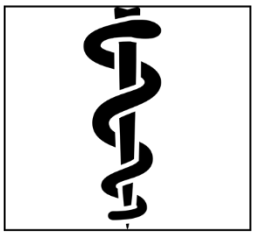

IWISH - Intelligent Workflow optimization and Intuitive System interaction in Healthcare

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State of the Art Description of Procedure Scheduling Techniques for Operating Theatre

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1 Introduction

Operation theatres (OT) lie at the heart of modern hospitals. The planning of medical procedures has a decisive impact on the level of service provided, the revenue of the hospital, and the cost structure of the hospital. A variety of scheduling requirements, ranging from equipment availability to ethical considerations, turns operation theatre scheduling into a complex task.

OT procedure scheduling optimization is a critical aspect of hospital management that aims to effectively allocate and manage surgical procedures within a hospital's operating rooms. The primary objective of this optimization process is to maximize the utilization of scarce resources, such as operating rooms, equipment, instruments and medical staff, while maintaining high standards of patient care and ensuring staff satisfaction. In recent years, there has been significant advancement in the development of scheduling optimization methods, utilizing cutting-edge techniques and algorithms to address the complex constraints and preferences inherent in the problem.

OT scheduling optimization methods can be broadly categorized into three main approaches: mathematical optimization, heuristic algorithms, and simulation-based methods.

a) Mathematical optimization: These methods involve formulating the scheduling problem as a mathematical model, such as integer programming, linear programming, or mixed-integer programming. These models can precisely represent the constraints and objectives of the problem and can be solved using powerful optimization algorithms. However, the complexity of the models may limit their applicability to large-scale problems or situations with significant uncertainty.

b) Heuristic algorithms: Heuristics are problem-solving techniques that utilize simple rules and approximations to find satisfactory solutions in a reasonable time. In the context of OT scheduling, heuristic algorithms, such as genetic algorithms, particle swarm optimization, and ant colony optimization, have been successfully applied to tackle the problem. These algorithms are more flexible and scalable than mathematical optimization methods, although they may not always guarantee optimal solutions.

c) Simulation-based methods: Simulation-based approaches, such as discrete-event simulation or agent-based modeling, are used to model and analyze the dynamic nature of the scheduling problem. These methods enable the assessment of different scheduling strategies under various scenarios, including uncertainty and disruptions. Simulation optimization techniques, such as the Simulated Annealing or the Cross-Entropy method, can be combined with simulation models to search for near-optimal solutions.

OT procedure scheduling optimization techniques aim to address the numerous hard and soft constraints involved in the problem, including resource availability, procedure durations, staff preferences, and workload balancing. By employing these advanced methods, hospitals can achieve more efficient scheduling, improved patient care, reduced waiting times, and increased staff satisfaction, all while optimizing resource utilization and cost management. A literature study has been conducted based on references listed in chapter 5 and summarized in chapters 2, 3 and 4. In this project, we will be exploring state-of-the-art optimization methods by incorporating AI (machine learning) techniques, to further enhance the scheduling optimization and its adaptability to the ever-changing healthcare landscape.

2 Studies on OT Efficiency and Systems

The utilization of OTs is widely regarded as a critical issue in hospital management. OT equipment typically comprises a significant part of a hospital's medical equipment. Major manpower expenditure is required to render an OT functional in any given day. It is therefore not surprising that the utilization of OTs has been the subject of numerous government studies and scholarly publications.

As observed in [1], "Improving the efficiency with which human and material resources are utilized is expected to result in an increase in the number of procedures performed over a period of time. This will result in a reduction in the unit cost of surgery and the waiting list of OTs." Thus, the main focus of the published studies is how to improve OT utilization.

The reported utilization rates are 63% in [2], 73.8% in [1] and 80% in [3]. An extreme case of under-utilization is reported in [4]: "Twenty-five per cent of theatre sessions were not allocated for use, 23% of general surgical lists were cancelled and, of the lists which did take place, a further 23% of theatre time was not utilized." This amounts to a utilization rate of only 44.5%!

The focus of most utilization studies lies in the medical practice. For example, a study in NSW, Australia, [5] suggests that operating times vary greatly between hospitals, and that the streamlining of medical practices can significantly improve the utilization of OTs.

