Dissecting Complexity

The Impact of Medical Technology on Healthcare Professionals

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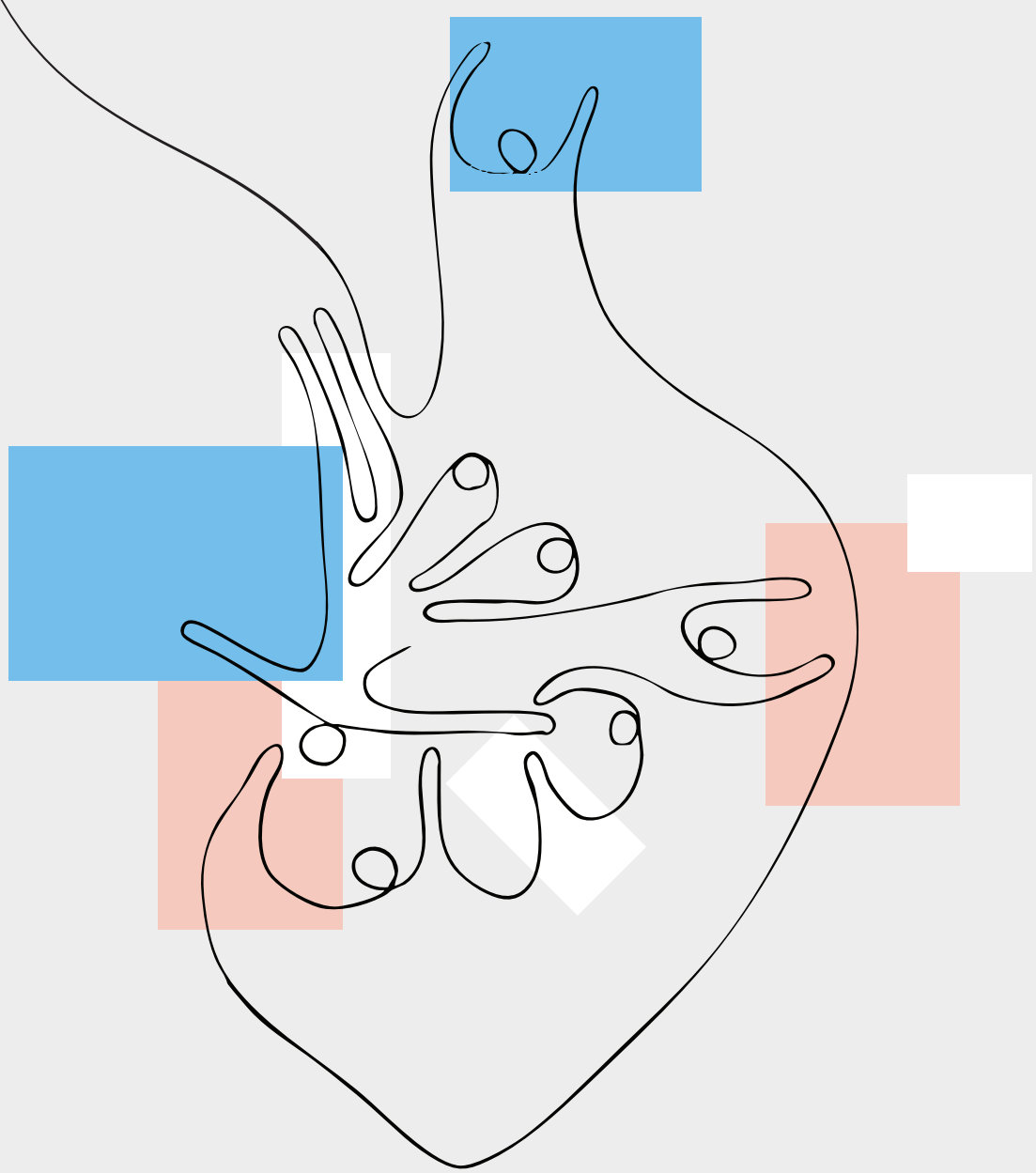

Anneke M. Schouten

Dissecting Complexity

The Impact of Medical Technology on Healthcare Professionals

Dissertation

for the purpose of obtaining the degree of doctor
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by

