individual patient for a given cancer site, in order to determine the total incoming demand for daily appointment slots for each cancer site. A second convolution adds up the demands over all cancer sites and results in the probability distribution of the overall demand for appointment slots for the specific test. Once the overall demand is known, the perishable inventory problem can be solved by means of general queueing models, which then produce the required number of daily slots that results in an arbitrarily small probability that the waiting time exceeds a prescribed maximal threshold. The proposed approach simplifies the problem by allowing the decision maker to disaggregate the problem and solve it separately for each available diagnostic test. The overarching aim is provide public health and cancer services with recommendations to align capacity and demand for cancer diagnostic tests effectively and efficiently.

2 - Peri-operative elective path optimization through math-heuristic algorithms in the Local Health Authority of Bologna
Marco Leonessi, Stefano Guicciardi, Annamaria Longanesi, Enrico Malaguti, Paolo Tubertini

High costs of healthcare and population ageing force the health system to constantly improve its efficiency in order to provide patients the best possible care with the available resources. In this perspective, the Local Health Authority and the University of Bologna started an experimentation to re-organize, manage and control the peri-operative elective path of general surgery, a discipline that works in a multiplatform environment according to a Hub & Spoke logic. The experimentation is built on two mathematical programming models, the first one defining patient preparation appointments (i.e. diagnostic and anesthesiologic visits), while harmonizing patient preparation with available resources, and planning migration from Hub to Spoke platforms, in order to optimize waiting time and facilities utilization. The second model defines weekly optimal admission plans. Both models consider the availability of resources in terms of surgical teams, operating room

slots and number of beds for each operating unit. The proposed approach works on a four-week time horizon following a rolling horizon framework (weekly update) in order to effectively manage high priority patients. Both models have been tested on real-world instances over a six-month observation period.

■ FA-03

Friday, 9:30-11:30 - 3

Chemotherapy/Radiotherapy Scheduling

Stream: Friday
Invited session
Chair: *Alejandra Duenas*

1 - Chemotherapy production bilevel problem: Cost versus delay

Alexis Robbes, Yannick Kergosien, Jean-Charles Billaut

The biopharmaceutical unit of Oncology Clinic (UBCO) of the hospital of Tours (France) produces around 150 chemotherapy drugs per days. To satisfy a certification process of quality management (ISO 9001), the UBCO schedules the chemotherapy production in order to minimize the total delay. The production scheduling is determined after making the patients appointments. These appointments which provide the due dates of each chemotherapy drugs, are scheduled by an oncology administrative service (OAS) that also manages the beds and the care staff. The production of chemotherapy drugs requires the use of costly perishable resources (cytotoxic molecule) supplied in vials. The production cost induced by the consumption of these resources is more than 10 million euros per year, part of which could be reduced by improving the management of the remaining resource (i.e. reducing the vials waste). So, the UBCO tries to meet the drugs demands from OAS as quickly as possible on the one hand, and on the other hand, the OAS tries to schedule the patient appointments by minimizing the cost production and subject to the UCBO production capacity. We propose to model this decision process as a bilevel optimization problem that is defined by two players with their own objectives: a leader and a follower. The leader minimizes the production cost by scheduling the patient appointment. The follower minimizes the total delay by scheduling the chemotherapy drug production. To solve the bilevel problem, we propose a Matheuristic method composed of Local Searches and MILPs to solve subproblems.

2 - MCDA modelling in an outpatient chemotherapy service

Alejandra Duenas, Annabelle Glaize, Christine Di Martinelly, Isabelle Fagnot

Background - As the number of cancer patients increases worldwide, oncology departments face a rise in the number of chemotherapy treatments in their outpatient services. This increase in numbers puts a strain on the quality of services and overall patient satisfaction. Objective - The objective of this article is to analyze and to improve the decision-making processes of outpatients' services in an oncology hospital in the north of France (using multiple criteria decision analysis). The aim is to improve both service quality and the satisfaction of patients. Method - It was decided to apply an outranking method (ELECTRE III); to prioritize improvement opportunities for the outpatient service. The stakeholders' characteristics were assessed in terms of their relative importance in the decision process. Then the aggregation and exploitation phases of ELECTRE III were applied after considering the stakeholders' preferences. A sensitivity analysis was performed to study the impact of a change in the method's parameters. Results - The expert panel considered five decision criteria and evaluated five improvement alternatives. The concordance, discordance and credibility matrices were calculated to determine the differing priorities of the improvement opportunities for the chemotherapy outpatient service. Conclusion - ELECTRE III demonstrated that it is not only a robust decision-aid that mirrors real decision-making processes but also helps to visualize these processes in a structured and transparent way. This study shows the importance of the stakeholders' involvement in the creation of a decision-making model that closely represents reality.