However, in [4] it is recognized that "[t]he single largest cause of underutilization was understaffing." If we add to understaffing the significant number of procedures that are delayed or cancelled due to patient unavailability, it becomes clear that OT scheduling can be regarded as a scheduling problem, which is subject to uncertainty from patients, medical staff and equipment.

Several hospital information systems provide a component for OT scheduling. These systems focus on the allotment, cancellation and rescheduling of procedures. Auxiliary components include patient registration, patient evaluation and inventory management. OT Management systems such as Cerner SurgiNet, Epic OpTime, MEDITECH Surgical System, Allscripts Sunrise Surgical Care, McKesson OR System, Picis OR Manager and Surgical Information System (SIS) are integrated with a system to manage procedures, including anesthesia, allergies, complications, operation surgeons, and

tracking of the procedures in real-time. None of the existing systems use state-of-the-art optimization technology combined with AI techniques to schedule procedures, re-schedule patient appointments to optimize OT utilization and patient waiting times, and are tightly integrated with staff rostering.

The integration of the OT scheduling system into the entire IT infrastructure is crucial. Information needs flows between the OT scheduling system and the surrounding IT systems. The vision of a fully integrated, real-time, optimizing OT scheduling system is new and therefore, there are no studies available on such systems. A crucial objective of this project is to fill this gap to provide solid evidence for the practicality and efficacy of such a system.

3 AI Techniques for OT Scheduling

In recent years, artificial intelligence (AI) techniques have begun to play a significant role in addressing the challenges of OT procedure scheduling optimization. AI methods, such as machine learning and data-driven approaches, can enhance the scheduling process by learning from historical data, adapting to complex constraints, and improving decision-making in dynamic environments. Some AI techniques that can be applied to OT scheduling optimization include:

a) Machine Learning for Duration Estimation: A major challenge in OT scheduling is accurately predicting the duration of surgical procedures. Machine learning algorithms, such as decision trees, support vector machines, and neural networks, can be trained on historical data to generate more accurate duration estimates based on factors like patient demographics, procedure type, and surgeon experience. This improved estimation can help optimize resource allocation and reduce the chances of scheduling conflicts.

b) Reinforcement Learning: Reinforcement learning is a type of machine learning where an agent learns to make decisions by interacting with its environment and receiving feedback in the form of rewards or penalties. In the context of OT scheduling, reinforcement learning algorithms can be employed to learn effective scheduling strategies that balance multiple objectives, such as minimizing patient waiting time, reducing staff idle time, and optimizing resource utilization, while considering the inherent uncertainty in the scheduling process.

c) Deep Learning: Deep learning, a subfield of machine learning that focuses on neural networks with multiple layers, can be applied to complex OT scheduling problems. For instance, recurrent neural networks (RNNs) or long short-term memory (LSTM) networks can be used to model the temporal dependencies in scheduling data, allowing for better prediction and adaptation to dynamic changes in the scheduling environment.

d) Constraint Satisfaction and Optimization: AI techniques, such as constraint programming and AI-based optimization algorithms, can be utilized to effectively solve OT scheduling problems with multiple constraints and objectives. By integrating AI techniques with traditional optimization approaches, more efficient

and adaptive solutions can be developed for the complex and dynamic nature of OT scheduling.

Incorporating AI techniques in OT procedure scheduling optimization offers significant potential for improving the scheduling process, providing more accurate predictions, enhancing adaptability to dynamic situations, and ultimately leading to better resource management, improved patient care, and increased staff satisfaction.

4 Optimization Objective and Rules

The scheduling of procedures is a complex process that is governed by optimization objective and scheduling constraints. This section reviews the requirements of OT scheduling in detail.

4.1 Procedure Scheduling Problem

The OT procedure scheduling problem refers to the challenge of effectively allocating and managing surgical procedures within a hospital's operating rooms. This problem is an essential aspect of hospital management, as it impacts not only the hospital's efficiency and financial performance, but also the patient care quality and staff satisfaction. The problem involves several aspects and constraints, which make it a complex and multifaceted issue.