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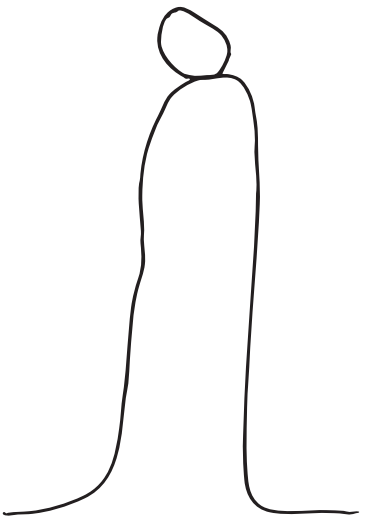
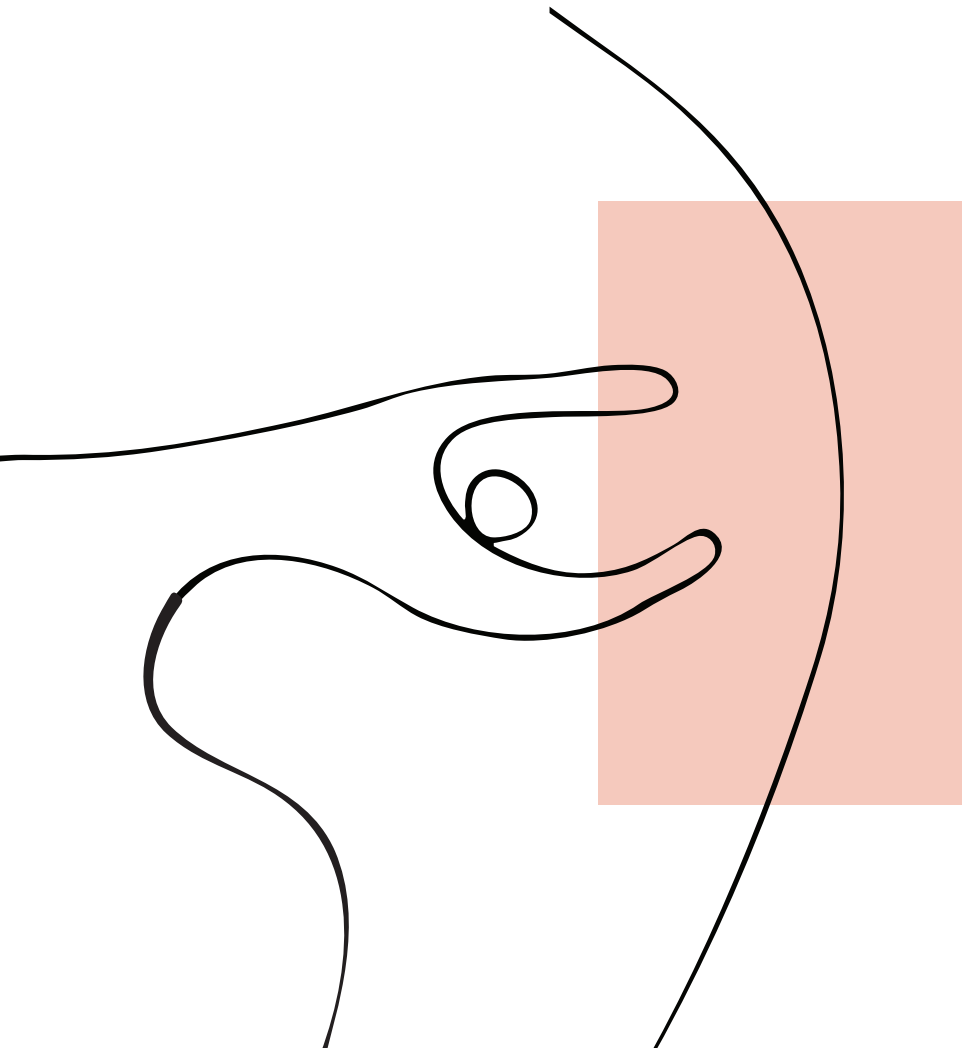
Voor papa

Both sides now

Joni Mitchell

I've looked at clouds from both sides now
From up and down and still somehow
It's cloud illusions I recall
I really don't know clouds at all





Contents

Summary

Technological advancements are accelerating at an unprecedented pace, reshaping societies, economies, and individual behavior. While these innovations offer benefits such as improved communication, and data-driven decision-making, they also present challenges, including ethical concerns, inequality, job displacement, and regulatory lag. Nowhere are these dynamics more critical than in healthcare, where emerging technologies promise to address rising demand and workforce shortages. However, the gap between technological potential and real-world implementation remains wide.

