ORAHS 2025

Program

July 6, 2025

TECHNICAL PROGRAM

Monday, 9:00-9:30

■ MA-01

Monday, 9:00-9:30 - Room: NTNU, Realfagbygget R5

Opening session

Stream: Keynotes and panels
Invited session

Monday, 9:30-10:30

■ MB-01

Monday, 9:30-10:30 - Room: NTNU, Realfagbygget R5

Plenary Nadia Lahrichi

Stream: Keynotes and panels
Invited session
Chair: *Anders N. Gullhav*

1 - Leveraging Operations Research to drive innovation in Healthcare Systems
Nadia Lahrichi

As healthcare systems face increasing pressure to deliver high-quality care efficiently, operations research (OR) offers powerful tools for driving innovation and enhancing system performance. In this keynote, we will explore how advanced OR methodologies and data analytics can transform healthcare delivery through practical case studies, including resource scheduling and allocation. We will also examine some critical questions such as: Does innovation in hospitals align with innovation in OR? And what are the key elements that drive meaningful change? While we may not have definitive answers, we will share insights and lessons learned that can help shape the discussion.

Monday, 11:00-12:30

■ MC-01

Monday, 11:00-12:30 - Room: NTNU, Realfagbygget R5

Simulation 1

Stream: Sessions
Invited session
Chair: *Roberto Aringhieri*

1 - Comparative analysis of parametric and nonparametric probability distributions for uncertainty quantification in simulation studies
Sara Garber

When modeling and analyzing parameters subject to uncertainty, e.g., in Monte Carlo simulation studies, the triangular distribution is frequently used due to its intuitive interpretability, making it particularly accessible to practitioners. However, its simplistic assumptions can introduce bias, potentially affecting the reliability of modeling results in various applications, such as decision support systems. To address this issue, our paper presents a comparative analysis of various parametric probability distributions, including the triangular, beta, and two-sided power distribution, as well as nonparametric methods such as kernel density estimation with various kernel functions. By combining simulation-based approaches with analytical methods, we systematically assess their suitability for modeling, considering key properties of real-world data. Our empirical analysis focuses on a medical use case. This work provides insights into the practical implications of distributional choices in both simulation and analytical modeling and is aimed at statisticians and quantitative researchers involved in the design and methodological refinement of (medical) modeling and simulation studies.

2 - Optimizing Healthcare Resources through AI-Enhanced Diabetic Foot Screening: A Long-Term Cost-Effectiveness Analysis
Yan Sun, *Gary Ang*, *Lixia Ge*, *Zhiwen Lo*, *Huiling Liew*, *Donna Tan*, *Daniel Chew*, *John Abisheganaden*

Background: Diabetic foot ulcers (DFUs) are a serious complication of diabetes mellitus requiring substantial healthcare resources. While regular foot screenings prevent lower extremity amputations (LEAs), conventional annual screening approaches are resource-intensive. This study evaluates how AI can help optimize screening resource allocation while maintaining care quality.

Method: We developed a Markov state-transition model simulating disease progression across five health states: diabetes, DFU, minor & major LEA, and death. The model leverages national disease registry data for transition probabilities and costs. We compared AI-enhanced screening approach against routine annual screening for 500,000 low-risk diabetic patients over 40 years. The AI model recommends screening interval tailored to individual risk profile. Effectiveness was measured in quality-adjusted life years (QALYs). Monte Carlo microsimulation was performed for probability sensitivity analysis (PSA).

Results: The AI-enhanced strategy demonstrated significant resource optimization, eliminating 6.8 million unnecessary screenings and saving healthcare costs by S$657.5 million over 40 years with minimal QLAY loss (ICER: S$174,572/QLAY, SD:13,296), proving its cost-effectiveness.

Conclusion: AI-enhanced screening AI-enhanced DFU screening optimizes healthcare resources through personalized risk assessment, significantly reducing unnecessary screenings while maintaining clinical outcomes.

3 - Managing the Ripple Effect: Dynamic Waiting Lists, Resource Constraints, and Adaptive Hospital Case Mix Planning for Internal Management and External Influence
Sebastian Kraul

Hospitals operate as complex service systems under constant pressure to enhance efficiency, ensure financial viability, and provide equitable access, often facing scrutiny from policymakers and insurers regarding performance, particularly concerning waiting lists. Central to navigating these pressures is effective capacity management and strategic case mix planning. However, traditional case mix planning often relies on static assumptions, failing to capture the dynamic interplay between strategic plans, operational constraints, and evolving waiting lists. This disconnect hinders not only effective internal management but also the ability of external stakeholders to design interventions, as they often lack instruments grounded in the operational realities of waiting list dynamics. This research develops a novel hybrid simulation-optimization framework for dynamic case mix planning. We employ Discrete-Event Simulation to evaluate the impact of waiting list policies. The simulation output dynamically informs an optimization model that adjusts the target case mix to better align strategic goals with operational realities reflected in waiting list dynamics. By simulating the downstream operational consequences of different strategic hospital choices or potential external incentive structures, it provides a tool to better understand system levers and design policies aimed at improving timely access to care and managing waiting lists systemically.

4 - How different drivers can influence patients' decisions
Roberto Aringhieri, *Luca Bartoletti*

The operational management of healthcare services aims to improve the governance of productive areas where care processes take place (e.g., operating rooms, inpatient areas, outpatient and diagnostic platforms) through the planning, management, and control of logistical flows. In this context, the patient's perspective is not always duly considered, partly due to the inherent difficulty in representing their decision-making model. In this talk, we investigate the drivers that may influence the patient's decisions when choosing the healthcare facility in which to receive a specific specialist treatment. For instance, a patient may choose the best facility, the closest one, or the one with the shortest waiting times. It is therefore necessary to study how their perceptions evolve over time, depending on factors including past experience, personal social networks, and institutional information. We present an agent-based simulation model designed to analyse the emergent behaviour of this system describing the main agents of the system (hospitals, general practitioners, and patients), their behaviours, and the networks (both social and otherwise) that connect them. We validate the model, implemented using the NetLogo, in accordance with three "extreme" scenarios. Finally we discussed the application of the model to a real case study based on vascular surgery in the metropolitan area of Turin.

■ MC-02

Monday, 11:00-12:30 - Room: NTNU, Realfagbygget R8

Implementation

Stream: Sessions
Invited session
Chair: *Gréanne Leeftink*

1 - Condorcet ranking for developing co-designed outcome measures in clinical research under the "Tournament Methods" framework
Hannah Johns, *Leonid Churilov*

It is increasingly mandated by funding bodies that clinical research is co-designed with people that have lived experience of the condition under investigation. "Tournament Methods" are a class of statistical methods that satisfy this need by defining for each possible pair of patients, who had the better outcome. Under this approach, "better outcome" can be co-designed with patients, carers and other stakeholders to reflect trade-offs between multiple, potentially conflicting criteria.

However, biostatistical literature has only just begun to developed methods for facilitating the co-design of definitions of "better outcome" under the Tournament Methods framework. Determining preferences among alternatives with multiple, conflicting criteria is a mainstay of multicriteria decision analysis methods.

In this presentation, we discuss the methods currently used in biostatistics to elicit preferences that can be used to define "better outcome" under the Tournament Methods framework. We then discuss how well-established methods from operations research may be leveraged to improve this practice.

We demonstrate the application of these methods in practice by using Condorcet ranking to co-design a definition of "better off" in stroke research with a group of stroke survivors. We apply this definition to analyse data from a secondary prevention trial in a manner that reflects the experiences and preferences of stoke survivors.

2 - A systematic review of studies that mention the implementation of OR in health services
Guillaume Lamé, Coco Newton, Luca Grieco, Sonya Crowe, Tom Bashford, Saba Hinrichs-Krapels

Reviews suggest that less than 10% of healthcare OR articles mention the implementation of results. Taking a 'positive deviance' stance, we focused on these articles. To better understand 'what works', we reviewed studies that do mention the implementation of OR in health services. We searched the Web of Knowledge, Scopus, and PubMed for articles mentioning the implementation of OR methods in healthcare. We performed single-reviewer abstract screening with 10% double-screening, and double-blind full-text screening. A single reviewer extracted information. We screened 4,992 studies and included 163. All articles described a decision to implement change. 121 (74%) described implemented changes, of which 91 (56%) provided some elements of evaluation (mostly before-after comparisons). 134 (82%) described stakeholder engagement. 57 (35%) mentioned implementation in two-three sentences, 82 (50%) in one paragraph to one section, and in 24 (15%) implementation was a key aspect. In these 24 articles, some influencing factors were recurring (e.g., client commitment, perceived usefulness of the intervention), while others were barely mentioned (e.g., time and cost of implementation). No paper referred to an implementation science framework, but some referred to Soft OR or improvement science as implementation strategies. The number of studies we identified is encouraging, but inconsistent reporting is an issue.

3 - Perinatal mental health plan assessment in Ile de France region (IDF)
Catherine Crenn-Hebert, Bruno Renevier

According to french national public policy of the 1000 first days (2020), IDF region has received sustainable grants to enhance or promote multidisciplinary medico-psycho-social meetings in maternities since 2022. These meetings have the objective to organize coordinated pathways for vulnerable pregnant women during their pregnancy or just after birth.

These meetings take part in the perinatal mental health regional plan whose assessment is still in progress.The results are obtained from 54 maternities (among 65 granted in 2023) activity reports and after implementation of a specific evaluation tool.

46 % have given complete specific evaluation with mental health in 45 % , social in 39 % , medical vulnerability in 16 % as main indication for medico-psycho-social meeting referal. Reported risk of child mistreatment occured in 3.6 %. Intended care after maternity stay is also described.

This work is on going with a new enquiry among the 72 granted maternities in 2024.

4 - From models to implementation: the impact of embedded OR research in a Dutch hospital
Gréanne Leeftink, Erwin W. Hans, Hayo Bos

Despite a wealth of OR models in the literature, their implementation in healthcare organizations remains limited. This talk presents the impact of a CHOIR PhD project conducted in-residence at a Dutch hospital, embedded in the integral capacity management team — showing how embedded research can bridge the gap between theory and practice. We discuss two impact cases: a probabilistic model predicting daily ward bed occupancy using LOS data and expert input, and a Monte Carlo simulation model forecasting surgical block durations. Both models are integrated into the hospital's business intelligence suite and actively support planning decisions. We also reflect on key success factors, such as close collaboration with practitioners, model transparency and user autonomy, and integration in existing IT systems, as well as challenges, such as managing expectations, data quality, and aligning academic timelines with hospital decision cycles.

■ MC-03

Monday, 11:00-12:30 - Room: NTNU, Realfagbygget R9

Staff scheduling

Stream: Sessions
Invited session
Chair: *David Ajit Kirpekar-Sauer*

1 - Operating room scheduling under limited turnover staff
Gabriela Pinto Espinosa, Aida Jebali, Erik Demeulemeester, Angel Ruiz

Operating room (OR) scheduling is a widely studied problem because of the OR's crucial role in patient care, its impact on healthcare institutions' costs and revenue, and its complexity related to the presence of various sources of uncertainty, and the involvement of multiple physical and human resources. Among these resources, the staff responsible for turnover procedures, including patient transportation and OR cleaning and preparation between surgeries, is often unaccounted for. The occurrence of multiple turnover requests in short spans of time may lead to delays due to the unavailability of transportation or cleaning staff. These delays can propagate throughout the schedule, increasing the risk for overtime and cancellations. Our approach generates different schedules from both heuristic and mixed-integer programming-based methods. These schedules are then evaluated through discrete-event simulation over a set of experiments to compare their performance and to identify potential conflicts related to turnover requests, overtime and cancellations. The experiments include different settings and policies for managing the turnover staff, and multiple scenarios for elective surgery and recovery durations. Finally, we iteratively refine solutions to mitigate the occurrence of these conflicts.

2 - Nurse to patient ratios in South Africa and its impact on nurse and patient outcomes
Siedine Coetzee, Jacoba Bührmann

Introduction: Systematic reviews confirm that higher nurse-to-patient ratios are associated with poorer nurse and patient outcomes. Countries worldwide have adopted varied approaches to managing nurse staffing but developing countries such as South Africa (SA) provide little guidance. Aim: To determine the current nurse-to-patient ratio and its impact on nurse and patient outcomes. Method: The dataset was a national survey conducted in 2021/2022 among nurses in SA (n=4554). Principal component analysis was used to identify key explanatory variables of nurse-to-patient ratios, which were then compared to key outcomes. Trend analysis highlighted negative declines in outcomes as nurse staffing ratios increased. Robust logistic models estimated the association between nurse staffing and adverse outcomes. Results: The overall nurse-to-patient ratio was 4.70, while for Registered Nurses it was 14.23. Each additional patient per nurse led to a 16.2% increase in job dissatisfaction, a 17.0% increase in emotional exhaustion, and a 9.9% increase in turnover intention. Patient outcomes showed a 21.2% decrease in nurse-perceived patient safety and a 25.7% decrease in nurse-perceived quality of care. Conclusion: SA's

current RN-to-patient ratio is considerably higher than what is recommended in developed countries and negatively impacts both nurse and patient outcomes. The researchers recommend a nurse-to-patient ratio of at least 1:8 based on national data.

3 - An automated doctor rostering decision support tool for Knysna Hospital
Klara Engelbrecht, *Linke Potgieter*

Hospitals often face a shortage of doctors, placing significant strain on the available staff to meet patient care demands. In public hospitals in South Africa, physician and nurse rosters are typically set up manually by the clinical manager. This is a time-consuming task that is difficult to accomplish with the number of regulations, preferences, and fairness that must be considered. In this study, a mixed-integer programming model (MIP) was formulated that can be used to automate the rostering task for physician scheduling at Knysna Hospital in the Western Cape of South Africa. Hard constraints ensure that all shift demands are met and hospital regulations are followed, while soft constraints promote fairness, minimises consultant usage, and allow doctors sufficient weekends off. Additionally, the model was integrated into a decision support tool with a user-friendly interface designed to automate the doctor scheduling process for the clinical manager at Knysna Hospital. During the development of the model and user interface, frequent discussions with the clinical manager ensured the user-friendliness of the interface and that the model correctly reflects context specific constraints and variables. In this talk, the model and decision support tool will be presented, as well as results from model analysis and comparison with the actual Knysna Hospital schedule. It was found that neither Knysna Hospital nor the model achieves perfect fairness between doctors, but the mode

4 - Healthcare staffing using split shifts
David Ajit Kirpekar-Sauer, *Jens Brunner*

Healthcare struggles with a serious staffing shortage. On the other side, demand fluctuates wildly. Due to the often rigid structure of shifts, this often leads to over staffing in periods with low demand. As healthcare staff are a sparse resource, over staffing is highly undesirable. There is a need for better matching supply with demand, i.e., new shift system might be a solution. Current scheduling literature has tried to combat this problem via flexible shifts, planned overtime, or part-time staff. Our aim is to use split shifts as a novel option. Split shifts consist of two short shifts on a single day, separated by reduced inner working day rest time. Split shifts have partially been used in the transport sector, where bus drivers work split shifts to cover the morning and afternoon rush hours. We transfer the idea to general personnel scheduling in healthcare. We consider a generic staffing problem subject to generic working time, labor regulations, and highly fluctuating demand. We formulate a mathematical model incorporating split shifts to handle multiple daily demand peaks. We investigate the effect of split shifts in combating staff shortages in healthcare. We develop a branch-and-price procedure and compare it to standard solvers. The methods are tested on both real-life instances, based on data from a disabled-care facility, and randomly generated instances. We present preliminary results and show that split shifts are able to reduce staffing.