3 - Online algorithms for the radiotherapy patient scheduling problem

Roberto Aringhieri, Davide Duma, Giuseppe Squillace

A radiation therapy consists in the effective clinical use of ionizing radiation for the treatment of malignant tumors. The radiation could be delivered by a linear accelerator or linac, which is a special device whose main function is to concentrate in beams and accelerate the emission of subatomic particles. Radiotherapy could be the primary therapy or deliver together with other therapies. A radiotherapy treatment consists in a given number of radiation sessions, one for each (working) day, which should start before a given release date. Patients are usually classified into classes of urgency having different release date and number of sessions.

Waiting time is the main critical issue in the management of a radiotherapy health system: actually, the delay between the first consultation and the first treatment is typically rather long. Such a delay has the potential to damage the health status of the patients both directly and indirectly.

Optimisation techniques applied to the scheduling of radiotherapy patients can improve both the quality of the health service provided (reducing the waiting times) and the utilisation of the involved resources. The Radiotherapy Patient Scheduling (RPS) problem falls into the broader class of multi-appointment scheduling problems in hospital in which patients need to visit sequentially multiple or single resource types in order to receive treatment or be diagnosed.

After deriving a general problem statement from the literature, we present online optimization algorithms that tries to exploit the particular structure of the solution, and we compare their results with online algorithms with look-ahead. Further we provide some computational insights regarding the mathematical formulations of the problem.

Friday, 12:00-14:00

■ FB-01

Friday, 12:00-14:00 - 1

ÖGOR Disaster Session

Stream: Friday
Invited session
Chair: *Patrick Hirsch*
Chair: *Tina Wakolbinger*
Chair: *Walter Gutjahr*

1 - Orchestrating Coordination between Humanitarian Organizations
Maria Besiou, Lea Ruesch, Murat Tarakci, Niels Van Quaquebeke

In case of a disaster, hundreds of humanitarian organizations may mobilize. Despite their common objective to help beneficiaries, the coordination of their efforts remains a challenge. In order to improve coordination during disaster response, the United Nations formed clusters. These clusters facilitate information and resource exchange among humanitarian organizations. Yet, recalling coordination failures from previous disasters, the evidence for the effectiveness of clusters in coordinating relief efforts remains conflicting. To better understand the barriers of coordination, we combined a qualitative case study and agent-based simulation. We observed in the case study that the cluster lead not only facilitates coordination but very often is also invested in own operations on the ground, thus resulting in a dual role. Such dual role of the cluster lead emerged as the central theme for impairing trust and consequently coordination among cluster members. The simulation findings generalize and augment the detrimental effects of the cluster lead's dual role vis-à-vis a pure facilitator role that would coordinate meetings without having own operations. In sum, our findings aim to improve the coordination in humanitarian operations and contribute to more effective partnerships.

2 - Outsourcing in humanitarian logistics - status quo and future directions
Tina Wakolbinger, Timo Gossler, Christian Burkart

Outsourcing of logistics has great importance in disaster relief and aid agencies spend several billion U.S. dollars every year on logistics services. However, the concept of outsourcing has not been established adequately in literature on humanitarian logistics, leading to a fragmented view of the practice. This paper provides a holistic perspective on the concept by constructing a conceptual framework to analyze both practice and research of outsourcing in humanitarian operations. Based on this synthesis of practitioners' views and research, we explore future trends and identify existing gaps in research.

3 - Dynamic Prioritized Home Healthcare Routing and Scheduling in Emergencies and Routine Services
Sibel Salman, Ahmet Cinar, Ozgur Araz

In home healthcare services, we optimize which patients to serve each day of a planning horizon and the sequence in which patients are to be visited by field teams during their requested time windows. We assign a priority to each patient according to factors such as the last visit time and the severity of her condition so that the priorities of unvisited patients increase exponentially by day. The objective is to maximize the total priority of the visited patients primarily and to minimize the total traveling time as well as the overtimes secondarily. For the dynamic prioritized home healthcare scheduling and routing problem, where urgent patient visit requests may emerge during a day. We propose a near real-time re-optimization framework together with an Adaptive Large Neighborhood Search (ALNS) algorithm. Emergencies accumulate until predetermined re-optimization times and the current plan is re-optimized with new arrivals, in addition to the remaining existing ones, by a multi-period static mathematical model. Solutions generated according to different processing rules for handling the new arrivals are evaluated by means of several performance measures, including the waiting time of urgent patients and the number of delayed patients. We perform extensive computational tests on data sets based on the COVID-19 pandemic response of Istanbul via simulation studies. In addition, a decision support system consisting of forecasting, prioritization, optimization and simulation modules is developed. The prioritization module captures medical expert information and transforms it into a dynamic score based on multi-criteria decision making and the principle of fairness. The scoring facilitates selecting the right patients at the right time and increasing service quality.