Healthcare systems, particularly in surgical care, struggle to adopt and sustain innovations like AI and robotics due to their complex, context-specific environments. A projected global shortage of 12.9 million healthcare professionals by 2035, with surgical nurses playing pivotal roles, underscores the urgency of aligning technology with clinical practice. Many MedTech solutions fail to move beyond pilot stages, hindered by a disconnect between design and real-world use.

This thesis investigates how medical technology interacts with the complex, high-stakes environment of the operating room. Across five studies, it examines both systemic and human-centered factors that influence technology adoption, with a focus on workflow dynamics, performance metrics, and professional experiences. A key finding is that successful implementation depends on integrating MedTech into clinical ecosystems, rather than introducing it as isolated technical upgrades.

Hospital hierarchies, limited professional autonomy, and insufficient involvement of frontline staff – particularly nurses – create significant barriers to improving workflows through technology in the operating room. While reducing workload is often a primary objective, doing so without addressing job satisfaction or preserving autonomy can lead to disengagement. The thesis advocates for greater transparency in workflows and more inclusive innovation practices, where technology is designed to support, not replace, human judgment.

The research also draws parallels with other sectors, such as manufacturing and finance, where automation has reshaped roles and skill requirements. Healthcare faces similar crossroads: it must either upskill staff to manage and interpret technology or prioritize human-centric roles, or risk a polarized workforce – characterized by growth in high-skill (e.g., tech integration, clinical data science) and low-skill (e.g., basic support care) positions, while middle-skill roles diminish. However, due to the inherently human nature of healthcare, hybrid systems that combine technological support with human oversight are the most likely path forward.

Recommendations for innovators, hospital management, and policymakers emphasize early user involvement, context-aware design, role clarity, data-driven feedback, and frameworks that bridge engineering and clinical realities. Serious games and interactive tools can aid understanding of OR complexities and foster stakeholder dialogue.

The thesis concludes that technological advancement in healthcare is outpacing organizational change, leading to inefficiencies, staff dissatisfaction, and underuse of promising innovations. Bridging this gap requires rethinking implementation as a design challenge in its own right – one that demands not only technical solutions but also organizational and cultural transformation. MedTech can only become a sustainable driver of improved care if professional autonomy, workflow transparency, and staff well-being are prioritized throughout the innovation process.

Samenvatting

Technologische ontwikkelingen versnellen in een ongekend tempo en hervormen daarmee samenlevingen, economieën en individuen. Hoewel deze innovaties voordelen bieden, zoals verbeterde communicatie en datagestuurde besluitvorming, brengen ze ook uitdagingen met zich mee, waaronder ethische vraagstukken, ongelijkheid, baanverlies en achterblijvende regelgeving. Nergens is deze dynamiek zo cruciaal als in de gezondheidszorg, waar nieuwe technologieën mogelijkheden bieden om de stijgende zorgvraag en het tekort aan personeel aan te pakken. Toch blijft de kloof tussen technologische mogelijkheden en daadwerkelijke toepassing in de praktijk groot.

Zorgsystemen hebben moeite om innovaties zoals kunstmatige intelligentie en robotica effectief te implementeren en te behouden, vanwege de complexe en contextgebonden aard van hun werkomgeving. Het wereldwijd voorspelde tekort van 12,9 miljoen zorgprofessionals in 2035, waarbij operatieassistenten een sleutelrol vervullen, benadrukt de urgentie om technologie beter af te stemmen op de klinische praktijk. Toch komen MedTech-oplossingen niet verder dan de pilotfase, doordat er een kloof bestaat tussen ontwerp en praktische inzetbaarheid.

Dit proefschrift onderzoekt hoe medische technologie zich verhoudt tot de complexe en veeleisende omgeving van de operatiekamer. In vijf studies worden zowel systemische als mensgerichte factoren geanalyseerd die de adoptie van technologie beïnvloeden, met specifieke aandacht voor werkprocessen, prestatie-indicatoren en professionele ervaringen. Een belangrijke conclusie is dat succesvolle implementatie afhangt van de integratie van MedTech in het bredere klinische ecosysteem, in plaats van het introduceren van losse technische “upgrades”.