Monday, 13:30-15:00

■ MD-01

Monday, 13:30-15:00 - Room: NTNU, Realfagbygget R5

Home healthcare

Stream: Sessions
Invited session
Chair: *Fatemeh Alidoost*

1 - Barriers to Participation in Personalised Home Care: A COM-B-Informed Review of Self-Directed Support and International Models
Shafkat Ibrahimy, *Le Khanh Ngan Nguyen*, *Lynn Williams*, *Itamar Megiddo*

This talk discusses a work-in-progress systematic review that forms the foundation of a broader research agenda systematically integrating behaviour theories from psychological sciences into systems simulation models for home care planning. The review investigates how active, informed participation in personalized home care planning by older adults is influenced by multiple barriers and facilitators. The study considers Scotland's Self-Directed Support (SDS) model and international approaches in person-directed or consumer care that are comparable. Despite growing policy emphasis on personalization, there remains limited operational understanding of how behavioural factors affect engagement with self-directed care processes, creating a gap between policy intentions and implementation. Literature is being reviewed from academic and grey sources, including Scottish government reports, with initial coding in progress to extract themes related to planning process, user engagement and service-level constraints. The next stage will apply the COM-B behaviour framework (Capability, Opportunity, Motivation) as a lens to analyse and interpret these themes to examine their behavioural links and implications for care system design. The longer-term aim is to use these findings to underpin the development of a hybrid simulation model for planning and service improvement. The talk invites discussion on applying behavioural theory to qualitative findings in support of care planning models.

2 - Enabling Efficient Telemedicine: The Potential of OR/OM Applications in Healthcare Delivery
Ali Ghavamifar, *Jens Brunner*

Telemedicine has become an essential part of healthcare systems worldwide, offering flexible and remote care options that can improve access, reduce costs, and enhance patient experiences. As its adoption expands across various healthcare settings, there is a growing need to understand how telemedicine systems function and how they can be improved. To address this, we investigate the application of operations research (OR) and operations management (OM) in healthcare delivery, with a focus on telemedicine. This study reviews existing literature and practical cases to explore how OR/OM approaches have been used to tackle key challenges such as resource allocation, service scheduling, patient flow coordination, and capacity planning. By examining how these tools can model system complexities and support performance improvements, we highlight their value in designing more efficient, equitable, and resilient telemedicine services. This research offers a system-level perspective that bridges healthcare delivery needs with analytical opportunities, aiming to inform future research and practical implementations in digital health.

3 - Multi-Objective Models for Efficient and Patient-Centered Home Healthcare Routing and Scheduling
Soumen Atta, *Michael Emmerich*, *Vitor Basto-Fernandes*

Home healthcare (HHC) plays a crucial role in enabling patients, particularly the elderly and chronically ill, to receive medical and personal care services at home. The efficient routing and scheduling of caregivers is essential to ensure service continuity, reduce operational costs, and enhance patient satisfaction. However, designing such

schedules is highly complex due to multiple conflicting objectives, such as minimizing travel time and cost, balancing caregiver workload, satisfying time windows, respecting service durations, ensuring continuity of care, and incorporating patient preferences. Multi-objective optimization (MOO) models offer a powerful framework to address these challenges by simultaneously considering these competing goals. This study provides an overview of recent MOO models in HHC routing and scheduling, highlighting key modeling features, objectives, and real-world constraints. We also identify open research directions, including the incorporation of uncertainty, dynamic requests, interdependent services, sustainability, and personalized care. Such advancements can support healthcare providers in making better-informed and patient-centered scheduling decisions.

4 - Investigating the Incorporation of Circular Economy, Resilience, and Sustainability Concepts in Healthcare Supply Chain Modelling: A Narrative Review with Expert Insights
Fatemeh Alidoost

Healthcare supply chains (HSCs) support resource-intensive and high-throughput operations and play a critical role in addressing supply chain disruptions and uncertainties, all of which impact economic sustainability and resilience. HSCs are also the primary carriers of healthcare products, and thus, another dimension of sustainability is the reduction of waste and CO2 emissions. A regenerative Circular Economy (CE) that aims at preserving products through circulation in a closed-loop system and reducing waste, can potentially promote both sustainability and resilience, although the dynamics of its application in HSCs remain largely unexplored. This study reviews the current literature on HSC, with a focus on the adoption of circular economy, resilience, and sustainability (CERS) principles and approaches in modelling practice. Our research design includes a structured narrative review to identify CERS measures that were part of existing models, as well as a semi-structured interview with a rating exercise to map the identified measures and practices to empirical settings. Our findings highlight the challenges in evaluating the cost-effectiveness of CE practices as well as their social and environmental impact on HSCs. Our study also unravels the interactions among CERS measures, leading to the development of a framework for integrating CERS into HSC modelling practices, emphasising resilience strategies and sustainability aspects.

■ MD-02

Monday, 13:30-15:00 - Room: NTNU, Realfagbygget R8

Patient to room

Stream: Sessions
Invited session
Chair: *Thierry Garaix*

1 - Generating realistic patient data
Tabea Brandt, Christina Büsing, Johanna Leweke

Developing algorithms for real-life problems that perform well in practice highly depends on the availability of realistic data for testing. Obtaining real-life data for optimization problems in health care, however, is often difficult. This is espacially true for any patient related optimization problems, e.g., for patient-to-room assignment, due to data privacy policies. Furthermore, obtained real-life data usually cannot be published which prohibits reproducibility of results by other researchers. Therefore, often artificially generated instances are used.

In this talk, we present a configurable instance generator for the patient-to-room assignment problem. Configurability is in this case especially important as we observed in an extensive analysis of real-life data that, e.g., the probability distribution for patients' age and length of stay depend on the respective ward. We show in this talk how our instance generator can be used to create artificial instances that mimic the situation of a desired real-life ward and allow a feasible patient-to-room assignment. Further, we present combinatorial insights used to ensure that all generated instances are feasible for the specified room setting.

2 - Allocating Patients to Rooms under Uncertainty: An MDP-Based Approach
Philipp Pelz, Justus Arne Schwarz, Alexander Hübner, Fabian Schäfer

Effective bed management in hospitals is becoming increasingly important due to rising demand and limited bed availability. Patient-to-room allocation is a challenging task influenced by (i) stochastic factors, such as the arrival for emergency patients and the variability in the length of stay; (ii) constraints like limited bed capacities in specific rooms and gender-based room-allocations; and (iii) the handling of overflow situations. Undesirable actions—such as patient transfers, overflow area allocations, or rejections—should be minimized to ensure high-quality patient care.

The existing literature often relies on deterministic approaches that either assume full prior knowledge or use dynamic rolling-horizon approaches, which iteratively solve deterministic problems while updating current states. In contrast, we propose a Markov Decision Process (MDP) formulation that incorporates explicitly stochastic influences within a finite planning horizon. The model considers allocating patients to regular rooms, the overflow area, or rejecting them, as well as transferring patients to a different room based on the current state. We present the MDP model and preliminary numerical results, highlighting the value of modeling uncertainty.

3 - Trade-off analysis of different objective functions for the patient-to-room assignment problem
Johanna Leweke, Christina Büsing, Tabea Brandt

Upon arriving at a hospital, patients need to be assigned to rooms where they will spend most of their stay. This patient-to-room assignment serves multiple objectives such as minimizing patient transfers between rooms and/or maximizing single-room requests. It is insufficient to consider these objectives independently; practitioners are often interested in solutions that simultaneously optimize multiple objectives and the trade-offs between them. We first consider theoretical questions such as: What is the maximum number of single-room requests that can be fulfilled when no transfers are allowed? And what is the minimum number of transfers required to fulfill the maximum number of single-room requests? We then evaluate the empirical trade-off between these two objectives and the effect of using combinatorial insights on the optimization in a computational study based on real-world data.

4 - Optimizing Case-Mix Planning at the Territorial Level : A Pathway-Centered and Resource-Aware Approach
Thierry Garaix

The increasing demand for healthcare services, combined with limited resources, requires hospitals to optimize both patient allocation and resource utilization. Regional Case Mix Planning aims to address this challenge by strategically allocating patients across healthcare facilities while ensuring equitable access and quality care. Our approach extends traditional models by incorporating multiple care pathway options for the same pathology, enabling transfers of patients between healthcare entities and considering the reallocation of resources between facilities. We propose a linear programming model that optimizes the allocation of patients among different care pathways while considering regional needs and available resources. The model is tested on real-world data from hip and knee replacement cases. Results show that incorporating multiple care pathways increases the number of patients treated. However, some patients may follow lower-quality pathways. Additionally, allowing patient transfers between facilities enhances capacity without altering the proportion of patients in optimal pathways. Finally, enabling resource transfers between institutions leads to a higher number of treated patients or improved patient care by assigning them to better-quality pathways. This study highlights the value of a regionalized approach to care pathways planning, supporting decision-makers in improving healthcare system efficiency while balancing quality and accessibility.

■ MD-03

Monday, 13:30-15:00 - Room: NTNU, Realfagbygget R9

ED and ICU

Stream: Sessions
Invited session
Chair: *Daniel García-Vicuña*

1 - Addressing Emergency Department Overcrowding through Efficient Queue Management: a Deep Reinforcement Learning Approach

Luca Zattoni, Andrea Eusebi, Cristiano Fabbri, Marco Leonessi, Enrico Malaguti, Paolo Tubertini

Emergency Department (ED) overcrowding is a growing concern in modern healthcare systems, as it often leads to prolonged waiting times, patient discomfort, and potential deterioration of clinical conditions, as well as increased stress on medical staff. This stress may also negatively affect decision-making capabilities, further exacerbating inefficiencies in patient management. While structural limitations and increasing demand represent major challenges, they also emphasize the need for advanced Decision Support Systems capable of adaptive, real-time responses. In this work, we propose a Deep Reinforcement Learning (DRL) approach to dynamically manage patient queues, aiming to mitigate overcrowding by optimizing the allocation of medical services. By modelling the ED as a sequential decision-making environment, our model learns to prioritize patients based on their clinical features and expected resource needs, while considering the overall system state. This enables the development of intelligent queue management strategies that adapt to evolving conditions and heterogeneous patient flows. The model is trained and evaluated in a Discrete Event Simulation environment which realistically replicates ED dynamics and variability in patient pathways. Preliminary results show a reduction in both the length of stay and the average number of patients in the system, demonstrating the potential of DRL in supporting operational decisions and improving ED performance under stress.

2 - ICU capacity management: An AI-based transparent scoring model for integrated clinical decision support

Christina Bartenschlager

The intensive care unit (ICU) is a critical and costly asset within hospital settings. Effective and efficient ICU management strategies are paramount for patient care. A large subset of ICU admissions arises from elective surgeries. Artificial intelligence (AI) and analytics as decision support tools are promising to support capacity management challenges. However, the practical implementation of such systems remains limited, hindered by factors including digitization gaps and skepticism surrounding AI transparency. This work presents the development and validation of a transparent scoring model utilizing AI and analytics to provide decision support. Focused on the decision of post-surgery ICU transfer for elective patients, our model aims to aid physicians, especially those with less experience, while enhancing capacity planning efficiency. Drawing from existing research on AI-based decision support systems, we propose a novel approach that integrates machine learning (ML) algorithms to identify key features influencing the need for post-operative ICU care. Through rigorous experimentation and validation, our clinical decision support system (CDSS) demonstrates its potential to accurately predict ICU requirements, thus optimizing resource utilization and enhancing patient care. The practical relevance and usability of our transparent scoring model are evaluated through a comprehensive experiment involving physicians. By addressing the gap between AI innovation and practical

3 - Keep Waiting or Leave Without Being Seen? The Impact of Early Assessment in Emergency Departments

Chiara Morlotti, Mattia Cattaneo

Leaving the emergency department (ED) without being seen (LWBS) is acknowledged to lead to serious consequences, such as worsening health conditions and increased resource utilization, including a higher risk of hospital (re)admission. To help reduce this phenomenon, alternative strategies have been introduced. One of these is early assessment, defined as any interaction between healthcare professionals and patients, such as monitoring of health conditions and preliminary treatment, that takes place before the formal medical evaluation by a physician. In this study, we investigate the role of early assessment in reducing the probability that a patient leaves the ED before being seen. By leveraging one year of data encompassing all ED accesses to a multi-hospital network in Northern Italy, we perform logistic regression and survival analysis to assess its impact on patients' likelihood of staying until their medical evaluation — that is, the probability of being present when called for the physician's visit. Our findings reveal that early assessment reduces the likelihood of LWBS by approximately 25%. Additionally, we also demonstrate that patients who experience longer waiting times are more likely to leave without being seen.

4 - Dynamic Predictive Modeling for Decision Support and Patient Management in Intensive Care Units

Daniel García-Vicuña, Ana María Anaya-Arenas, Janosch Ortmann, Angel Ruiz, Fermin Mallor

The limited availability of Intensive Care Unit (ICU) beds highlights the critical challenges hospitals face when demand exceeds capacity. In such contexts, healthcare providers must make complex decisions regarding admissions, discharges, and surgery scheduling—often under significant uncertainty and pressure. These decisions, while necessary, can lead to logistical bottlenecks and adverse patient outcomes. This work presents a dynamic predictive model that supports decision-making by anticipating ICU patient trajectories and enabling more efficient bed management. Built on real-world patient data, the model combines clinical variables and historical information to estimate ICU length of stay and evolving occupancy levels. The approach integrates predictive analytics with simulation techniques to evaluate the operational impact of different strategies under variable demand scenarios. Our results show that informed forecasting can help reduce premature discharges and surgical delays by guiding clinicians toward more balanced resource allocation. The model is designed as a practical decision-support tool to assist ICU managers in aligning patient care needs with available capacity, particularly in periods of high stress or crisis.

Monday, 15:30-17:00

■ ME-01

Monday, 15:30-17:00 - Room: NTNU, Realfagbygget R5

Access to care

Stream: Sessions
Invited session
Chair: *Felipe Rodrigues*

1 - Understanding the Impact of Accessibility on Hemodialysis Outcomes in India
Sachin Bodke, Narayan Rangaraj

Hemodialysis is a vital treatment for patients with End-Stage Renal Disease, but many in India face challenges in accessing it regularly due to travel burden and associated costs. This study analyzes dialysis accessibility and its link to treatment adherence and survival outcomes using data from 16,104 patients undergoing dialysis for over 90 days. It combines Geographic Information System data, survival analysis, and logistic regression to assess how distance, center type, and location affect care patterns. Patients receiving irregular dialysis traveled significantly longer compared to those with regular dialysis (20 vs. 13 km) and had shorter median survival (6.2 vs. 9.6 years). While average travel distances to public and private centers were similar (33 km), public centers saw more frequent dialysis and served a broader cross-section of patients. Adherence was better in Tier 1 cities, and logistic regression confirmed tier and travel distance as key predictors. Among the states analyzed, Telangana, showed high adherence and survival despite longer average travel. A patient survey supported these findings, where 67% reported financial stress and 26% missed sessions due to travel issues. Many spent up to 2000 Rs per trip and relied on caregivers for visits. These insights suggest that improving access through transport support and better distribution of services can help patients maintain regular care and improve health outcomes.