■ FB-02

Friday, 12:00-14:00 - 2

Health Care Modelling in Developing Countries

Stream: Friday
Invited session
Chair: *Honora Smith*
Chair: *David Barrera Ferro*

1 - Sustainability in Hospital Supply Chain Management: Empirical research in a developing country in Latin America
Veronica Duque-Uribe, William Sarache, Elena Valentina Gutiérrez

Healthcare logistics has recently gained attention from researchers and practitioners due to the increase on healthcare expenditures, the representativeness of logistics costs in hospital budgets, and the possible contribution of supply chain management to organize logistics processes more effectively and efficiently. Furthermore, besides the economic dimension, aspects that include the environmental and social impact of hospital supply chains have also generated interest in the field. A recent literature review identified a set of constructs and indicators to characterize sustainable supply chain management (SSCM) practices in hospitals and provided theoretical evidence on the influence of such practices in hospitals performance, from the economic, environmental and social dimensions. Based on that evidence, a structured survey was designed and applied aiming at understanding the influence of SSCM practices on hospital sustainable performance. In this work, we present preliminary results of an empirical research developed with a sample of hospitals from different cities from Colombia, Latin America. These results provide useful and relevant information for construct validity, to then analyze the causal relationships between SSCM practices and sustainable performance, and the role of moderating variables such as hospital size, hospital type, and service complexity.

2 - Contract Analysis for Rotavirus Vaccine Supply Chain in India
Dheeraj Chandra, Vipin B

Introduction: Rotavirus is an infectious disease that affects millions of children every year in developing and developed nations. According to the WHO estimates of 2013, approximately 0.2 million children under five years died of rotavirus globally, of which 22% of children were from India. From the literature and field survey, we identified that the existing supply contract that the universal immunization program (UIP) India uses in the procurement of rotavirus vaccines from a single supplier neglects the uncertain nature of demand and considers only stochastic supply. Aim: Various researchers have identified that using an effective supply contract between the buyer and seller can help improve entire supply chain performance. In this study, we put an effort to analyze the existing supply contract that UIP India uses in the procurement of rotavirus vaccines from the supplier. We analyze the traditional wholesale price (WSP) contract for the existing situation and

identified that the WSP contract cannot improve coordinate the supply chain, which is one of the primary reasons for the poor performance of UIP India. Then, we design contracts by considering different aspects such as supply and demand uncertainties, on-time delivery, quantity delivered, and observe that our newly designed contracts can optimize the supply chain and help to improve system performance. Research methods and data: Using mathematical models and expert opinions, we suggest some well-performing supply contracts that may help to improve the UIP performance. Originality/novelty: Observations from previous literature reveal that no such study is available that considers supply and demand uncertainties, on-time and quantity delivered performance while designing vaccine supply chain contracts.

3 - Resource delivery and allocation strategies for epidemic response in a rural context
Linke Potgieter, Dean Matter

Humanitarian aid in developing countries is often faced with the challenge of insufficient and unstable road infrastructure. In the context of an epidemic, this may result in inefficient outbreak responses such as the late delivery of vaccines. Unmanned aerial vehicles have emerged as a potential alternative to land-based delivery methods. In this presentation, the effectiveness of unmanned aerial vehicles for vaccine delivery in the context of a rural epidemic outbreak is evaluated in comparison with land-based delivery, along with various resource allocation strategies. A network approach is followed, with the network consisting of local populations connected by the migration of individuals. The epidemic is simulated by using a compartmental model, which comprises of a system of difference equations for each local population, with a small proportion of each population migrating to other local populations daily. During each time step, resource allocations are determined using an integer programming model. The objective is to minimise the expected number of people exposed. Heuristic approaches for resource allocation are also considered. Optimised resource allocation resulted in a 22% reduction in simulated costs, and unmanned aerial vehicles are shown to be capable of meeting demand for vaccines in a simulated outbreak, and reduce costs and deaths when used instead of a land-based delivery in areas with poor road infrastructure.