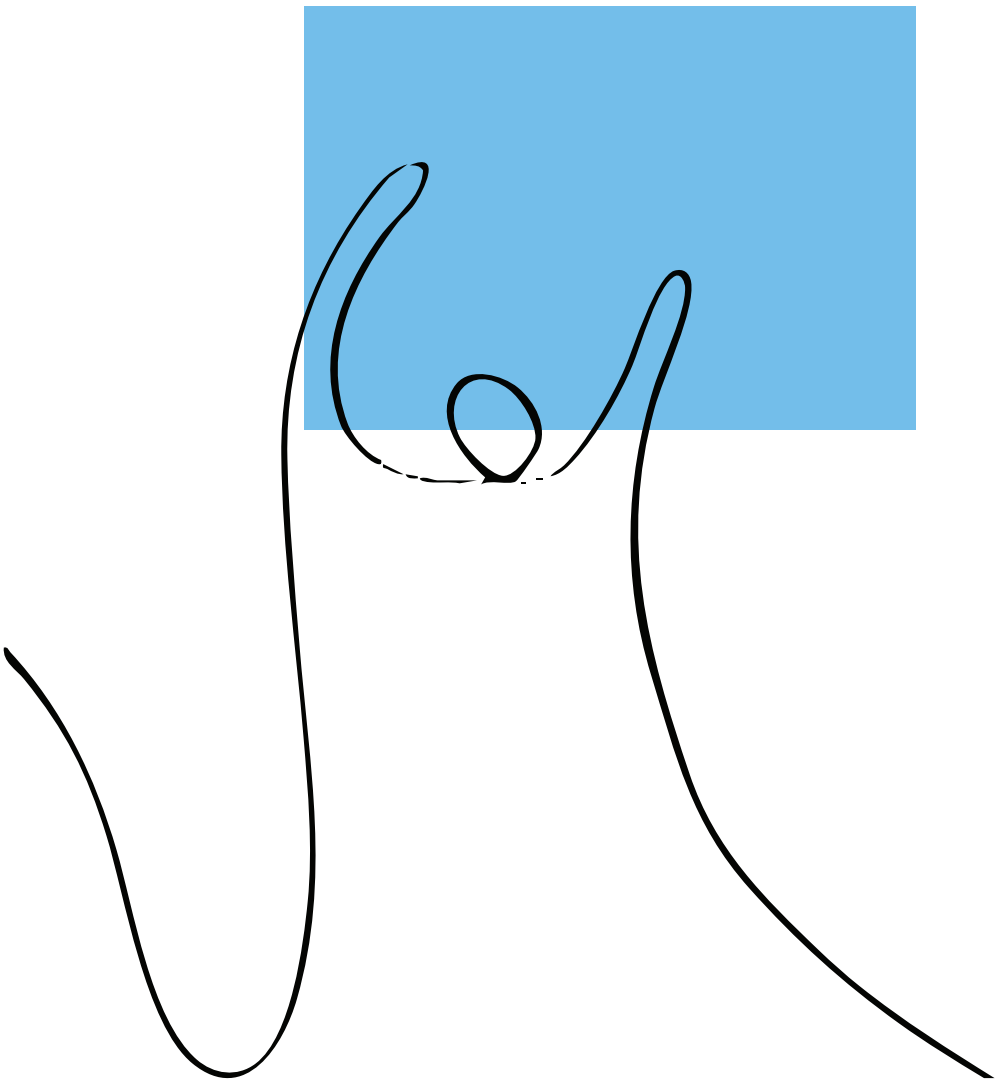
Ziekenhuishiërarchieën, beperkte professionele autonomie en onvoldoende betrokkenheid van zorgverleners aan de frontlinie – met name operatieassistenten – vormen aanzienlijke obstakels bij het verbeteren van werkprocessen met behulp van technologie in de operatiekamer. Het verminderen van werkdruk is vaak een belangrijk doel, maar als dit gebeurt zonder aandacht voor werkplezier en behoud van autonomie, kan dit leiden tot demotivatie.

Dit proefschrift pleit daarom voor meer transparantie in werkprocessen en een inclusieve benadering van innovatie, waarin technologie bedoeld is om menselijke besluitvorming te ondersteunen, niet te vervangen.