2 - On Surgery Ward Resilience: Quantitative Concepts, Evaluation, and Analysis
Gabriela Ciolacu, Siamak Khayyati, Emilia Grass

Effective surgical ward management in the context of disasters is especially challenging. It requires balancing meeting uncertain and increasing patient demand with limited and costly resources for prolonged periods. To evaluate if the ward can meet the demand for surgical care without straining medical resources, hospital decision-makers introduced resilience to dynamically assess the disaster's impact, considering that the ward is the costliest medical unit. Resilience is the surgical ward's capacity to prepare (1), withstand (2), absorb (3), and recover (4) from disasters, implying multiple phases. This study examines quantitative resilience indicators and their application to surgical wards following disasters. While reviewing 30 healthcare resilience publications, we noticed that quantitative evaluation heavily depends on the definition of performance indicator. To the best of our knowledge, the current healthcare state of the art excludes surgical care, focuses on engineering performance assumptions, and relies on cumulative resilience indicators, neglecting the four aforementioned phases. To account for such shortcomings and guided by literature, this study proposes a quantitative resilience evaluation that provides a granular view of each phase and tailors its performance and interpretation to the surgical ward. We illustrate the usefulness of the proposed evaluation in a simulation that models the surgical ward and adjacent units as a queueing network.

3 - Using queueing games and contract theory to improve access to care: The case of the Ontario Autism Program
Felipe Rodrigues, Saha Malaki, Salar Ghamat, Camila Pedroso Estevan de Souza, Greg Zaric

In 2024, wait times for autism treatment funding under Ontario's Autism Program grew to 7 years. Delaying early interventions for autism treatments burdens families with high out-of-pocket expenses, affecting child development and family well-being. We propose a contract-based queueing game model between families and a governmental autism funding provider (AFP) to improve access to public funding and treatment services. Families decide whether to exclusively wait for public assessments and funding or to wait while incurring out-of-pocket expenses with private services based on a threshold policy that reflects their sensitivity to delays. Meanwhile, the AFP sets an optimal service rate and may introduce a rebate scheme to balance quality and efficiency. We analyze two scenarios: one without rebates and one where rebates partially offset out-of-pocket expenses. We also extend our model to an integrated care system in which a central planner coordinates incentives to maximize overall welfare. Analytical and numerical results demonstrate that calibrated rebate schemes can increase service capacity, shorten wait times, and reduce out-of-pocket expenses, ultimately benefiting families. Our findings offer timely policy insights for designing contract mechanisms to enhance access to autism funding and services.

■ ME-02

Monday, 15:30-17:00 - Room: NTNU, Realfagbygget R8

Cancer and personalised care

Stream: Sessions
Invited session
Chair: *Christos Vasilakis*

1 - From Theory to Clinic: Operationalizing Evolutionary Cancer Therapy for Metastatic Non-Small Cell Lung Cancer
Arina Soboleva, Kailas Honasoge, Eva Molnárová, Irene Grossmann, Jafar Rezaei, Katerina Stankova

Evolutionary cancer therapy (ECT) applies principles of evolutionary game theory to prolong the effectiveness of cancer treatment by curbing the development of treatment resistance. The therapy schedule is informed by mathematical models of cancer growth and dynamically adapted based on cancer response. ECT increases the time to progression while decreasing the cumulative drug dose. However, it requires careful follow-up of disease progression with more frequent tests and doctor consultations, which is an important consideration for ECT implementation in clinics. In this study, we translate the results of patient-level ECT models to the hospital operational level to foresee the feasibility and requirements of ECT for non-small cell lung cancer (NSCLC) in clinical practice. The research has two objectives: (i) to assess the robustness of the ECT protocol considering the constraints of hospital resources, and (ii) to estimate the effect of ECT on hospital operations. We implement commonly used models of cancer growth under treatment calibrated with real-world data of NSCLC patients to determine the test frequency required for ECT. We then simulate a pool of virtual patients following ECT and evaluate the effect of the increased testing and consultation frequency for these patients on hospital operations. Our research facilitates the future implementation of ECT by estimating its impact and providing the basis for discussion and collaboration among healthcare stakeholders.

2 - An Online Algorithm for Integrated Scheduling of Pre-Treatment and Treatment Appointments in Radiotherapy using Deep Reinforcement Learning
Maxim Frankish, Broos Maenhout

Scheduling patients for radiotherapy within the oncology department is vital for ensuring timely and effective treatment. The patient's therapy consists of a sequence of pre-treatment consultations, i.e. preliminary investigations to define the required treatment, followed by the radiotherapy treatment sessions on linear accelerators. Timely scheduling of pre-treatment consultations is crucial to prevent unnecessary delays in radiotherapy treatment, thereby impacting patient health. Therefore, we suggest integrating both scheduling problems. We employ a Reinforcement Learning-based scheduling technique to solve the multi-appointment scheduling problem in an online fashion. We

design a reward function comprising three components to guide the agent towards learning an effective scheduling policy involving multiple appointments. Additionally, we compare our proposed model with benchmark online heuristics inspired by the ASAP procedure. We further provide insight into the reward function design, which steers the agent to learn a feasible policy that leads to high-quality solutions. Experiments show that our algorithm outperforms the benchmark heuristics.

3 - Distributionally Robust Chance Constraints for VMAT Treatment Planning
Houra Mahmoudzadeh, Stoyan Hristov, Johnson Darko, Ernest Osei

Radiation therapy (RT) seeks to irradiate a cancerous tumour while minimizing damage to the nearby organs at risk (OARs). Throughout a treatment session, a patient's geometry might change unpredictably, which can degrade the treatment quality. Volumetric Modulated Arc Therapy (VMAT) is a modern form of RT in which the beam follows a path around the patient while continuously delivering radiation. Despite better OAR sparing and shorter treatment times, VMAT planning results in a large-scale nonlinear mixed integer program (NLMIP) that becomes even more complex when geometric uncertainty is incorporated. We propose a distributionally robust chance constraints VMAT model and a heuristic solution scheme that outputs near-optimal treatment plans which are robust to uncertainty in tumour position. Finally, we compare the robustness of nominal, robust, and distributionally robust plans and discuss tradeoffs.

4 - Innovative Approaches to Managing Demand and Capacity in Mental Health
Christos Vasilakis, Elizabeth Yardley, Alice Davis

The NHS Talking Therapies (TT) programme in England follows a "stepped care" approach for treating patients with common mental health problems, where effective but less resource intensive treatments are delivered to patients first and more intensive interventions are provided only if required. Limited resources and pressure to achieve service standards mean that providers are keen to explore ways of improving patient flow. Existing evidence points to variation in clinical performance and stepped care implementation across organisations, and positive associations between service delivery and patient outcomes. We aimed at developing innovative, advanced, analytical tools to help improve understanding and management of demand and capacity in this setting. We used individual level data to explore and model patient flows through TT care pathways using process mining and other data-driven methods. Second, we aimed at investigating the impact of wait times on patient engagement with TT services. The aim was to link the patient trajectory maps developed previously with analytical methods that will allow to draw insights on the way patients experienced the care pathway and their likelihood of engaging fully or partially with their treatment. Third, we built dynamic capacity models for NHS Talking Therapies services with "what if" capability, combining historic service performance with estimates of the likelihood of engaging with treatment to predict future capacity requirements.

■ ME-03

Monday, 15:30-17:00 - Room: NTNU, Realfagbygget R9

Appointment scheduling

Stream: Sessions
Invited session
Chair: *Jedidja Lok - Visser*

1 - Predictive decision-support tool for improved nurse scheduling through the application of artificial intelligence
Agita Solzemniece, Jens Brunner

The nurse scheduling problem is a complex optimization task that needs to be solved. While conventional optimization approaches provide an optimal solution, relying on static nursing demand limits the adaptability to the real-world hospital setting. Given the highly specific and dynamic nature of the nursing workload, there is an extraordinary need for adaptive and data-driven decision-support methods. This research project aims to investigate how novel artificial intelligence (AI) methods can be utilized to identify key factors influencing nursing workload and how these can be leveraged to develop a predictive modeling tool for improved decision-support. Various aspects of nursing workload can be tackled to enhance the effectiveness of the nurse scheduling task, such as exploring underlying patterns of workload variables, estimating the required capacity levels, or improving the workload measurement. Applying machine learning to gain better insights into the complexities of nursing workload can deepen the understanding of the nurse scheduling task, leading to better estimates of demand, and better resource management. The main objective of this research is to design a predictive decision-support tool that can provide more accurate projections for required nurse resources and potentially lead to more efficient critical healthcare resource scheduling. We present our modeling ideas and preliminary experiments based on real-world data from a university hospital.

2 - Warm-Starting Outpatient Appointment Scheduling Using Historical Solutions
Sara Cambiaghi, Davide Duma

Most Outpatient Appointment Scheduling (OAS) problems require a recurring optimization task: for each planning period, a new but structurally similar instance of the problem must be solved. Typically, near-optimal solutions for new instances are computed from scratch, without leveraging the knowledge embedded in past solutions. In this talk, we present a novel approach that applies machine learning to exploit historical scheduling solutions, accelerating the optimization process and improving the quality of future schedules.

As a case study, we examine an OAS problem for the CT-scan service in the context of Emergency Departments. In this setting, efficient resource allocation is critical due to the competing demands of three patient categories (outpatients, inpatients, and emergencies) that differ in terms of uncertainty, urgency, and needs.

We propose a stochastic programming model aimed at minimizing outpatient waiting times, inpatient and emergency completion times, and staff overtime. To solve this complex problem efficiently, we employ a non-dominated sorting genetic algorithm. Additionally, we introduce an optimal assignment-based k-Nearest Neighbor algorithm to generate first-generation solutions as a warm start, enhancing the approximation of the Pareto front.

A computational analysis based on real-world data from a regional trauma hub in Pavia, Italy, demonstrates the effectiveness of the proposed approach.

3 - An Integrated Scheduling Model for Optimal Management of Medical Examinations in Tertiary Hospitals
Jingshan Li, Yikai Cao, Zhaoyang Liu, Qing Wang, Zhiwei Chen, Chun Yang

Medical examination is one of the key elements in hospital services. Traditional methods to schedule medical examinations are carried out individually and lead to long patient waiting times. Through an in-depth analysis of MRI examination data, significant differences in equipment usage can be observed, and the examination change can substantially increase preparation time. Using these features, this presentation aims to develop an integrated scheduling model based on a multi-objective optimal design for medical examinations to enhance hospital resource utilization and improve patient experience. The predictive models are integrated into the scheduling system to achieve accurate predictions of MRI usage, thereby optimizing the scheduling process. Various scheduling options, such as shortest time, minimum trips, and shortest distance, are provided for flexible and diverse choices of patients.

This work not only offers a new solution for managing hospital medical examinations but also provides references for resource optimization.

4 - The impact of forecasting: Dynamic appointment scheduling with elective and semi-urgent patients
Jedidja Lok - Visser

In appointment scheduling, it is a common practice to reserve a number of slots for (semi-)urgent demand arrivals, that require service on short notice. The other slots are then given to clients that request an appointment upfront. To determine the number of reserved slots, the (semi-)urgent demand arrivals are often modelled as a distribution with static or seasonal distribution parameters. However, in many appointment scheduling processes, more information becomes available about the urgent demand arrivals over time. For example, in a radiology department, the number of patients present in the ED could forecast the required number of emergency scans. In this study, we propose near-optimal scheduling policies that reserve slots for (semi-)urgent clients, given updated information on the arrival distribution of (semi-)urgent clients in the near future. We formulate the sequential decision-making problem as a Markov decision process, and we develop two approximate dynamic programming approaches to solve our problem, which we compare with a heuristic in a Monte Carlo simulation. We test our approaches on a real-life case study in a Dutch neurology department, where we can use remote patient monitoring information of the stroke patients to forecast the number of semi-urgent requests for outpatient appointments. We discuss first results on this case study and additional theoretical instances, and present managerial implications of near-optimal policies that we derived.

Tuesday, 9:00-10:30

■ TA-01

Tuesday, 9:00-10:30 - Room: NTNU, Realfagbygget R5

Surgery scheduling 1

Stream: Sessions
Invited session
Chair: *Jacoba Bührmann*

1 - Fairness and efficiency, can we achieve both? A case study in training of vascular surgery trainees
Alice Daldossi, Viola Clerici, Roberto Aringhieri, Erwin W. Hans

Operating room planning and scheduling covers a wide range of organisational challenges, from the strategic to the operational level. In recent years there has been an increased focus on integration with upstream and downstream resources. Such an integration determined more challenging optimisation problems.

To the best of our knowledge, the training of junior doctors (junior residents, trainees, etc.) is not yet considered in the healthcare management literature. As a matter of fact, residents must follow a structured learning path that lasts for years, beginning with simpler procedures and gradually progressing to more complex ones as they gain experience. Ensuring a fair and balanced training opportunity for all trainees is essential. Additionally, senior residents require regular practice to maintain their technical skills, as long breaks can negatively affect their performance.

In this talk, we address an advanced scheduling problem that integrates the assignment of trainees to scheduled surgeries, aiming to guarantee a fair training opportunities over the considered time periods (typically months). Validation is based on data from the vascular surgery unit at Città della Salute e della Scienza Hospital (Molinette), Turin, collected between 2020 and 2023.

2 - Evaluation of the performance of machine learning models for the prediction of the operating room occupation time of non-elective surgeries
Anem Dupré, Oualid Jouini, Guillaume Lamé, Thomas Botrel

The optimal planning of non-elective surgeries is made difficult by a lack of visibility on patients' future resource needs. Our study aims at improving the pre-operative visibility of schedulers through the prediction of the operating room occupation time (OT) and post-operative length of stay. We report initial results on OT prediction.

Four machine learning models (MLMs) were selected based on their performance on similar problems: Ridge Regression (RR), Random Forest (RF), XGBoost (XGB), and Multilayer Perceptron (MLP). Using nested cross-validation and a 20% validation set, the models were fitted on the data of patients that underwent non-elective surgery in a large French public teaching hospital between 2015 and 2018.

We included OT for 3,053 patients. On the validation set, the algorithms predicted durations within 20% of actual times (within 20 min for OTs below 100 min) for 58.6% of cases (95% CI [58.1, 590]) for RR, 59.2% [58.5, 59.9] for RF, 59.3% [58.8, 59.8] for XGB and 56.7% [55.8, 57.8] for MLP, respectively. In comparison, using the average of the previous 5 similar surgeries yielded a 48.6% [48.0, 49.4] performance. Surgeons' predictions before surgery obtained 45.5% [44.3, 46.5] performance. Mean Absolute Percentage Error followed similar trends. Performance varied between surgical specialties.

MLMs improve predictions compared to surgeon's estimations by around 10%. Further work is needed to better practical usefulness.