■ FB-03

Friday, 12:00-14:00 - 3

Health Care Workforce Scheduling II

Stream: Friday
Invited session
Chair: *Monica Oliveira*

1 - A decomposition-based heuristic procedure for the Medical Student Scheduling problem
Babak Akbarzadeh, Broos Maenhout

In this paper, we consider a real-life medical student scheduling problem in order to ensure students are able to complete the relevant training program to acquire the postulated medical proficiency. Each training program includes mandatory and elective disciplines that students are able to select based on their interests and availability. These internship positions are offered by local hospitals that specify minimum and maximum staffing requirements. The curriculum manager tries to assign students with different seniority levels to particular disciplines and hospitals while considering the objectives and the large number of requirements of different stakeholders, i.e. the educational requirements set by the medical school, the staffing requirements set by the involved hospitals and the student characteristics. We propose a heuristic solution methodology composed of a constructive heuristic and two local search heuristics to improve the initial solution. These heuristics embody different complementary neighborhood structures derived based on the decomposition of the problem in order to find high-quality solutions very efficiently. In order to show the robust performance of the proposed solution methodology, we conducted computational experiments on a comprehensive synthetic dataset of smaller-sized instances generated in a controlled and structured manner and large-scale real-life instances. Results demonstrate that our approach can produce (near-)optimal solutions in a very short timespan. A comparison is made with the real-life approach, demonstrating significant improvements and the contribution to real-life decision-making.

2 - A multi-objective approach for staff scheduling at emergency medical services
Mariana Cunha, Pieter Smet, Inês Marques, Ana Paula Barbosa-Póvoa

Staff scheduling is a complex task required in many industries. In the health care sector, scheduling problems become even harder to solve due to the large number of personnel involved, strong variety in employee qualifications and nonstop service requirements. When looking at emergency medical services, the dispersed locations for personnel assignments and the fact that an ambulance can only operate with a specific number of qualified staff, scheduling becomes even more complex. This work presents a multi-objective approach for staff scheduling at emergency medical services, assigning both shifts and tasks to each staff member. Three objectives are considered: 1) demand coverage, where both understaffing and overstaffing are allowed in some tasks; 2) fairness concerning employee preferences and balanced undertime, overtime and incomplete weekends; 3) overall schedule quality with respect to changes of team, stand-alone shifts and undesired shift patterns. Apart from contractual constraints, the proposed model accounts for scheduled holidays, possible inter-task dependencies (i.e. one task can only be staffed if another is also fully staffed), and a heterogeneously skilled workforce. As solution approach we propose a multi-objective matheuristic combining local search and mathematical programming. This methodology is applied to a case of the Portuguese emergency medical service and is furthermore tested on different scenarios inspired by real-world data.

3 - Nurse Scheduling for a Community Health Centre in Vancouver, Canada, using an Optimization and Simulation Approach
Samantha Zimmerman, Alan Bi, Trevor Dallow, Krisztina Vasarhelyi, Cameron Bye, Nicole Latham, Andy Day, David Hall, Tamon Stephen, Alexander Rutherford

Marginalized individuals often experience barriers to accessing health care, and often have complex clinical and psycho-social needs. In Vancouver, Canada a network of community health centres (CHC's) provide primary-care for these patients. This project is the result of a collaboration with one such CHC. To meet the needs of its clients, the CHC provides a diverse range of services on both a booked and walk-in basis. Care providers at the CHC identified staff scheduling as a way to improve accessibility. Working together with CHC management, we developed a combination optimization and simulation approach to nurse scheduling. The method is tailored to the CHC context, and identifies better combinations of nurse shifts while measuring changes in key performance indicators. A new mixed-integer linear programming model was built to optimize nurse schedules. The optimization model maximizes average patient-nurse contact time while maintaining coverage and hours. It works directly with average demand, which can carry over between time intervals within a waiting limit. Using two weeks each of data from summer and winter, we produced two seasonal weekly schedules. Patient wait times for the original and optimized schedule were assessed using a discrete event simulation model. The significance of wait times in the CHC context was motivated by anecdotal indication of client impatience and reneging. The simulation model also considers patient priority, and breaks down wait times over multiple service types, including triage. Without increasing staffing levels, ten more patients could be seen each week by implementing the optimized schedule. Access for urgent patients is improved by removing gaps in coverage and increasing walk-in patients seen within 30 minutes by 5%.

Friday, 15:00-16:00

■ FC-01

Friday, 15:00-16:00 - 1

ORAHS Business Meeting

Stream: Friday
Invited session
Chair: *Inês Marques*
Chair: *Roberto Aringhieri*

Friday, 16:30-18:30

■ FD-01

Friday, 16:30-18:30 - 1

Closing Session

Stream: Friday
Invited session
Chair: *Marion Rauner*
Chair: *Margit Sommersguter-Reichmann*
Chair: *Patrick Hirsch*
Chair: *Roberto Aringhieri*
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