Some of these aspects include:

a) Limited resources: Operating rooms, surgical teams, equipment, instruments, beds, and support staff (anesthetists, nurses, etc) are limited resources, and their optimal utilization is crucial for minimizing costs and maximizing efficiency.

b) Variability in procedure duration: The duration of surgical procedures can vary widely, depending on factors such as the complexity of the operation, patient conditions, and surgeon expertise. Accurate estimation of procedure duration is vital for efficient scheduling.

c) Surgeon availability: Surgeons often have multiple roles, including clinical, academic, and administrative duties. Their availability needs to be considered when scheduling surgeries, along with their specific skill sets and expertise.

d) Patient needs: Each patient's individual condition, medical history, and urgency of surgery must be taken into account. Emergent cases and elective cases often need to be prioritized and balanced.

e) Scheduling preferences: Different stakeholders, such as surgeons, anesthesiologists, and nursing staff, may have specific scheduling preferences, which must be considered and balanced against other constraints.

f) Uncertainty and disruptions: Unplanned events, such as emergencies or equipment malfunctions, can disrupt the schedule, and it's essential to have a flexible scheduling system that can adapt to these changes.

   Examples include:

   - Unforeseen unavailability of patient: Due to changes in the medical condition of the patients, procedures need to be canceled or moved.
   - Unforeseen unavailability of beds: Unforeseen circumstance may prevent a previously allocated intensive care bed to be unavailable for a patient.
   - Unforeseen availability of OT equipment due to technical failure
   - Unforeseen unavailability of surgeons, anesthetists, or nurses
   - Unforeseen complications in a previous operation that leads to the unavailability of the operating team as well as theatre and equipment.

The resulting challenges can only be met by a real-time integrated OT scheduling solution.

4.2 Scheduling Constraints

The following are requirements that constrain the scheduling of procedures to theatres:

a) OT requirements:

   - OT allocations: In public-sector hospitals, OTs are often allocated to principal surgeons for time blocks. This assignment must be met unless permission for re-allocation is given by the surgeon.
   - The number of operating rooms is limited, and each room can only accommodate one procedure at a time.

b) Staff requirements:

- Qualification of staff: The nature of medical procedures requires professionals to serve in particular roles during a procedure. The staff member assigned to a role must have the right qualifications for the role.

- Availability of staff: Staff members such as surgeons often have commitments outside the operations theatre. OT scheduling must take into account that staff members are only available in certain periods of time.

- Team considerations: Often, medical staff have a specific team that supports operations. OT scheduling must make sure that team requirements are met. For example, a surgeon may require a specific anesthetist to be on duty for an operation.

c) Patient requirements: Patients and/or relatives may specify when they are available/unavailable for planned procedures. It also includes the patient's medical condition, any preoperative preparations or tests required, and the urgency of the procedure.

d) Equipment requirements:

- Equipment restrictions per procedures: Certain procedures require specific equipment, such as dialysis equipment, incubators etc.

- Equipment restrictions per staff: Medical staff members may have specific requirements for specific pieces of equipment.

- Equipment restrictions per OT: Certain pieces of equipment may be fixed to specific OTs; others may be deployed in several but not all OTs.

- Equipment restrictions due to break-down and servicing: Equipment may become unavailable indefinitely due to break-down, or may become unavailable for a fixed period of time due to scheduled servicing.

- The scheduling process is complicated by the fact that some but not all equipment is mobile, and thus can be moved from one OT to another, sometimes requiring a significant amount and involving set-up cost for each move.

e) Procedure duration estimation: Accurate estimation of procedure duration is essential for efficient scheduling, but the actual duration may vary due to the complexity of the case or other factors.

4.3 Optimization Objective

Optimization criteria for OT scheduling refer to the various objectives and goals that should be considered when planning and organizing surgical procedures. These criteria help create an efficient schedule that maximizes resource utilization, minimizes costs, and ensures high-quality patient care.