3 - Optimizing OR Efficiency with Just-In-Time Surgical Case Carts: A Combined Simulation and DEA Approach
Joke Borzée, Brecht Cardoen, Mehmet Begen, Isabel Verniers

Just-in-Time (JIT) principles are widely used for inventory management, including in healthcare to optimize surgical material purchasing. However, JIT has yet to be applied to the preparation of surgical case carts, which are carts containing all the material needed for a specific surgery. These are typically assembled one day in advance, increasing the risk of losing sterility, incomplete carts due to ongoing material use, and corridor congestion. In collaboration with a Belgian General Hospital, we explored the feasibility of JIT case carts, where materials are gathered just before surgery. Our study began with direct observations to identify challenges and opportunities. We then used Simulation and Data Envelopment Analysis (DEA) to evaluate 567 JIT-implementation alternatives, varying in buffer type and staffing schedules. Of these, the 217 alternatives that ensured timely readiness in the simulation were benchmarked using a DEA model with three outputs (buffer efficiency, required corridor space at peak hours, and overall space needed throughout the day) and one input (personnel costs). Seven alternatives emerged on the efficiency frontier, with one ultimately implemented after two pilot studies. JIT case carts led to a cost reduction of more than 65%, 68% fewer carts in corridors, and improved sterility and completeness of carts. Overall, the JIT approach enhanced surgical logistics and addressed staff shortages, making it a promising innovation for hospital efficiency.

4 - Predicting nurse turnover intention using machine learning algorithms
Jacoba Bührmann, Siedine Coetzee, Maria Van Zyl, Alwiena Blignaut

Introduction: Nurse turnover is a global issue, worsened by the COVID-19 pandemic. Although risk factors have been widely studied in many countries, research in developing nations is limited. Furthermore, there is a lack of global studies using machine learning algorithms to predict nurse turnover intention. Aim: To predict nurse turnover intention in South Africa using machine learning algorithms. Method: The dataset, from a 2021-2022 national survey of South African nurses (n=4554), was tested against 61 regression machine learning models. The top five models were selected for further comparisons with accuracy scores ranging between 0.7257 - 0.7617. Results: Features highlighted in at least four of the five modules were (in order of ranking): age, satisfaction with wages, job satisfaction, frustration with job, work environment, years worked as nurse and BMI. Conclusion: In line with global research, the findings of this study confirmed that individual factors (e.g., age, health status, years of experience as a nurse), work environment factors (e.g., positive practice environments, job frustration, job satisfaction), and organizational factors (e.g., satisfaction with wages) are the most significant predictors of nurse turnover. However, the ranking of these factors was unique to this study. While turnover is inevitable, targeted interventions at the individual, work environment, and organizational levels could help mitigate high turnover rates.

■ TA-02

Tuesday, 9:00-10:30 - Room: NTNU, Realfagbygget R8

EMS and cyber attacks

Stream: Sessions
Invited session
Chair: *Marion Rauner*

1 - Mapping and assessing cyberattack propagation through digitally interconnected hospitals
Abhilasha Bakre

Digital technologies are being increasingly adopted in hospitals, rendering them vulnerable to cyberattacks. Recent examples can be found of blocked computer systems, breached intranets and theft of patient data. Their consequences include forcing staff back to offline processes, cancellation of numerous appointments, transferring patients

to other hospitals, surgery delays and closing emergency rooms. Additionally, hospitals need to communicate with each other for sharing clinical data, electronic health record, patient management platforms and diagnostic services. An affected hospital could hence act as a vector for a cyberattack to spread to others, causing cascading effects within a healthcare network, shutting down multiple units and disrupting systems. In order to better understand the sequential disruption in clinical services, this study takes a holistic approach by constructing a patient- and data-sharing network to identify the connections between hospitals. The proposed model captures the heterogeneous and inconsistent information security landscape of a hospital, accounting for the complex interrelated structures. An agent-based simulation facilitates analysis of the spread of cyberattacks among various hospitals, in turn providing insights for decision support aimed at ensuring an entire multi-hospital network is more capable of preparing for, responding to and recovering quickly from such attacks in the future.

2 - Quantitatively measuring cyber risk in healthcare
Aiman Zainab, *Emilia Grass*

Cyber attacks in healthcare are increasing rapidly, posing serious risks to patient safety and data security. Although numerous works are offering qualitative assessments of cyber risk, quantitative models remain rather under-researched. This work aims to cover the gap by using the FAIR model to assess cyber risk in healthcare with sector-specific risk scenarios quantitatively. However, as healthcare sector faces dynamic and unique loss, FAIR needs to be modified from its static loss nature to adapt to dynamic healthcare-specific losses such as patient trust loss, reputational damage and other operational damage alongside direct financial losses. Among various risk assessment frameworks, the FAIR model offers a consistent approach to estimating cyber risk in financial terms that makes it an appropriate foundation for the purpose capable of extension. It also breaks risk into factors such as type of threat, vulnerabilities, and impacts that allow threat-specific modifications without breaking its logical framework. This feature of the model is suitable, particularly for healthcare where threats and impacts require individualized treatment and investment decisions are high priority. In addition, it emphasizes the estimation of the frequency of loss events, which is crucial to determine the overall cyber risk incurred due to a cyber attack in healthcare, enhancing predictive power and decision-making accuracy.

3 - Using simulation modelling to compare the impact of alternative hospital operational policies on patient outcomes following flood disasters
Sorour Farahi, *Steffen Bayer*, *Stephan Onggo*, *Sally Brailsford*

This research introduces a discrete-event simulation model examining hospital resilience during and after urban flooding disasters. The model uniquely captures both immediate physical damage to hospital infrastructure and the two-wave patient surge pattern characteristic of flooding events: first physical injuries, then infection-related illnesses. The simulation experiments analyse how different mitigation and response policies affect both routine patients and disaster victims. This work is intended to provide hospital managers with a decision support framework to develop evidence-based disaster response strategies that optimise patient outcomes during crises. We also introduced a novel patient-centred KPI by developing a health utility function that accounts for health-related outcomes in addition to process-based metrics. This function quantifies patient health states across different groups, including both disaster victims and routine patients. Unlike traditional process-based metrics that focus solely on operational efficiency, this comprehensive KPI provides a more complete assessment of hospital performance. The integration of health utility as an outcome measure advances hospital modelling, shifting focus from operational metrics to the quality of patient care and overall health outcomes.

4 - Experimental investigation of personality and strategy types of paramedics from the Austrian Red Cross
Marion Rauner, *Julia Kaltenböck*, *Benjamin Erbschwendtner*, *Ayşegül Engin*

We examine the personality traits and stress coping strategies of paramedics from the Austrian Red Cross. To assess personality traits by an online questionnaire, we used the efficient Big Five Inventory Short Version (BFI-K) to identify three main personality types: 1) resilient, 2) overcontroller, and 3) undercontroller. Furthermore, three different scenarios were designed to investigate stress coping strategies of participants under time pressure (1) active coping, 2) planning, and 3) behavioral disengagement). Additionally, we collected sociodemographic data as well as information about the length of service at the Red Cross and the participants' training. The data were analyzed using regression analysis. This study found no correlation between stress coping strategies and the personality types of paramedics from the Austrian Red Cross. Therefore, the assumption of an existing rescue personality could not be confirmed. Regarding the personality types of the paramedics, a strong self-selection in favor of the resilient personality type was observed. Our research provides insights for policymakers to improve the support systems and working conditions for paramedics, ultimately contributing to the wellbeing of these important critical medical professionals.

■ TA-03

Tuesday, 9:00-10:30 - Room: NTNU, Realfagbygget R9

Location and logistics

Stream: Sessions
Invited session
Chair: *Angel Ruiz*

1 - Inventory management for mobile clinics in the Witzenberg region, South Africa
Isabelle Nieuwoudt, *Linke Potgieter*, *Natasha Sibanda*

In rural South Africa, many communities face challenges accessing healthcare due to long distances to facilities, often requiring travel on foot. Mobile clinics, like those in the Witzenberg region, were introduced to address this issue, offering services like immunizations, chronic disease management, TB screening, HIV testing and women wellness to farming communities. The mobile clinics follow a four-week cycle, visiting different farms, and the inventory required varies based on the number of patients and services needed. At the Prince Alfred Hamlet clinic, which supports two mobile clinics, inventory management is done manually, leading to errors and confusion. Staff, based on experience, stock the clinics weekly, but sometimes need to replenish mid-week, or have to return to some farms if supplies run out. This project aimed to improve inventory visibility and introduce a safety stock approach. Services provided from the patient data was used to estimate weekly inventory demand. A knapsack model was developed to optimize inventory packing, minimizing over- and under-stocking. ABC classification prioritized high-demand items, and penalty weights were applied to critical items to reduce understocking risks. Model results indicate an improvement in understocking issues as well as an improvement in mobile clinic capacity usage by prioritizing more important items to be packed first. It also provided better insight into weekly inventory needs.

2 - A Novel Cross-Entropy Heuristic for Location-Allocation Problems in Healthcare Applications
Mark Tuson, *Owen Jones*, *Elizabeth Williams*, *Paul Harper*

This talk introduces a novel cross-entropy optimization heuristic designed to tackle the high-dimensional location-allocation problems often encountered in healthcare systems. These problems include critical applications such as placement of emergency response resources, equitable placement of public health clinics, and dynamic resource distribution during crises response operations. With solution spaces often exceeding 1030 in size, these problems are computationally intensive and traditionally difficult to solve. We describe the heuristic and benchmark it against established methods across various test functions. While results are similar in low-dimensional settings, the heuristic significantly outperforms others as dimensionality increases. To demonstrate practical impact, we apply the method to real-world ambulance

deployment data, showing measurable operational improvements. The presented work advances the field by offering a scalable, effective solution to a class of problems known to be NP-complete, with potentially strong implications for both research and practice.

3 - Optimising Department Allocation in Hospital Layouts
Allan Larsen, Gaspard Hosteins, David Ajit Kirpekar-Sauer, Dario Pacino

Patient arrivals in hospitals exhibit significant variability, requiring efficient positioning of departments to optimize room usage. This study proposes a novel approach to the Hospital Layout Problem (HLP) in the context of fully flexible nursing room setups. By strategically placing department centres and using the flexibility of nursing rooms, our method dynamically accommodates patients close to the centres, accounting for the departments' variability. To achieve an efficient layout, we develop a Hybrid TABU Search and simulation methodology that prioritizes compact and connected departments, minimizing cross-departmental movement. Incorporating a graph-based formulation of the HLP and a novel quantitative assessment method, we evaluate patient misplacement within flexible layouts. This research optimizes room usage and addresses the complexities of modern healthcare environments. It emphasizes the importance of nursing ward layouts for enhancing operational efficiency and offers a practical methodology for efficient layout design and performance evaluation. In a newly constructed Danish hospital, our approach successfully reduces patient misplacement disruptions over 45% compared to an initial benchmark developed by the hospital management.

4 - Improving accessibility to basic healthcare services by mobile clinics
Angel Ruiz, Julia Isabel Serrato Fonseca, Ana María Anaya-Arenas

Mobile Clinics (MCs) are vehicles designed to improve healthcare accessibility by providing ambulatory services to vulnerable communities that are typically hard-to-reach and lack access to healthcare infrastructure. MCs depart from depots in larger cities (which they generally do not serve) and visit communities to deliver recurrent or one-time primary care to local populations, as well as to individuals from nearby localities. At the end of their routes, MCs return to the depots to replenish supplies, deposit medical samples, and allow personnel to rest. This research is inspired by the Mexican program Fomento a la Atención Médica launched in 2010, which initially targeted 20,000 localities with around 3.9 million people. Given that the program's demand exceeds its capacity, managers aim to plan MC trips that maximize satisfied demand while prioritizing the needs of the most vulnerable population. To this end, two mathematical models are proposed, and their performances are compared.

Tuesday, 11:00-12:30

■ TB-01

Tuesday, 11:00-12:30 - Room: NTNU, Realfagbygget R5

Poster session

Stream: Sessions
Invited session

1 - A multiperiod resource minimization model for rural emergency medical services networks with ground and air ambulances
Lieke Jansen, Iris F.A. Vis, Ilke Bakir, Durk-Jouke van der Zee

Emergency Medical Services (EMS) must meet strict response time standards to ensure timely care for life-threatening emergencies. However, achieving these standards in rural areas is challenging due to long travel distances, low call volumes, and staff shortages. Since increasing the number of ambulances is usually not feasible in rural EMS systems, they could benefit from replacing some of their ground ambulances with air ambulances with a large range to enhance coverage. We propose a model that optimizes the number and locations of ground and air ambulances across different shifts while ensuring response time compliance. Unlike traditional EMS optimization approaches, our model evaluates system-wide response time compliance rather than individual demand-node performance. The problem is formulated as a mixed-integer nonlinear programming (MINLP) model incorporating nonlinearities in the coverage computation. Given the complexity of large-scale instances, we develop an adaptive large neighborhood search (ALNS) metaheuristic. Additionally, we introduce an approximation method to assign calls to vehicles and estimate busy probabilities, including less urgent calls. Our approach is validated using real-world EMS data from the Dutch Province of Friesland, incorporating electric vertical take-off and landing (eVTOL) aircraft as air ambulances. Results show that integrating air ambulances as rapid response units enhances coverage while minimizing resource use.

2 - Panel Size Management for Enhanced Patient Care: A Data-Driven Simulation Approach
Mina Moeini, Jessica Stockdale, Alexander Rutherford, Krisztina Vasarhelyi, Le Tuan Minh Nguyen, Jacob Umbach, Tarnjit McCauley, Cassandra Djurfors, Jenny Hamilton Harding, Kenneth Hawkins, Harleen Arora

Determining optimal panel size—patients assigned to a healthcare provider—is crucial for ensuring timely access to care and provider well-being. While conventional methods rely on population averages, they fail to address the unique needs of primary care in Community Health Centres (CHCs) serving biopsychosocial complex populations, including individuals experiencing homelessness, mental health conditions, and barriers to care. CHCs often operate with providers working less than full-time while managing complex cases. In partnership with Vancouver Coastal Health, we developed a discrete event simulation (DES) model that simulates CHC operations as discrete events occurring over time. This approach captures the unpredictability of client arrivals and service demands, providing a predictive, adaptive representation of patient flow and provider workload. Using three years of administrative data to model walk-in and booked appointments and no-shows, we determined optimal panel size ranges meeting key performance indicators, including time to next available appointment and frequency of multiple-patient overbooking. Our recommended panel sizes were consistently smaller than those produced by standard calculation methods, aligning with the complex care needs of CHC clients and the unique operational models of each center. Our simulation model is a practical decision-support tool enabling CHCs to address capacity management challenges through data-driven decision-making.

3 - When Every Minute Counts: Predictive Modeling and Simulation in Organ Donation Management

Arianna Freda, Maurizio Naldi, Gaia Nicosia, Andrea Pacifici, Gianfranco Teti, Mariano Feccia

Organ transplantation is a life-saving procedure that replaces a damaged organ in a patient. Its success depends not only on medical expertise, but also on how efficiently and quickly the organ donation process is managed, as delays can lead to organ degradation and reduced transplant success rates. Using real-world data from the Regional Transplant Center of Lazio (Italy), we model the organ donation process, quantifying the duration and cost of each activity. We propose a simulation-based framework to explore and optimize the entire process, focusing on the trade-off between time efficiency and cost-effectiveness. Specifically, Monte Carlo simulations are performed to evaluate alternative management policies that govern activity scheduling, particularly in relation to consent acquisition—one of the most critical and uncertain steps in the process. To further support decision-making under uncertainty, we introduce a predictive model that estimates the probability of obtaining family consent. By incorporating consent prediction into the simulation process, we enable more informed assessments of each policy's effectiveness under varying conditions. Overall, our results provide a decision support system that helps decision-makers at the Transplant Center select the most appropriate strategy for each case, while minimizing delays and avoiding unnecessary costs.