De studie trekt ook parallellen met andere sectoren, zoals de industrie en de financiële sector, waar automatisering de invulling van functies en benodigde vaardigheden ingrijpend heeft veranderd. De gezondheidszorg staat voor een vergelijkbaar keerpunt: het personeel moet óf worden bijgeschoold om technologie te kunnen beheren en interpreteren, óf de nadruk moet liggen op mensgerichte taken. Zo niet, dan dreigt een gepolariseerde arbeidsmarkt, waarin vooral hooggeschoolde (zoals tech-integratie, klinische datawetenschap) en laaggeschoolde functies (zoals basale zorgondersteuning) groeien, terwijl functies op middelniveau afnemen. Gezien het sterk menselijke karakter van de zorg, is het echter waarschijnlijker dat hybride systemen – waarin technologie menselijke supervisie ondersteunt – de toekomst zullen bepalen.

Aanbevelingen voor innovators, ziekenhuismanagement en beleidsmakers benadrukken het belang van vroege en betekenisvolle gebruikersbetrokkenheid, contextbewust ontwerp, duidelijke rolverdeling, datagestuurde feedback en kaders die de kloof tussen techniek en klinische praktijk helpen overbruggen. Serious games en interactieve hulpmiddelen kunnen helpen om de complexiteit van de operatiekamer beter te begrijpen en de dialoog tussen belanghebbenden te stimuleren.

Dit proefschrift concludeert dat technologische vooruitgang in de zorg sneller gaat dan de organisatorische aanpassingen die daarvoor nodig zijn, met als gevolg inefficiëntie, ontevreden personeel en onderbenutte innovaties. Om deze kloof te dichten, moet implementatie worden herzien als een ontwerpuitdaging op zich – een uitdaging die niet alleen technische oplossingen vergt, maar ook organisatorische en culturele verandering. MedTech kan alleen een duurzame drijvende kracht worden voor betere zorg als professionele autonomie, transparantie in werkprocessen en het welzijn van zorgverleners centraal staan in het innovatieproces.



Introduction

We are living in an era where technological advancements are not only frequent but accelerating at an unprecedented pace. This exponential rate of innovation is reshaping society, the economy, and individual behavior in profound ways (Vernyuy, 2024). Driving this acceleration are multiple converging forces: exponential growth in computing power, increased global connectivity, the vast availability of data, and significant investment in research and development (European Environment Agency, 2020). As technologies rapidly build on one another, innovation cycles become shorter, enabling new solutions to emerge faster than ever before (Persoon et al., 2020). While this brings clear benefits – such as greater efficiency through automation, enhanced communication, and data-driven decision-making – it also presents serious challenges. These include ethical concerns, digital inequality, job displacement, and psychological strain from continuous adaptation (Floridi et al., 2018). Institutions and regulatory systems often struggle to keep pace, leading to gaps in oversight and rising tensions around the inclusiveness and trustworthiness of technological change (Vernyuy, 2024).

One area where these rapid technological shifts have particularly significant implications is healthcare. Emerging technologies such as artificial intelligence, robotics, and wearable devices offer the potential to address persistent challenges in the sector, including rising patient demand, increasing case complexity, and a global shortage of healthcare workers (Thacharodi et al., 2024; Topol, 2019). However, healthcare systems often struggle to effectively implement and sustain these innovations. The urgency is amplified by a projected global shortfall of 12.9 million healthcare professionals by 2035, with nurses accounting for approximately 40% of this gap (World Health Organization, 2009, 2024). Surgical care is particularly at risk, as it is highly dependent on surgical nurses who not only perform technical tasks but also play critical roles in intra-operative communication, coordinating workflows, and ensuring the practical integration of new technologies into complex operating room environments (Porto & Catal, 2021).

The problem lies in the widening gap between technological potential and real-world implementation. Despite the pressing need for innovation, many promising MedTech solutions fail to move beyond the pilot phase and are never meaningfully adopted in clinical practice. This so-called *"valley of death"* between development and implementation remains a persistent challenge in healthcare (Cosma et al., 2025).

One key reason is a disconnect between technological design and the complex, context-specific realities of clinical care (World Health Organization, 2010). Innovations that overlook this complexity risk adding burden rather than support, especially in already overstrained environments like the operating room.

Addressing this challenge requires more than technological excellence. It calls for collaborative, practice-based approaches that bridge the worlds of engineering and clinical care. Medical process engineering plays a vital role in this effort by systematically analyzing and improving workflows, thereby aligning innovation with day-to-day practice. These interdisciplinary strategies are crucial not only for effective implementation but also for supporting the well-being, adaptability, and professional agency of healthcare workers (Allers et al., 2024; Yoda, 2016).