Here is a list of common optimization criteria for OT scheduling:

a) Maximize operating room throughput: Increasing the number of surgeries completed within a given timeframe can lead to better resource utilization and cost-efficiency.

b) Minimize patient waiting time: Reducing the waiting time for patients awaiting surgery can help enhance patient satisfaction and reduce anxiety. It also contributes to better clinical outcomes, particularly for urgent or time-sensitive cases.

c) Minimize staff idle time: Efficiently utilizing the time of surgical staff, including surgeons, anesthesiologists, and nurses, can lead to increased productivity and reduced staffing costs.

d) Minimize overtime: Limiting overtime for surgical staff can help control labor costs and prevent staff burnout.

e) Balance workload among surgeons and staff: Distributing surgical workload evenly among medical personnel can help prevent overburdening specific individuals, which may lead to a decrease in performance and increase the risk of errors.

f) Minimize the number of canceled or rescheduled surgeries: Reducing the occurrence of canceled or rescheduled surgeries can lead to better resource utilization and improved patient satisfaction.

g) Prioritize urgent and time-sensitive cases: Scheduling time-critical cases in a timely manner can lead to improved clinical outcomes and patient satisfaction.

h) Surgeon preferences: Surgeons may have preferences for specific operating rooms, times, or days, which should be considered when possible.

i) Anesthesia and nursing staff preferences: Similar to surgeons, anesthesiologists and nursing staff may also have preferences for specific operating rooms, times, or days.

5 References

[1] Caleb D Mpyet FWACS, An Audit of the Use of Ophthalmic Theatre Time. Community Eye Health Vol 44 2002, p62.

[2] The Use of Operating Theatres. Report to Parliament and the Northern Ireland Assembly by the Comptroller and Auditor General for Northern Ireland (HC 552 and NIA 111/02)

[3] Vinukondaiah K, Ananthakrishnan N, Ravishankar M., Audit of operation theatre utilization in general surgery. Natl Med J India. 2000 May-Jun;13(3):118-21.

[4] DC Haiart, AB Paul and JM Griffiths, An audit of the usage of operating theatre time in a peripheral teaching surgical unit. Postgraduate Medical Journal, 1990, Vol 66, 612-615.

[5] NSW Health. Operating Theatre Management Project – Supplementary Report on Information Management Survey, NSW Health Department 2002.

[6] Cardoen, B., Demeulemeester, E., & Beliën, J. (2010). Operating room planning and scheduling: A literature review. European Journal of Operational Research, 201(3), 921-932. https://doi.org/10.1016/j.ejor.2009.04.011

[7] Guerriero, F., & Guido, R. (2011). Operational research in the management of the operating theatre: a survey. Health Care Management Science, 14(1), 89-114. https://doi.org/10.1007/s10729-010-9144-1

[8] Van Essen, J. T., Hurink, J. L., Hartholt, W., & van den Akker, B. J. (2012). Decision support system for the operating room rescheduling problem. Health Care Management Science, 15(4), 355-372. https://doi.org/10.1007/s10729-012-9199-0

[9] Marques, I., Captivo, M. E., & Vaz Pato, M. (2013). Surgical case scheduling as a generalized job shop scheduling problem. European Journal of Operational Research, 230(3), 506-517. https://doi.org/10.1016/j.ejor.2013.04.041

[10] Vancroonenburg, W., Sörensen, K., & Demeulemeester, E. (2015). A metaheuristic approach for the preoperative scheduling problem. Journal of Heuristics, 21(4), 457-476. https://doi.org/10.1007/s10732-014-9281-8

[11] Roland, B., Di Martinelly, C., & Riane, F. (2016). Operating theatre optimization: A resource-constrained based solving approach. Operations Research for Health Care, 10, 28-37. https://doi.org/10.1016/j.orhc.2016.06.002

[12] Xu, W., & Meskens, N. (2017). A stochastic optimization approach for the surgical cases assignment problem. Omega, 66(Part A), 109-120. https://doi.org/10.1016/j.omega.2016.01.006

[13] Riise, A., & Burke, E. K. (2018). A review of the sequential operating room scheduling problem. Journal of Scheduling, 21(4), 363-381. https://doi.org/10.1007/s10951-018-0566-z

[14] Dexter, F., & Macario, A. (2002). Changing allocations of operating room time from a system based on historical utilization to one where the aim is to schedule as many surgical cases as possible. Anesthesia & Analgesia, 94(5), 1272-1279. https://doi.org/10.1097/00000539-200205000-00042

[15] Baril, C., Gascon, V., & Martel, A. (2016). A simulation-based approach for scheduling elective surgeries with cyclically allocated operating room time. Computers & Operations Research, 66, 58-71. https://doi.org/10.1016/j.cor.2015.07.003