4 - Reusable Simulation of Emergency Departments: A Domain-Specific Modelling Language Approach

BoFan Zhang, Steffen Zschaler

Discrete event simulation (DES) has long supported process improvement in emergency departments (EDs). However, because most DES models are not designed for reuse, they are often developed from scratch for each ED setting. This limits their broader potential to support efficient and evidence-based change in healthcare. Additionally, non-technical stakeholders (e.g. ED clinicians) often depend on simulation experts to translate their knowledge into models, slowing iteration and reducing direct engagement.

To address this, we propose a reusable simulation framework based on a domain-specific modelling language (DSML) tailored for ED operations. The DSML offers intuitive, high-level modelling constructs aligned with ED workflows, enabling healthcare experts to build and adapt models without requiring programming knowledge.

Utilising a design science approach, we aim to develop a web-based modelling workbench that integrates graphical and text editors to help experts better use the DSML. We will validate our DSML-based approach through case studies in multiple EDs, including evaluations of model correctness, cross-ED reusability, and usability for healthcare professionals.

We build on existing efforts on generalise ED simulation modelling and extend them with DSML and toolchain. We expect our approach to promote more accessible and transferable simulation practices in time-critical ED settings.

5 - Volatility-stratified surgical portfolios with layered spackling strategy for operating room capacity planning

Chao Pan, Erik Demeulemeester

Effective operating room (OR) capacity utilization is crucial for both patient care quality and healthcare financial performance. Traditional OR planning struggles to balance scheduled elective surgeries with unpredictable emergency cases, often leading to inefficiencies like overtime and undertime. This paper adopts a design science approach to propose a novel solution featuring volatility-stratified surgical portfolios and shared OR capacity allocation. In collaboration with hospital managers and surgeons, we first framed the challenges of OR planning and explored demand-side flexibility strategies. A critical review of current methods revealed key opportunities for more adaptive and efficient planning. Drawing on volatility portfolio theory and the layered spackling strategy, we introduce a volatility-stratified portfolio that classifies surgeries into emergency (high volatility), general elective, and flexible elective (low volatility) categories. This enables the strategic use of low volatility surgeries to absorb fluctuations and mitigate emergency-related uncertainty. Comprehensive simulation—incorporating uncertainty and sensitivity analyses with empirical data from two hospitals (pre- and mid-COVID-19)—demonstrated notable improvements in OR utilization. Final validation through simulation-based assessments and workshops with practitioners confirmed the approach's feasibility, applicability, and potential for broader adoption across service sectors.

6 - The impact of forecasting: Dynamic appointment scheduling with elective and semi-urgent patients

Jedidja Lok - Visser

In appointment scheduling, it is a common practice to reserve a number of slots for (semi-)urgent demand arrivals, that require service on short notice. The other slots are then given to clients that request an appointment upfront. To determine the number of reserved slots, the (semi-)urgent demand arrivals are often modelled as a distribution with static or seasonal distribution parameters. However, in many appointment scheduling processes, more information becomes available about the urgent demand arrivals over time. For example, in a radiology department, the number of patients present in the ED could forecast the required number of emergency scans. In this study, we propose near-optimal scheduling policies that reserve slots for (semi-)urgent clients, given updated information on the arrival distribution of (semi-)urgent clients in the near future. We formulate the sequential decision-making problem as a Markov decision process, and we develop two approximate dynamic programming approaches to solve our problem, which we compare with a heuristic in a Monte Carlo simulation. We test our approaches on a real-life case study in a Dutch neurology department, where we can use remote patient monitoring information of the stroke patients to forecast the number of semi-urgent requests for outpatient appointments. We discuss first results on this case study and additional theoretical instances, and present managerial implications of near-optimal policies that we derived.

Tuesday, 13:30-15:00

■ TC-01

Tuesday, 13:30-15:00 - Room: NTNU, Realfagbygget R5

Analytics and healthcare management

Stream: Sessions
Invited session
Chair: *Thomas Kingsley*

1 - Prediction of Diabetic Foot Ulcer Using Bayesian Networks
Malavika Krishnakumar, Vivek Lakshmanan, Georg Gutjahr, Ulla Hellstrand Tang, Agnetha Folestad

In European clinical practice, the D-Foot tool (Tang et al., 2017) has been introduced as a structured method for screening diabetic patients and assessing their risk of developing diabetic foot ulcers (DFU). However, its applicability outside Europe has not been explored. This prospective cohort study starts with investigating to what extent D-Foot is applicable in India. We observe that the D-Foot tool can be assessed with substantial intra- and inter-rater agreement, as measured by Cohen's kappa, and high clinical usability, as measured by the System Usability Scale (SUS). Moreover, the study proposes a general approach using Bayesian network (BN) classifiers to predict patient outcomes such as new-onset DFU, Charcot foot, neuropathy, amputation, and mortality. The predictors include demographic data, clinical history, laboratory parameters, ankle-brachial index (ABI), vibration perception threshold tests (VPT), as well as the items from the D-Foot tool. The BN worked well on the Indian data, as measured by cross-validation, and it provides a promising approach for similar applications in diverse clinical and epidemiological environments.

2 - Optimizing Total Flow Time in Hospital Sterilization Departments Using Column Generation
Robin Schlembach, Sebastian Schiffels, Jens Brunner

The Central Sterile Services Department (CSSD) ensures, that reusable medical devices are sterilized and available for operating procedures. However, scheduling the sterilization stage, where instruments are batched and processed, poses challenges due to demand variability and strict turnaround requirements. We model the sterilization process as a parallel batch scheduling problem with job release dates, sizes, and family-dependent processing times, aiming to minimize total flow time. Given the problem's NP-hard nature, standard solvers struggle with realistic instances. To address this, we develop a column generation heuristic that decomposes the problem by job families, enabling fast convergence. Additionally, a specialized heuristic efficiently solves subproblems and generates promising columns. Validated on real-world CSSD data, our approach solves instances with over 200 jobs in an average of 2 minutes while maintaining an LP-IP gap below 1%. This scalable method enhances scheduling efficiency, reduces total flow time, and improves hospital workflow.

3 - Measuring the effect of deprivation on primary health care performance using data envelopment analysis and malmquist indices
Holly Merelie, Carla Amado, Sérgio Santos

Life expectancy is typically shorter in areas with higher deprivation, highlighting the need for policymakers and healthcare managers to focus on reducing health inequalities through efficient and effective care. This study aims to assess the impact of deprivation on primary healthcare performance using data from the National Health Service (NHS) in England. Two methods are applied: Data Envelopment Analysis (DEA) to evaluate the performance of 188 Clinical Commissioning Groups (CCGs), whose duties were recently taken on by the new Integrated Care Systems (ICSs), and the Malmquist Index (MI) to assess deprivation's effect on performance. The DEA results reveal significant variation among CCGs in equity, efficiency, and effectiveness, indicating substantial room for improvement. The MI results show that while CCGs in more deprived areas had more resources per capita and higher efficiency, they were generally less effective than those in less deprived areas. This emphasizes the need to enhance health and social policies to address persistent health inequalities due to deprivation, a critical challenge for the new ICSs. This study illustrates how DEA and MI can support policymakers and managers in this effort.

4 - Hierarchical Bayesian Model for 30-Day Hospital Census Forecasting and Resource Optimization at a Large Academic Medical Center
Thomas Kingsley

Our team developed a hierarchical Bayesian model designed to accurately predict hospital census 30 days in advance across inpatient service lines for Mayo Clinic sites located in southeast Minnesota, Arizona, and Florida. Utilizing forecasts generated by this model, operational adjustments were made through the hospital command center to optimize staffing levels and elective surgical scheduling. This proactive approach effectively maintained inpatient census around the target level of 85%, avoiding critical overcapacity or inefficient undercapacity situations (below 70%). Initially critical during Mayo Clinic's COVID-19 pandemic response, the model has since continued to provide substantial operational value and remains integral to daily decision-making processes within command centers across Mayo Clinic's major healthcare facilities.

The forecast model was trained on existing census data collected in Mayo Clinic's electronic health record relational database. Elective surgical data was separately stored in a curated database created at Mayo Clinic over a decade prior to our model development. Several time-series modeling approaches were assessed and the hierarchal Bayesian model performed the best especially when considering inter-hospital transfers across sites - a large source of inpatient admissions at Mayo Clinic and most academic medical center's in the United States.

■ TC-02

Tuesday, 13:30-15:00 - Room: NTNU, Realfagbygget R8

Integrated planning

Stream: Sessions
Invited session
Chair: *Sara Ceschia*

1 - Swap-Stability in Nurse-to-Patient Assignment considering personal preferences
Bianca Lauer, Christina Büsing, Gréanne Leeftink

In hospitals, assigning available nurses to a ward's inpatients is performed whenever a change in nurses or patients occurs. Although nurse-to-patient assignment requires considering multiple complex factors it is carried out manually in most hospitals, which is often time consuming. Suggested assignments usually aim to distribute patient workload evenly among nurses and to ensure continuity of care where possible. Yet, in practice nurses often swap patients when the given assignment does not fulfil their personal preferences. To ensure that schedules are accepted by staff, nurses' individual preferences need to be represented in the nurse-to-patient assignment.

In this talk, we present a mathematical model that considers a fair distribution of the workload between the nurses as well as incorporating personal preferences and stability constraints, ensuring that no pair of nurses would rather swap patients. Since the nurses' preferences are mostly unknown in practice, we use incomplete preferences in the form of a traffic light system. This enables us to group patients into three sets per nurse: those the nurse would like to care for, those they would rather not be assigned to and a usually larger group of patients they feel indifferent about. The model is evaluated in a computational study making use of real-world data.

2 - An Adaptive Large Neighborhood Search Approach for the Integrated Patient-to-Room and Nurse-to-Patient Assignment Problem

Emily Lex, Fabian Schäfer, Alexander Hübner

Optimizing patient-to-room and nurse-to-patient assignments is crucial for efficient hospital workflows, high-quality care, and patient and staff satisfaction. Integrating both assignment problems enables the optimization of additional objectives that depend on the interaction of the two assignment problems. For example, minimizing the walking distances of nurses or assigning the minimum number of nurses to patients in the same room to mitigate negative effects, such as the spread of infections between rooms by nurses or the disturbance of patients. For this recently proposed integrated problem formulation, we designed an Adaptive Large Neighborhood Search approach. For evaluation purposes, computational experiments are executed on both the available real-world and artificially generated instances. To evaluate the quality of the presented solution method, a comparison to the current best-known results is presented, underscoring the efficacy and superiority of the proposed solution method.

3 - A Two-Step Matheuristic for the Integrated Healthcare Timetabling Problem

Camille Pinçon, Nohaila Ahssinou, Flore Caye, Prakash Gawas

The IHTC 2024 competition involves integrating three interconnected subproblems: Surgical Case Planning (SCP), Patient Room Assignment (PAS), and Nurse-to-Room Assignment (NRA). To tackle this highly complex problem, we adopt a two-step approach. First, we construct an initial feasible solution by sequentially solving each subproblem, ensuring both feasibility and computational efficiency. Next, we refine this solution using a Fix-and-Optimize (F&O) matheuristic, which iteratively enhances solution quality by selectively optimizing decision variables. The SCP phase focuses on scheduling feasibility while accounting for capacity constraints and workload balance. The PAS phase assigns patients to rooms based on gender and capacity constraints, employing two alternative strategies to maximize feasibility. The NRA phase ensures continuity of care and workload balance through a segmented planning horizon approach. Additionally, we apply a set of targeted destroyers that unfix parts of the feasible solution and then resolve specific subproblems to improve overall quality. Parallel computing is leveraged to accelerate solution generation and refinement. Our methodology is implemented using the JuMP library in Julia, with Gurobi as the optimization solver, running on multi-core architectures. This approach effectively balances feasibility, computational efficiency, and solution quality.

4 - The Integrated Healthcare Timetabling Competition 2024 (IHTC-2024)

Sara Ceschia, Roberto Maria Rosati, Andrea Schaerf, Pieter Smet, Greet Vanden Berghe, Eugenia Zanazzo

We launched the Integrated Healthcare Timetabling Competition (IHTC-2024, https://ihtc2024.github.io/) to stimulate research on the specifics of integrated scheduling problems in healthcare. We introduced the Integrated Healthcare Timetabling Problem (IHTP), which brings together three critical problems in healthcare: surgical case planning, patient admission scheduling, and nurse-to-room assignment. In particular, it requires the following decisions: (i) the admission date for each patient (or admission postponement to the next scheduling period), (ii) the room for each admitted patient for the duration of their stay, (iii) the nurse for each room during each shift of the scheduling period, and (iv) the operating theatre for each admitted patient.

We provided a public dataset composed of 30 instances in JSON format, along with the solution checker (in C++) that certifies the quality of a given solution. We received 32 submissions from teams across various countries around the world. In the first stage of the competition, we selected five finalists from all the participants whose solution methods were evaluated on the hidden dataset on our machine in the second stage. In this talk, we will present the competition results and the general insights we gained about the competition, the problem, and the solution methods.

■ TC-03

Tuesday, 13:30-15:00 - Room: NTNU, Realfagbygget R9

Optimisation

Stream: Sessions
Invited session
Chair: *Christina Büsing*

1 - Elective Case Scheduling under Surgery Duration Uncertainty

Sonja Weiland, Martina Kuchlbauer, Lorenza Moreno, Alexander Müller

At the operational level, a central task of the operating room management is to plan upcoming elective surgeries. In the literature, this problem is referred to as Elective Case Scheduling (ECS). We develop a decision support tool for the ECS with a planning horizon of one day and uncertain surgery durations. For each planned surgery, we are given a discrete probability distribution of the surgery duration. These distributions are obtained using a machine learning approach applied to historical data from a large German hospital. We model the ECS as a mixed-integer program that determines the operating room and the starting time for each scheduled surgery, subject to resource constraints. In our baseline model, the expected values of the surgery durations are used as parameters of this mixed-integer program. To account for the uncertainty of the surgery durations more accurately, we add chance constraints to the model. So, we can control the probability that at most a certain number of overtime hours occur. We compare the baseline model and the chance constraint model.

2 - Resilience Optimization of a Network of Hospitals Against Cyberattacks

Stephan Helfrich

Over the past decade, hospitals have increasingly become prime targets for cyberattacks. These attacks can lead not only to the theft of sensitive patient data and financial losses but also to significant disruptions in hospital operations. Particularly, as seen during the WannaCry attack in the UK, multiple hospitals can be affected simultaneously due to shared IT infrastructure and virus spread. Even non-affected hospitals face increasing demands due to forced patient transfers from (partially) shut-down hospitals nearby. Consequently, a whole-hospital-network approach to assess and improve the resilience of hospitals against cyberattacks is of major importance.