This thesis

This thesis contributes to a deeper understanding of how MedTech innovations interact with the complex clinical reality of the operating room (OR) – a technology-intensive, high-stakes environment central to hospital operations. Across five complementary studies, this work examines both systemic and human-centered dimensions of technology implementation. It explores how performance metrics, professional experiences, and planning processes shape the uptake and use of innovations in practice.

By studying the OR from multiple angles, this thesis aims to (1) highlight overlooked factors that influence implementation outcomes, (2) offer practical insights for innovators working in and with hospitals, and (3) support the development of technologies that are both context-aware and transferable across healthcare institutions. While each chapter focuses on a distinct aspect of implementation, together these chapters are guided by the overarching research question:

How can we better understand and support the effective and sustainable implementation of medical technology in the operating room, considering both system-level processes and the experiences of healthcare professionals?

Readers guide

This thesis is structured around five studies, each addressing a different but interconnected element of MedTech implementation in the operating room.

Chapter 1 presents a scoping review of scientific literature on OR performance and MedTech evaluation. It identifies two critical gaps: (1) the well-being of healthcare professionals – particularly surgical nurses – is often overlooked in the development and assessment of technology, and (2) while innovations like AI-driven planning tools attract attention, their successful integration into daily OR routines remains rare in practice.

Chapter 2 responds to the first gap by examining how MedTech influences surgical nurses' workload and job satisfaction. Drawing on interviews and observations across varying levels of technological complexity, this chapter highlights design and implementation considerations for reducing unintended burdens on staff and improving acceptance.

Chapter 3 follows up on the second gap by investigating how OR planning is actually organized in practice. Based on a cross-sectional study of all Dutch university medical centers, it maps current planning strategies, clarifies roles and responsibilities, and uncovers common challenges that hinder the adoption of planning innovations.

Chapter 4 builds on these findings to explore the transferability of OR planning approaches. Through a comparative case study of one academic and one regional hospital, the chapter investigates how organizational context shapes the success or failure of implementation efforts, offering insights into what makes a strategy adaptable across settings.

Chapter 5 shifts focus to the broader impact of systemic constraints, such as workforce shortages and limited OR capacity. It introduces the design and evaluation of a serious board game aimed at future patients and healthcare stakeholders, simulating the real-life trade-offs involved in OR scheduling. The chapter illustrates how game-based learning can foster awareness and empathy in a time of increasing pressure on surgical services.

How can we better understand and support the effective and sustainable implementation of medical technology in the operating room, considering both system-level processes and the experiences of healthcare professionals?

CHAPTER I

Operating room performance optimization metrics: a systematic review

In literature, there is little focus on the well-being of healthcare professionals

Literature shows that improving OR planning with technology is difficult

CHAPTER II

Redefining Effective Surgery Assistance: Impact of Operating Room Technology on Intra-operative Nurses' Workload and Job Satisfaction

CHAPTER III

Operating Room Planning and Utilization Strategies of University Medical Centers

CHAPTER IV

Operating Room Planning and Utilization Strategies: a Case Study

CHAPTER V

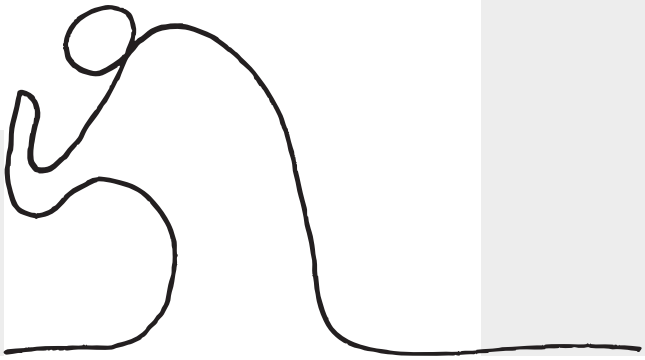
Development of a Serious Game to Raise Awareness Among Future Patients About Day-of-Surgery Cancellations

Medical technology can succesfully optimize the workflow of the OR if it is designed with the whole OR team in mind and if hospital data is used to create transparency.