We introduce a defender-attacker-defender optimization model designed to evaluate and optimize intra-hospital and inter-hospital preparation and respond strategies to withstand the negative impact of cyberattacks. Particularly, our model integrates the interdependency between the network of hospitals and their patient flow and attack scenarios on the hospitals' IT infrastructure based on attack graphs. This approach allows us to capture the criticality of vulnerabilities in the IT infrastructure and to evaluate both the negative impacts of cyberattacks and the positive effects of countermeasures on hospital operations. Finally, we discuss the application of our model to the hospital landscape of Baden-Württemberg, Germany.

3 - Coin making problem to Outpatient Pharmacy Automation System

Kiok Liang Teow, Eric Yang, Jabigo Mark Anthony Cadinong, Hong Yee Lim, Yong Chuan Goh, Hui Hui Wang, Edmund Liew, Supadhara Ramaiyah, Zhecheng Zhu

Some major public hospitals and polyclinics in Singapore collaborated to automate their outpatient pharmacies picking processes to improve safety and efficiency. Automated pharmacy dispensing machines (ADM) could process electronic prescriptions and pick medications stored in standardized boxes. Singapore's public healthcare institutions purchased medication in bulk pack size (e.g. 1000 tables per

pack), which then would be repackaged into smaller quantity packages that matched the prescribed quantity.

Our task was to optimise the re-pack configurations. This was like a coin-changing problem, but with more constraints, such as if pack sizes could be any number or had to be in multiples of blister-size, and rounding rules for medication.

This study was conducted by a team of pharmacists and operations researchers. Mixed integer programming was used. Historical prescription patterns were analysed to form the basis of the demand. The study aimed to determine the optimal medication pack size configuration for each mediation, with multiple objectives of: (1) maximising automation coverage for prescription fulfilment, (2) minimising the number of boxes used, and (3) minimising rounding of medications from the prescribed quantity. The mathematical model was applied across hundreds of medications, with each solution tailored to specific prescription patterns and drug characteristics. The resulting optimised configurations served as the foundation for inventory planning.

4 - Fair planning of out-of-hours service for pharmacies
Christina Büsing, *Timo Gersing*

Pharmacies ensure a continuous supply of pharmaceuticals at any day and night time. An out-of-hours plan assigns 24-hour shifts to a subset of pharmacies on each day such that an appropriate supply is guaranteed while the burden on pharmacists is minimized.

We present a model for the planning developed in collaboration with the Chamber of Pharmacists North Rhine. Using aggregation and matheuristics, we compute almost optimal plans for the North Rhine area in short time. The computed plans assign fewer shifts in total compared to the real plan, but they exhibit an unfair concentration of shifts. We propose a strategy for integrating fairness into the planning based on a lexicographic fairness criterion. Using theoretical insights, we compute out-of-hours plans that are almost maximally fair in short time.

Tuesday, 15:30-17:00

■ TD-01

Tuesday, 15:30-17:00 - Room: NTNU, Realfagbygget R5

Blood and sepsis

Stream: Sessions
Invited session
Chair: *John Blake*

1 - A Discrete-Event Simulation Model to Improve Blood Component Production
Aleyna Gürsoy, *Roberto Pinto*, *Federico Piccinini*, *Davide Ghezzi*, *Ettore Lanzarone*

The separation of donated whole blood units into blood components, including red cells, platelets and plasma, is a complex process that requires a dedicated production site with specific equipment and skills. Despite its importance, this separation step has received the least attention in the literature dealing the Blood Donation Supply Chain. However, this production system can benefit greatly from dedicated decision support systems to improve production efficiency and quality. In this regard, we address the blood component production process by developing a discrete-event simulation model of the production system, consisting of equipment and human resources that require close coordination. After validating the proposed model on real data from a large production system in Northern Italy, we used it to conduct "what-if" analyses, with the aim of assessing both performance and the impact of changes to the system. For example, we compared an inline production system, with sequential execution of operations, and a cellular production system, with operations executed in parallel. In addition, we used the simulation model to validate a previously developed scheduler based on a mixed integer linear programming model. Based on the promising results we obtained, further analyses will be conducted considering stochastic processing times, machine failures, or to improve the shift patterns of human operators.

2 - Optimising Early Warning Systems: Exploring Enhanced Digital Sepsis Alerts and Equity Challenges in Patient Care
Kate Honeyford, *Alf Timney*, *Ceire Costelloe*

Early Warning Scores are used in hospitals to support clinical staff in the identification of patients at risk of deterioration. In England, the National Early Warning Score, now in its second iteration (NEWS2), is mandated in all acute hospitals. As hospitals adopted electronic health systems (EHRs), NEWS2 was embedded into EHRs alongside digital sepsis alerts (DSAs), as sepsis is a common cause of patient deterioration. However, NEWS2 and the majority of DSAs do not take advantage of the rich data in EHRs. It is not known whether adopting two alerting systems improves patient outcomes. We have previously shown that the introduction of a DSA which included blood biomarkers was associated with reduced mortality. In this study we show that this DSA identified a higher proportion of additional patients who were at risk of deterioration than the DSAs which relied on clinical observations. Initial findings indicate that ethnicity can influence DSA triggers, highlighting potential biases in alerting systems. This poses challenges for clinical staff in responding to alerts. As EHRs continue to be embedded in hospitals, the richness of the data should be exploited to ensure the patients in most need of intervention are rapidly identified.

3 - Sequential Selection of Biomarkers in Sepsis Risk Scores Using Reinforcement Learning
Anandakrishnan Nandakumar, *Dipu T. S.*, *Georg Gutjahr*

Sepsis is a life-threatening condition caused by a dysregulated host response to infection. Early recognition and timely treatment are crucial, as delayed diagnosis can rapidly lead to organ damage, tissue injury, and mortality. Sepsis risk scores help quantify disease severity, predict disease onset and progression, and guide treatment strategies.

High-precision risk scores often rely on costly biomarkers, including cytokines, procalcitonin, and immunophenotyping markers. In low-and-middle-income countries, a key question is whether a combination of surrogate markers can initially substitute for the costly markers, reserving the latter for high-risk patients identified during the initial screening phase. To address this question, we consider the sequential decision-making problem of selecting an initial set of biomarkers and subsequently adding more costly markers over the following days in a data-dependent way. We formulate the problem as a Markov decision process and use reinforcement learning to find a policy that minimizes cost while maintaining a high predictive performance, measured by the Net Reclassification Improvement (NRI) metric compared to full risk scores. The model is developed using data from the Indian OASIS cohort and the US MIMIC cohort and validated with a training-test split. We identify the potential for cost savings with an acceptable reduction in predictive accuracy.

4 - Facilities Planning at CBS to meet collection targets in the 2030's
John Blake

After COVID-19 donor behavior in Canada shifted—fewer individuals became donors, and existing donors lapsed more often. This, coupled with converting whole blood centers to plasma donation centers and higher demand for packed red cells, led to lower inventory levels.

Analysis shows donor participation declines with distance from collection sites. To meet collection targets, more collection opportunities (fixed or mobile) are needed. However, adding new centers alters the Canadian Blood Services (CBS) network structure. To address this, a network optimization model was developed to:

1) Identify the number and types of facilities to be operated (and over what time frame) by CBS. 2) Assign geographic regions of donors (FSAs) to collection sites. 3) Set annual targets for collection sites. 4) Develop a minimum cost assignment of transportation links between collection and production sites. 5) Determine an annual production plan for production sites. 6) Make a minimum cost assignment of products at distribution sites to demand sites to minimize transportation costs.

In this talk we discuss the develpment of the model, describe the interesting process of validating it, and provide preliminary results.

■ TD-02

Tuesday, 15:30-17:00 - Room: NTNU, Realfagbygget R8

System dynamics

Stream: Sessions
Invited session
Chair: *Esma Gel*

1 - Using system dynamics to assess the availability of emergency care at a regional level
Matthew Pentecost, Britt Zweers, Geert-Jan Kommer, Ingrid Seinen, Victoria Shestalova, Jeljer Hoekstra

We present a system dynamics model of a regional emergency and urgent care network encompassing hospital emergency departments (ED), ambulances, and urgent primary care. By connecting these services, the model identifies levers for reducing ED bottlenecks by improving resource allocation within the care system. It provides insights into how different policies can affect available ED capacity (beds and personnel) as well as patient turnaround times (waiting and treatment times), enabling scenario analyses of policy options. The model features two key innovations. First, it covers the complete regional emergency and urgent care system, allowing for the study of substitution possibilities within the system. Second, each ED is modeled as a separate entity, offering flexibility and granularity at a regional level. A region can have any number of EDs, with different sizes, patient mixes, and other characteristics. This level of detail provides insight into within-region differences in ED use and allows for the study of patient reallocations linked to changes in the supply of care. The model was calibrated using data from one region in the Netherlands. A scenario analysis was conducted to assess the impact of developments such as increased demand for care and the closure of an ED. We present the results of this application and discuss the model's future potential. Although developed for the Netherlands, many aspects of this model are potentially useful in international settings.

2 - Exploring the drivers of unsustainable pressures in health and social care: A qualitative system dynamics approach.
Le Khanh Ngan Nguyen, Holly McCabe, Susan Howick, Itamar Megiddo, Soumen Sengupta, Alec Morton

Health and social care systems face substantial pressures arising from intricate interdependencies between system elements. While theoretic perspectives like "complex adaptive systems" and "sociotechnical systems" exist to characterise this complexity, translating them into coordinated action remains challenging. This research presents an innovative application of qualitative system dynamics through Causal Loop Diagrams (CLDs) to uncover underlying structural patterns driving persistent issues and policy resistance. Developed through stakeholder interviews in Scotland and corroborated with UK-wide evidence, our CLD illustrates how well-intended interventions create unintended cross-sectoral effects. Organisational silos and time delays obscure feedback complexities, while competing perspectives and reactive coping strategies generate emergent system characteristics that challenge the simplified concept of "whole system working". We identify a paradox: cross-sector collaboration initiatives can undermine personalised care delivery when strategic and political objectives conflict. Our research advances system dynamics methodology by integrating individual and cascaded system archetypes, improving policy-insight communication clarity while preserving essential feedback loops. This provides decision-makers with an accessible tool to understand complex system behaviour, engage stakeholders through iterative model refinements, and guide systems toward a more equitable states.

3 - Investigating health policies in childhood obesity using system modelling
Hannah Callaghan, Linke Potgieter

Since 1990, global obesity rates have doubled. The 2023 World Obesity Federation's Atlas predicts that half the world's population will be overweight or obese in the next 12 years. South Africa is not exempt to this growing crisis, as half of the country's adult population falls into these classes. Although obesity is often perceived as an issue of adulthood, a rising number of South African children are affected, with 13% classified as overweight or obese. Childhood obesity is a strong predictor of obesity in adulthood and is linked to an increased risk of chronic diseases. Since children are heavily influenced by their immediate environment, it is important to investigate the effects of environment changes on children. It has been shown that obesity is largely a result of social networks. Based on this understanding, this research develops a mathematical model to examine the spread of obesity across different population and BMI groups. The model captures the complex dynamics of obesity through a system of differential equations. It was calibrated to South African data and validated from past studies on dynamics and prevalence of obesity, as well as surveys conducted with healthcare professionals specializing in bariatrics. Additionally, the model is used to explore the possible impact of prevention strategies through sensitivity analysis and simulation experiments, identifying where the focus of interventions for reducing childhood obesity in South Africa should be.

4 - Simulation and Optimization Approaches for Pandemic Response: EpiMORPH
Esma Gel, Sanjay Mehrotra, Joseph Mihaljevic

Epidemiological modeling is a critical tool for understanding the dynamics of pathogen transmission and predicting future outcomes, supporting public health responses. While illustrating the power of modeling in epidemic management, SARS-CoV-2 also highlighted inefficiencies in current modeling practices, with myriad models of varying

assumptions, approaches, and quality flooding public forums. One of the main issues is that modeling studies and software are so customized that scientists must often start from scratch to create model-based technologies that address new pathogens or that seek to understand transmission dynamics in new locations. Moving epidemiological modeling from a collection of independent studies towards a more efficient, consensus-building endeavor will require the innovation of tools that accelerate the construction and testing of models, and that facilitates rigorous model comparison. This talk introduces EpiMoRPH (Epidemiological Modeling Resources for Public Health), a groundbreaking tool for advancing epidemiological modeling. It provides a robust framework for rapid model development and evaluation, promoting deeper understanding of epidemic dynamics. EpiMoRPH features an advanced optimization toolkit, empowering public health practitioners to make informed decisions on intervention placements and strategies. We will focus on the latest components of the tool, including its system dynamics modeling and resource allocation optimization capabilities.

Thursday, 9:15-09:30

■ HA-04

Thursday, 9:15-09:30 - Room: St Olavs, Kunnskapssenteret KA12

Opening Practitioner Day

Stream: Keynotes and panels
Invited session

Thursday, 09:30-10:30

■ HB-04

Thursday, 09:30-10:30 - Room: St Olavs, Kunnskapssenteret KA12

Plenary Lina Grännö

Stream: Keynotes and panels
Invited session
Chair: *Henrik Andersson*

1 - Transforming healthcare delivery through data-driven organizational development and strategic planning
Lina Grännö

As healthcare strives to meet patients' needs with high quality and accessibility, operations research (OR) offers opportunities to streamline and improve healthcare processes. In this keynote, we will explore how data-driven organizational development and strategic planning can transform healthcare delivery through practical examples from Karolinska University Hospital. We will discuss critical questions such as: How can we ensure optimal use of healthcare resources? While we may not have all the answers, we will share insights and experiences that can help shape future discussions.

Thursday, 11:00-12:30

■ HC-04

Thursday, 11:00-12:30 - Room: St Olavs, Kunnskapssenteret KA12

Innovation 1

Stream: Sessions
Invited session
Chair: *Kjartan Kastet Klyve*

1 - Integrated care modelling utilising a shared patient information system
Joe Viana, Anders N. Gullhav, Heidi Dreyer, Marte Holmemo, Aud U Obstefelder, Hanne M. Rostad, Øystein Døhl

The HARMONI project addresses the growing challenges in healthcare systems caused by aging populations, complex patient needs, and workforce shortages. Funded by the Research Council of Norway, HARMONI is a transdisciplinary initiative involving Trondheim Municipality, St. Olavs Hospital, and academic partners.

At the heart of HARMONI is a suite of modelling and simulation tools, including dashboards, simulators, optimization algorithms, and a shared patient information system. These tools support tactical-level planning, capacity dimensioning, and process redesign. The project emphasizes participatory model development, drawing on stakeholder engagement and action research to ensure relevance and usability.

HARMONI integrates insights from operations and supply chain management, health services research, and change management. It aims not only to support decision-making but also to serve as a pedagogical tool for fostering systems thinking among healthcare professionals.

This presentation invites discussion on several fronts: How can modelling and simulation models be effectively validated across disciplinary boundaries? What are the best practices for integrating simulation tools into real-world healthcare planning? How can participatory modelling approaches be scaled across institutions? And how might these tools influence long-term policy and practice in integrated care?

2 - Explainable Optimisation in Healthcare
Felix Engelhardt, Christina Büsing, Catherine Cleophas

Explainability is an important topic in AI research, since many common techniques are "Black Boxes" for users. In comparison, in optimisation and operations research, we like to think that our models are explainable by nature. However, is that really the case? To actual users such as industry partners, doctors or nurses, a mixed-integer programming solver is as arcane as a deep neural network. The same applies to many combinatorial algorithms and heuristics.

In this session, we raise several examples of explainability in optimisation in the specific context of healthcare optimisation. These include modelling to generate alternatives for rostering problems, counterfactual explanations for (integer) linear programming, and simulation - showcasing the broad range of notions of explainability that might be relevant in practice.

Based on this we would like to discuss the following questions: * What types of explainability do practitioners in healthcare desire (e.g. counterfactuals vs transparent vs rule-based)? * To what extent can explainability help with successfully implementing real-world problems? * What techniques are being used to do so? * Where are potential deficits in terms of the current explainability of healthcare OR, and where could research be strengthened by including explainability considerations?

3 - Introducing capacity planning in home care
Annelies Van Der Ham

Driven by an ageing population, ongoing nurse shortages, and the shift of care from hospitals to homes, home care organisations face growing demand and increasing planning complexity. Next to matching capacity and demand, home care planners must also create routes, meeting patients' care needs at specific time windows while minimizing travel times. Currently, appointment scheduling and routing are performed by nurses or local team planners, resulting in inefficiencies, lagging performance, and rising stress among staff. To reduce workload and enhance capacity, a more professional and data-driven approach is essential.

In this presentation, we will discuss our approach to implementing integrated capacity planning in home care, connecting strategic, tactical, and operational decision-making. Key components include setting concrete goals, measuring performance, professionalising the planner's role, and introducing advanced planning and routing software. We share lessons learned from real-world implementation, and conclude with our plans for the future, offering guidance for organisations seeking to future-proof their home care planning.

4 - Algorithmic surgical planning at Oslo University Hospital
Kjartan Kastet Klyve, Jørgen André Schreiner

We present the Surgical Cockpit, a comprehensive software developed and implemented in an innovation partnership with Oslo University Hospital, which leverages selected Operations Research methods. A key feature of the product is algorithmic planning of surgeries. Furthermore, the product includes numerous other capabilities, e.g. a patient portal where patients can communicate their availability, a calendar view reflecting different patients' risk of no-show, a re-planning module for planning of emergency cases, real time surveillance of surgical activity etc. In our session, we will tell the story of the product and how.

■ HC-05

Thursday, 11:00-12:30 - Room: St Olavs, Kunnskapssenteret KA11

Innovation 2

Stream: Sessions
Invited session
Chair: *Alexander Rutherford*

1 - The last mile of research: How do we spread ORAHS' knowledge and make it stick?
Sebastian Rachuba, Erwin W. Hans

Effective knowledge dissemination is crucial for bridging the gap between research and practice and, ultimately, for creating awareness and impact. While the academic reward and recognition system often prioritizes top-tier journal publications and citation metrics, this emphasis can overshadow the importance of reaching broader audiences – practitioners, policymakers, and communities – who can act on the findings. To sustainably influence healthcare systems and decision-makers, we must explore and value alternative, accessible dissemination formats that go beyond traditional academic outputs.

This discussion session explores innovative strategies for sharing research, providing example case studies to facilitate creative out-of-the-box thinking. We will use already existing dissemination channels to exemplify possibilities and facilitate a discussions focused on but not limited to the following questions: How can we make research more digestible without losing depth? What formats truly bridge the gap between evidence and action? Participants will collaborate to share insights and co-create ideas for improving knowledge translation in health services.

2 - Balancing waiting lists and workloads in hospitals
Rob Vromans

Long waiting lists and access times are persistent challenges for many healthcare organisations. Efforts to reduce external waiting lists by increasing outpatient consultations can inadvertently create unmanageable workloads and growing internal waiting lists. This presentation explores an innovative method for balancing and coordinating scarce capacity across departments such as outpatient clinics, operating rooms, and wards. With the aim to reduce waiting times for patients and optimize the patient flow.

Using real-world patient flow data, our method systematically allocates weekly capacity across medical specialties and develops daily schedules that balance workloads for downstream departments, such as diagnostics and wards. Drawing insights from implemented prototypes, we illustrate the broader potential for this approach in diverse hospital and clinical settings. By sharing lessons learned, this presentation offers hospitals and other healthcare organisations insight in how to effectively improve patient access to healthcare.

3 - Developing an Embedded Program for Operations Research Applied to Community Health Services and Public Health in a Canadian Health System: A Discussion of Lessons Learned
Alexander Rutherford, Jessica Stockdale, Krisztina Vasarhelyi

Simon Fraser University and Vancouver Coastal Health (VCH) have embarked on an embedded research program in which graduate students in operations research work on research projects at VCH embedded in the health authority environment. The students work directly with clinicians, operations directors, and data analysts at VCH. The focus of the initial phase of this program is on community health services, public and population health, and Indigenous health. During the pilot phase of the program, four projects were undertaken: 1. Determining optimal panel sizes for physicians caring for complex patients; 2. Developing methods for identifying people who are homeless or precariously housed from administrative data; 3. Optimizing the client pathway for people in need of mental health and substance use supported housing; 4. Using simulation modelling to better understand models of care and panel sizes for community care in Indigenous communities. In this discussion talk, I will describe our experiences and lessons learned in developing this program. I hope to engage a wider discussion on embedded research in healthcare operations research—what works well and what works less well.

4 - Activity planning for surgeons with Deepinsight
Arvind Chawla

Since 2022, Deepinsight has been working on Deepinsight Hero, a smart AI tool designed to help hospitals plan surgeries more efficiently. It makes it easier to manage resources, schedule operations, and make informed decisions using data. More than just new software, it also brings a new way of working, with Deepinsight supporting hospitals through the change process.

In this presentation, Arvind Pedersen Chawla, Head of Data Science at Deepinsight, will share how one of their AI models helps hospital staff with the challenging task of coordinating surgeons' time between surgeries, outpatient clinics, and other clinical responsibilities

Thursday, 13:30-14:00

■ HD-04

Thursday, 13:30-14:00 - Room: St Olavs, Kunnskapssenteret KA12

Poster session 2

Stream: Sessions
Invited session
Chair: *Joe Viana*

Thursday, 14:00-15:00

■ HE-04

Thursday, 14:00-15:00 - Room: St Olavs, Kunnskapssenteret KA12

Panel discussion on innovation in healthcare

Stream: Keynotes and panels
Invited session

1 - Enabling healthcare innovation through Operations Research
Jarl Reitan, Birger Endreseth, Kjartan Kastet Klyve, Gréanne Leeftink, Øystein Døhl

The panel will discuss the main challenges faced by the healthcare sector, and how innovation can enable better services in the coming years. Then, we will narrow down into OR-innovations and what specific challenges that these can target, and discuss how to increase the presence of OR practitioners in healthcare. The panelist represent different actors, including academia, business consulting, primary care and specialist care, and they will elaborate on the topics from their different points of view. Before the discussion, each panelist will give an introduction on how their institution or company promotes innovation and OR in the public healthcare today.

Thursday, 15:30-17:00

■ HF-04

Thursday, 15:30-17:00 - Room: St Olavs, Kunnskapssenteret KA12

Innovation 3

Stream: Sessions
Invited session
Chair: *Simen T. Vadseth*

1 - Process Mining in Clinical Pathways: Bridging Challenges and Opportunities
Luca Murazzano, Paolo Landa, Jean-Baptiste Gartner, Andre Cote

This study presents a systematic literature review examining the application of process mining (PM) in clinical pathways. The research aims to explore the potential of PM to analyze, discover, monitor, and optimize healthcare processes through event logs derived from hospital information systems. With the increasing complexity of patient care, clinical pathways serve as crucial instruments to harmonize practices and enhance patient outcomes. Despite PM's promising opportunities—such as improving workflow efficiency, ensuring protocol conformity, and enabling predictive analytics—several challenges persist. These include inadequate regulatory frameworks governing PM usage in clinical contexts and uneven exploration of PM applications, particularly predictive process mining. By synthesizing findings from over 50 peer-reviewed studies spanning diverse specialties and healthcare settings, this review uncovers key methodologies, trends, and frameworks deployed in PM. Preliminary results emphasize the need for robust longitudinal data integration and regulatory alignment while highlighting gaps in specific applications like predictive process mining. This study paves the way for more targeted investigations to advance the quality, efficiency, and compliance of clinical pathways through PM methodologies.

2 - Process Mining Electronic Health Records of People with Multiple Sclerosis: A 5-year Longitudinal Study.
Märt Vesinurm

Chronic care delivery systems often rely on standardized outpatient pathways to ensure efficiency and consistency at scale. However, when these pathways fail to adapt to individual patient needs, system rigidity can result in delayed interventions and suboptimal outcomes. We apply process mining to a 5-year longitudinal dataset of 1279 people with multiple sclerosis (pwMS) to analyze real-world care trajectories and assess deviations from the intended patient pathway. Our method reconstructs patient-level event logs to identify common patterns, transitions, and escalations.

We find four phenotypes for patient trajectories: (1) those treated with only outpatient contacts, (2) those with outpatient contacts preceding escalation into the emergency department (ED) or inpatient care, (3) those with extended periods of no contact followed by escalation into the emergency department or inpatient care, and (4) 'others' with high variation within the service use patterns. We find that on the system level, there is little variation in proportion of different service utilization categories of outpatient, inpatient, ED, no contact. Additionally, annually roughly 70-80% of pwMS are treated with outpatient contacts only, with no escalation. With a significant proportion of costs of care stemming from the more expensive inpatient and ED services, our findings highlight the need for 'flexibility triggers' to allow prediction and more flexible reaction to possible care escalations.

3 - Staffing for Flexibility: Dimensioning and Scheduling Nursing Pools - A Case Study from St. Olav's Hospital
Aina Goday

Health care staff are becoming a scarce resource in the coming years, stressing the need for efficient use of nursing staff. At St. Olav's Hospital (Norway), we are addressing this challenge by assessing the potential of establishing pools of float nurses. Unlike traditional unit nurses,

float nurses can cover multiple units and can be assigned to units that require additional staffing on short notice. By relying on a pool of nurses, the hospital can meet a variable demand with staff working regular hours rather than summoning unit nurses for overtime work or hiring external nurses.

We have developed an optimisation model for dimensioning and scheduling nursing pools in a multi-unit setting. Based on a stochastic demand for additional nursing staff in each unit on each workday and shift, the model determines the optimal pool size, the base shift schedule, and daily assignment of float nurses. The model's objective is to minimise the costs of covering demand with either employed float nurses or by summoning unit nurses to work overtime.

We apply our approach in two real life case studies at St. Olav's Hospital. In the first case, we assess the existing pool in the Medical clinic to determine whether its current size aligns with our model recommendations. In the second case, we compare four pooling strategies across five of the hospital's smallest clinics to investigate the benefits of establishing a common pool as an alternative to individual pools.

4 - Automatized nurse rostering at St. Olav's Hospital
Simen T. Vadseth, Thomas Bovim

Nurse rostering is a time consuming process, and nurse leaders typically spend weeks and months preparing a roster for their unit. In St. Olav's Hospital, there is about 300 nurse rosters assembled each year, representing a massive workload for the leaders. Furthermore, striving to achieve staff satisfaction while respecting the organization's needs for staffing around the clock is a challenging task when performing the planning. Through an innovation project at St. Olav's Hospital we have developed and piloted an optimization based tool for automatized nurse rostering. The tool shows promising potentials for generating nurse rosters fast - typically within a day for large units. We will present the fundamentals of the optimization model, revealing how we take into account both the employee and the organizational perspectives to create high quality rosters. We will also report on feedback from the pilot studies performed at the Emergency Department and in the Medical Clinic.

■ HF-05

Thursday, 15:30-17:00 - Room: St Olavs, Kunnskapssenteret KA11

Innovation 4

Stream: Sessions
Invited session
Chair: *Joe Viana*

1 - Straight Home: An initiative to reduce the number of discharge ready patients
Tone Beate Svee, Ida Rasmussen Bjerke, Joe Viana

The South Trøndelag Health Partnership faces persistent challenges with high numbers of patients deemed ready for discharge, especially at St. Olavs Hospital, which reports up to 11,500 such days annually—the highest in Norway. Many of these patients could go directly home with enhanced follow-up, avoiding short-term municipal care. The "Rett hjem - forsterket utskriving" (Straight Home - Enhanced Discharge) initiative introduces an interdisciplinary discharge team to bridge hospital and municipal services. Its goals are to speed up discharges, increase direct-to-home transitions, and optimize municipal care use. In 2024, 1,318 patients from St. Olavs Hospital in Trondheim were classified as discharge ready—a number expected to grow due to aging demographics and seasonal pressures. Trondheim's home care services, divided into 12 geographic zones, operate with small, fixed-schedule teams. Weekly interdisciplinary meetings support coordination, but safe hospital-to-home transitions require adequate staffing and competencies, especially for frail elderly patients. The project explores how municipalities can sustainably scale this model to manage fluctuating patient volumes while ensuring safe, high-quality care transitions. We invite the ORAHS community to contribute insights to improve the initiative's delivery.

2 - Allocating operating room capacity to non-elective patients improves access and safety for elective patients at Aarhus University Hospital (DK)
Maartje Zonderland

We address surgical scheduling within the Department of Neurosurgery at Aarhus University Hospital (AUH). The department provides neurosurgical care to a population of 1.3 million in Denmark and has national treatment obligations for specific neurosurgical diseases. Efficient utilisation of the department's four operating suites is crucial to ensure that patients have timely access to both non-elective and elective neurosurgical procedures. Historically, the elective OR schedule was made without consideration of the possible arrival of non-elective patients. The challenge was to introduce a structured way of planning for non-elective surgical procedures that would minimise the need for cancelling elective surgeries. Using a mathematical model developed in a previous study at Leiden University Medical Center, the effect of allocating OR time during regular working hours for non-elective neurosurgical procedures at AUH was analysed. This allocation was tested in a six-week pilot study before being implemented in 2021. In the 35 weeks following the implementation, the new allocation strategy resulted in a significant 77% decrease in the cancellation of elective neurosurgical procedures when compared with the same period in 2019, with a significant 16% increase in surgical productivity. We demonstrate how mathematical modelling solves complex problems in the distribution of OR capacity, improving both patient safety and the working environment of surgeons and OR staff.

3 - Constructing a polarity lexicon for depression-specific for sentiment analysis of social media posts
Kurt Marais

Online mental health communities are internet-mediated fora for individuals to share their experiences and challenges, gain understanding through the shared perspective of similar others and to seek advice or support with respect to their own mental health. Mental health information informed in this way also enables individuals without diagnoses to acknowledge the significance of their symptoms and seek professional help. A polarity lexicon for depression consisting of 5718 sentiment-bearing terms was constructed from using posts from the r/depression subreddit to better inform on depression experiences and expressions shared online. A depression-specific lexicon was constructed through a hybrid of traditional and embedding sentiment analysis techniques. The new depression-specific lexicon was evaluated against popular general-purpose lexica that are typically used in the absence of domain-specific corpora. The depression-specific lexicon performed well in the classification of longer social media posts related to depression, whereas the traditional domain-independent VADER lexicon performed marginally better in classifying shorter depression-related posts from Twitter/X. The depression-specific lexicon also improved on the classification of Reddit posts relating to anxiety, loneliness, PTSD and general mental health.