Figure 1 Structure of this dissertation

References

1. Allers, S., Carboni, C., Eijkenaar, F., & Wehrens, R. (2024). A Cross-Disciplinary Analysis of the Complexities of Scaling Up eHealth Innovation. Journal of Medical Internet Research, 26, e58007. https://doi.org/10.2196/58007
2. Cosma, S., Cosma, S., Pennetta, D., & Rimo, G. (2025). Overcoming the "valleys of death" in advanced therapies: The role of finance. Social Science & Medicine, 366, 117639. https://doi.org/10.1016/j.socscimed.2024.117639
3. European Environment Agency. (2020, May 11). Accelerating technological change (GMT 4).
4. Floridi, L., Cowls, J., Beltrametti, M., Chatila, R., Chazerand, P., Dignum, V., Luetge, C., Madelin, R., Pagallo, U., Rossi, F., Schafer, B., Valcke, P., & Vayena, E. (2018). AI4People—An Ethical Framework for a Good AI Society: Opportunities, Risks, Principles, and Recommendations. Minds and Machines, 28(4), 689–707. https://doi.org/10.1007/s11023-018-9482-5
5. Kalra, N., Verma, P., & Verma, S. (2024). Advancements in AI based healthcare techniques with FOCUS ON diagnostic techniques. Computers in Biology and Medicine, 179, 108917. https://doi.org/10.1016/j.compbiomed.2024.108917
6. Persoon, P. G. J., Bekkers, R. N. A., & Alkemade, F. (2020). How cumulative is technological knowledge?
7. Porto, C., & Catal, E. (2021). A comparative study of the opinions, experiences and individual innovativeness characteristics of operating room nurses on robotic surgery. Journal of Advanced Nursing, 77(12), 4755–4767. https://doi.org/10.1111/jan.15020
8. Thacharodi, A., Singh, P., Meenatchi, R., Tawfeeq Ahmed, Z. H., Kumar, R. R. S., V, N., Kavish, S., Maqbool, M., & Hassan, S. (2024). Revolutionizing healthcare and medicine: The impact of modern technologies for a healthier future—A comprehensive review. Health Care Science, 3(5), 329–349. https://doi.org/10.1002/hcs2.115
9. Topol, E. J. (2019). High-performance medicine: the convergence of human and artificial intelligence. Nature Medicine, 25(1), 44–56. https://doi.org/10.1038/s41591-018-0300-7
10. Turner, S. R., Mormando, J., Park, B. J., & Huang, J. (2020). Attitudes of robotic surgery educators and learners: challenges, advantages, tips and tricks of teaching and learning robotic surgery. Journal of Robotic Surgery, 14(3), 455–461. https://doi.org/10.1007/s11701-019-01013-1
11. Vernyuy, A. (2024). Impact of Technological Advancements on Human Existence. International Journal of Philosophy, 3(2), 54–66. https://doi.org/10.47941/ijp.1874
12. World Health Organization. (2009, June 24). Health workforce: the health workforce crisis. https://www.who.int/news-room/questions-and-answers/item/q-a-on-the-health-workforce-crisis
13. World Health Organization. (2010). Medical devices: managing the mismatch. https://iris.who.int/bitstream/handle/10665/44407/9789241564045_eng.pdf
14. World Health Organization. (2024, May 3). Nursing and midwifery. https://www.who.int/news-room/fact-sheets/detail/nursing-and-midwifery
15. Yoda, T. (2016). The effect of collaborative relationship between medical doctors and engineers on the productivity of developing medical devices. R&D Management, 46(S1), 193–206. https://doi.org/10.1111/radm.12131



I

OR Performance Metrics

Operating room performance optimization metrics: a systematic review

Literature proposes numerous initiatives for optimization of the Operating Room (OR). Despite multiple suggested strategies for the optimization of workflow on the OR, its patients and (medical) staff, no uniform description of 'optimization' has been adopted. This makes it difficult to evaluate the proposed optimization strategies. In particular, the metrics used to quantify OR performance are diverse so that assessing the impact of suggested approaches is complex or even impossible. To secure a higher implementation success rate of optimisation strategies in practice we believe OR optimisation and its quantification should be further investigated. We aim to provide an inventory of the metrics and methods used to optimise the OR by the means of a structured literature study. We observe that several aspects of OR performance are unaddressed in literature, and no studies account for possible interactions between metrics of quality and efficiency. We conclude that a systems approach is needed to align metrics across different elements of OR performance, and that the wellbeing of healthcare professionals is underrepresented in current optimisation approaches.