4 - Personnel scheduling in hospital emergency departments
Anniek Pelleboer, Henrik Andersson, Thomas Bovim, Anders N. Gullhav, Gréanne Leeftink

Personnel scheduling in hospital emergency departments (EDs) is challenged by highly variable patient arrivals and the need to balance staffing costs with quality of care. This thesis develops and evaluates a decision-support tool to optimize nurse shift scheduling in the ED of St. Olav's Hospital (Trondheim, Norway). The approach comprises two main components. First, a demand-modelling framework classifies patients by age and triage level into 25 care-intensity groups, assigning time-dependent workload across four care phases (triage, treatment, discharge, general care). Historical arrival data (one year, aggregated into 52 weekly profiles per hour) are cleaned via IQR-based outlier filtering and Winsorizing, then converted into hourly staffing percentiles. Second, a mixed-integer linear programming model determines optimal shift schedules under constraints on contract types, overtime,

weekend work, flexible tasks, and service-level targets, incorporating real-world cost parameters (base pay and premiums). Computational experiments demonstrate how the results of the proposed tool change the output measures.

Friday, 9:00-10:30

■ FA-01

Friday, 9:00-10:30 - Room: NTNU, Realfagbygget R5

Simulation 2

Stream: Sessions
Invited session
Chair: *Marie Petit*

1 - Modeling strategic-level decision-making in specialized healthcare using simulation, with a focus on reducing waiting lists in traumatology services.
Miguel Baigorri, Marta Cildoz, Fermin Mallor

Patient waiting list lengths are increasing in most countries worldwide due to the generalized aging of the population and the rising demand for health services. For instance, in the region of Navarra (Spain), waiting lists have reached 240,000 entries in a population of 660,000, marking a 29% increase since 2018. In this work, we present a discrete-event simulation model of a traumatology department to assess a strategic decision regarding changes in patient pathways aimed at reducing waiting list lengths in the mid-term. This model has been developed using real data provided by the University Hospital of Navarre and constitutes the first step toward creating a digital twin of the traumatology service. Digital twins enable the reproduction and optimization of systems through real-time data collection. The model allows for analyzing the impact of structural changes on patient waiting lists, including the effect of the behavior and use of different access pathways to specialized care by primary care physicians. Results show that the proposed changes in patient pathways may reduce waiting list lengths, provided that the hospital and primary care services make effective use of the new appointment options. The next step will be integrating real-time data into the model, thereby developing a digital twin and enabling operational decision-making in the short term.

2 - Evaluating the impact of staffing recommendations in maternity units in France: combining simulation and time-and-motion study
Louis Niffoi, Oualid Jouini, Marija Jankovic, Pierre-François Ceccaldi, Guillaume Lamé

Sufficient midwifery staff is crucial for the quality of maternity care. However, shortage of staff creates situations of understaffing, extending delays and compromising care continuity. In order to determine the required number of midwives in a given department, several guidelines have been presented in the literature. Yet, we lack evidence on how these guidelines affect quality of care, and on midwives' activities and their availability to provide continuous support during labour. In order to map and quantify midwives' activities, we observed midwives during a full shift and interviewed them afterwards, giving us a better understanding of their work. The first results of this study show a distribution of midwives' worktime. Most of their time is spent almost equally between direct care and administrative work (approximately a third of time on each). A significant part is also dedicated to communication, mainly between colleagues, to support collective situation awareness. We then implemented these results in simulation models of birthing areas of several French maternities. We varied the number of midwives in the system, and their availability for direct care, to evaluate the effect of staffing recommendations on continuous support during childbirth. In preliminary results, guidelines lead to frequent under- and over-staffing, showing the impact of variability on patient support. Final results will help inform trade-offs on staffing levels.

3 - A Generic Framework for Organizational Digital Twins in Healthcare: Application to an Emergency Department
Marius Huguet, Vincent Augusto

In recent years, there has been growing interest in leveraging modeling and simulation methods to support public health decision-making, particularly for complex healthcare systems. At the forefront of this movement is the development of digital twins—virtual representations of physical systems capable of real-time synchronization. In this study, we present a generic framework for synchronizing an organizational digital twin of healthcare systems. The framework is applied to a case study of an emergency department, using emulated data to validate its robustness. The emulator is calibrated with real data from a French hospital's emergency department. The proposed framework consists of two core components: a synchronous component and an asynchronous component. The synchronous component offers a real-time virtual representation of the physical system, specifically modeling patient flows. We introduce a flexible modeling approach for this component, designed to adapt to varying levels of real-time data availability—whether full, partial, or absent. The asynchronous component serves as a decision-support tool for conducting predictive simulations under different scenarios. A key feature of this component is its ability to automatically initialize based on the current state of the system, enabling dynamic and context-aware forecasting. This work introduces an adaptable digital twin framework designed to support strategic decision-making in healthcare systems.

4 - A discrete-event simulation model to improve the appointment process and the patient flow of an MRI department
Marie Petit, Erik Demeulemeester

In addition to operating rooms, diagnostic equipment ranks among the most critical resources in many hospitals. In Belgium, the number and distribution of scanners across hospitals are regulated by the government, while the demand for diagnostic imaging continues to rise. This discrepancy between regulated scanner availability and rising demand often results in long access times, particularly in university hospitals such as UZ Leuven, which offers the full spectrum of imaging services, including highly complex examinations. Depending on the type of examination, patients may face waiting times of several months to secure an appointment. This not only negatively impacts patient satisfaction but, more importantly, may lead to adverse medical outcomes.

This study presents a detailed discrete-event simulation model that replicates the Magnetic Resonance Imaging (MRI) process at UZ Leuven. The model captures both the appointment scheduling system and the patient flow, accounting for both direct and indirect waiting times. It incorporates multiple heterogeneous scanners, patient characteristics, unpunctuality and no-show probabilities. A variety of scenarios are simulated and evaluated using key performance indicators (KPIs). Based on the outcomes, recommendations are provided to the hospital regarding slot categorization, strategies for improving scheduling practices and measures to reduce direct and/or indirect waiting times.

■ FA-02

Friday, 9:00-10:30 - Room: NTNU, Realfagbygget R8

Surgery scheduling 2

Stream: Sessions
Invited session
Chair: *Davide Duma*

1 - Simulating the impact of errors on length-of-stay predictions and rescheduling policies on elective surgery planning
Martina Doneda, Pieter Smet, Ettore Lanzarone, Giuliana Carello

When planning the admission of elective surgical patients, it is crucial to ensure that the proposed plan takes into account the availability of downstream resources, with post-surgery recovery beds being among

the most scarce ones. Therefore, it is sensible for managers to incorporate an estimation of patients' lengths-of-stay (LOSs) into their admission planning, so to account for the number of bed-days each patient will consume.

However, LOSs observed in practice may deviate from the estimation used during the admission scheduling phase, potentially causing inefficiencies, or even making the schedule unfeasible. To address this issue, online rescheduling strategies can be implemented iteratively, leveraging operational flexibility to adjust schedule violations. Among these real-time modifications, it is possible to include postponing admissions, reallocating patients to different wards, or transferring those already hospitalized. A proactive approach to minimize the need for adjustments is to enhance the accuracy of LOSs estimations by predicting them using machine learning (ML) tools. However, these models can be costly to train and inherently imperfect and subject to error.

Building on prior research that explored simulated ML for preliminary evaluations of data-driven strategies, this study examines the relationship between LOS predictive error and rescheduling flexibility under various corrective policies.

2 - A kernel based approach for the estimate-then-optimize surgery scheduling problem
Ricardo Otero, Erik Demeulemeester

Efficient and robust surgery scheduling is crucial for optimizing hospital resources and patient flow. However, creating adequate schedules is challenged by the inherent uncertainties in surgery durations. This research addresses this problem using a kernel-based approach to estimate surgery duration behavior and then implementing a distributionally robust optimization (DRO) model to generate solutions robust to model mispesification. Our methodology integrates a residual-based DRO framework, which constructs ambiguity sets based on historical data, with kernel methods that capture complex non-linear relationships between contextual features (e.g., patient demographics, procedure type) and uncertainty in surgery durations. By defining data-driven similarity measures through kernel functions, we create ambiguity sets tailored to the specific context of scheduling decisions, leading to more accurate robustness. The resulting optimization model is reformulated as a mixed integer model that standard solvers can solve. Our approach is evaluated against traditional methods using computational experiments with real-world data, yielding better out-of-sample solutions.

3 - Scheduling surgery requests from outdoctors and indoctors under uncertainty
Serhat Gül, Arsham Atashi Khoei, Melih Celik

Hospitals increasingly allow surgeons who are not full-time employees (outdoctors) to rent operating rooms (ORs) to generate revenue. However, to have their surgeries scheduled, outdoctors need to compete with the full-time hospital-employed surgeons of the hospital (indoctors) for limited resources. Balancing the needs of both surgeon types while accounting for uncertainty in surgery durations creates a challenging surgery planning problem. To address this problem, we formulate a stochastic mixed-integer programming model to select outdoctor surgery requests and schedule both indoctor and selected outdoctor surgeries across ORs and days within a finite planning horizon. Key performance measures include revenue from accepted outdoctor requests, patient waiting times, and expected OR overtime and idle time. To solve the model, we propose a problem-based scenario reduction algorithm based on loss function minimization (LFM). We solve the LFM problem using both a mixed-integer second-order cone programming model and a sub-gradient-based heuristic using real surgery duration data. We compare our scenario reduction algorithm against three alternatives from the literature. Additionally, we provide insights into the benefits of incorporating outdoctor surgeries into hospital surgery planning and exploring different levels of flexibility in handling these requests. Finally, we perform sensitivity analyses on various model parameters and estimate the value of the stochastic solution.

4 - Shaping Outpatient Surgery Schedules: A Dual-Horizon Approach with Distributional Clustering
Davide Duma, Alice Salacrist

The growing demand for outpatient surgeries raises the challenge of minimizing two key performance indicators: direct waiting time, experienced on the day of surgery, and indirect waiting time, defined as the number of days between surgical request and procedure. While direct waiting time depends on short-term allocation decisions, indirect waiting time emerges from a sequence of planning choices made over time, making it inherently more complex to control. In addition, these objectives depend on the level of resource utilization and robustness, resulting in conflict since reducing one requires trade-offs in the other.

Our study proposes a dual-horizon approach that combines clustering and multi-objective stochastic programming to jointly manage direct waiting time, indirect waiting time, and overtime. Surgical procedures are grouped using K-Means-type algorithms based on the similarity of their duration distributions. These clusters form the basis for constructing a cyclic surgical schedule, which improves predictability and facilitates long-term control of indirect waiting times, with positive implications for fairness across patients.

A case study based on real data from the Obstetrics and Gynaecology Department of Policlinico San Matteo in Pavia, Italy, is used to analyze the impact of using Euclidean or Wasserstein distances in the clustering of surgical procedures and to explore the balance between competing criteria.

■ FA-03

Friday, 9:00-10:30 - Room: NTNU, Realfagbygget R9

Elderly care

Stream: Sessions
Invited session
Chair: *Geert-Jan Kommer*

1 - Care pathway optimisation using Markov chain modelling
Maik Overmars, Richard Boucherie

Designing effective care pathways can aid in the standardisation of the care process, and increase the efficiency of the healthcare institution. An important challenge lies in using Electronic Health Record (EHR) data to accurately model the pathways to gain insight into their effect on resources such as capacity. Typically, care pathways are multidisciplinary plans that describe the exact sequence of interventions that patients receive. We consider the setting where a pathway contains regular appointments per discipline over a longer period of time, and the pathway contains decision moments where healthcare professionals determine whether and how to continue treatment. Each section of the pathway between decision moments is described by the intensity of appointments received per discipline. In this paper, we propose a Markov chain model, in which the states correspond to sections of the care pathway, that is estimated using EHR data. With this Markov chain we are able to determine the exact distribution of capacity required given a set of pathways. We optimise the care pathways by modifying treatment intensities and the parameters of the Markov chain. We apply our approach to a rehabilitation clinic and show how our method can aid in the design of efficient care pathways.

2 - Improving access to long-term care
René Bekker

In many countries, the rapid aging of the population leads to an additional burden on already stretched long-term care (LTC) systems. This often manifests itself in excessive waiting times for long-term care centers, in abandonments (i.e., patients passing away while they are waiting), and in temporary placements in short-term care (STC) facilities. Interestingly, in practice, long waiting times are not only caused by a lack of available total capacity in the system, but by systematic inefficiencies in the allocation of patients, each with their personal preferences and (in)flexibility, to geographically distributed care centers. Motivated by this challenge, we propose a new and practical method for optimally allocating patients-in-need to nursing homes, balancing waiting time performance with individual preferences and flexibility

levels. Using a Markov Decision Process, we derive the optimal placement policy and show that, for small instances, the allocation model achieves a mean optimality gap of just 1.3%. We validate our approach through a simulation study based on real-world data from somatic patient placements in the Amsterdam region. To capture the broader system impact, we adopt a system-wide perspective, modeling how delayed long-term care access increases short-term care usage. Notably, over 50% of nursing home clients are admitted via STC, highlighting the interdependence of care settings. In this talk, we demonstrate how optimized LTC allocation strategies

3 - Choosing pathways through hospital care for older persons

Yvonne Li, *Ilze Ziedins*, *Michael O'Sullivan*, *Cameron Walker*

Hospitals aim to allocate limited bed resources fairly while ensuring timely care for urgent patients. Our work was motivated by challenges at Waikato Hospital in Aotearoa New Zealand, which provides integrated care for urgent patients, primarily older adults, in its Older Persons and Rehabilitation (OPR) unit. Non-urgent patients may also be admitted to the OPR when beds are available; however, if the unit reaches capacity, urgent patients will be admitted to general wards, where service times are longer.

We have developed a compartmental model for patient admissions to OPR and general wards. Our model considers heterogeneous arrival and service rates across three different patient priority classes: urgent, non-urgent, and elective, and includes readmissions. We use a simulation model to test various thresholds for non-urgent admissions to OPR, to evaluate their impact on bed occupancy and the probability of urgent patients being diverted to general wards. Simulation results can assist in setting safe admission thresholds for non-urgent patients while ensuring that urgent care is not compromised.

4 - Modelling (change in) health status and health care utilization in the 60+ population

Geert-Jan Kommer

In this research we studied the dynamic relationship between health status of the 60+ population in the Netherlands and the costs of health care utilization. We used longitudinal data from 1,900 participants aged 60-85 years who participated in the Doetinchem Cohort Studie in the period 2009-2022. The health status of individuals, categorized into four groups, was defined based on seven characteristics of both physical and mental functioning measured at 2 or 3 time points. The transition in health states over time was modeled using a Markov model. The individual health care utilization costs were based on register data. By linking these costs to the Markov model we create a model that can provide insight in the relation between changes in health status and health care expenditures.

Friday, 11:00-12:20

■ FB-01

Friday, 11:00-12:20 - Room: NTNU, Realfagbygget R5

Business meeting

Stream: Keynotes and panels
Invited session

Friday, 12:20-12:30

■ FC-01

Friday, 12:20-12:30 - Room: NTNU, Realfagbygget R5

Closing session

Stream: Keynotes and panels
Invited session

STREAMS

Keynotes and panels

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Track(s): 1 4

Sessions

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