List of Abbreviations

OR	Operating Room
FMEA	Failure mode and effects analysis
VSM	Value Stream Mapping
ER	Emergency Room
OSH	Occupational Safety and Health
PACU	Post Anaesthesia Care Unit

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1.1 Background

Operating Room (OR) performance optimization is investigated from many angles and numerous different strategies are proposed. Think hereby of new systems based on data analysis that enable more efficient OR scheduling. However, many of these promising initiatives that are meant to improve the OR do not seem to land in practice(1). Suggested changes do not always fit the overall workflow of the OR, or they solve the targeted problem ineffectively. Creating a support base amongst the people that implement or work with the innovation also tends to be problematic(2). To enable improvement of OR performance with innovations that fit well in practice, it should be clear what is exactly meant with the term OR performance. Furthermore, to know if an innovation improves overall OR performance, one must know how to measure the overall performance.

Below, we discuss what OR performance means according to literature and which elements it contains. Next, to investigate how to measure OR performance we make an inventory of the metrics used in literature to measure OR performance. Finally, to investigate how the field approaches OR performance optimization, we collected studies on this topic and addressed what methods were used and what aspect of OR performance the research focussed on. Besides perspectives on patients and healthcare professionals, we also consider economic perspectives on the OR on hospital budgets.

1.1.1 Pressures for change in the OR

The OR comprises a complex environment with multi-layered social interactions, unpredictability and a low tolerance for mistakes(3). Irregularities in the workflow are often triggered by a combination of factors such as demanding caseloads, pressure to perform complex tasks and conflicting priorities. This can result in increased mental strain and stress amongst the healthcare professionals(4). Irregularities in workflow on the OR also impact patients. Approximately 60% of the patients visit the OR at some point during their hospital stay(5). Undergoing hospital admission and an operation makes many people experience emotions such as nervousness, agitation and uncertainty. Irregularities in the process can worsen this(6).

Accounting for about 35% to 40% of the costs, the OR is a large contributor to a hospital's finances, also being one of the most costly units (7–9). Over the past years, healthcare costs have increased and diminishing returns have prompted healthcare administrators to alleviate institutional costs through reductions in budget allocations(10). Partly driven by the increasing demands for care on the one hand, and constrained resources on the other, a technological evolution has taken place over the last decades. This has played an important role in the development of surgery and resulted in dramatic changes in working conditions within the OR(11). But healthcare professionals are not always prepared for this transformation of their work. Healthcare professionals are reported to lack preparation for radical (technical) changes in their work(12).

Despite the growing influx of new healthcare professionals, the sector experiences a major exodus of healthcare professionals. Causes are the heavy workload and a lack of autonomy. The limited autonomy of healthcare professionals in their daily work is appointed as a long-standing issue(12). Research from the Dutch doctors organisation De Jonge Dokter has interviewed 622 young doctors about their work. About 50% of the interviewees has thought about quitting their job due to high work pressure, emotional pressure and working culture(13).

The impact of the workflow of the OR on patients, pressure on healthcare professionals that work on the OR, the vast changing work environment and economical constraints make that optimizing the OR is high on the academic agenda. However, the high expectations of patients, interactions between different professionals, unpredictability and complex surgical case scheduling make managing and changing the system difficult. Attempts to resort to commonly used industrial principles to increase factors such as efficiency have been demonstrated to easily fail due to these (and possibly other) particular characteristics of the OR(7): human factors have too great of an impact to standardize and automate certain OR processes. Another complicating factor is the divergent perspectives on OR performance optimization.

1.1.2 OR performance optimization metrics

The metrics used to quantify OR performance optimization reported in literature are diverse(14). Many articles focus on the efficiency aspect of OR performance optimization, some focus more on the quality aspects. For example, the work

of Bellini et al. (2019) speaks of the optimization related factor efficiency in the sense of more precise scheduling and limiting waste of resources. Costa Jr. et al. (2015) speak of both efficiency and optimization, hereby focussing on resources and time management. Sandbaek et al. (2014) refer to OR efficiency as maximizing throughput and OR utilization while minimizing overtime and waiting time, without additional resources. Tanaka et al. (2011) assesses OR performance using indicators such as the number of operations, the procedural fees per OR, the total utilization time per OR and total fees per OR. Rothstein & Raval (2018) refer to the metrics of OR efficiency based on the Canadian Paediatric Wait Times Project: off-hours surgery, same-day cancellation rate, first case start-time accuracy, OR use, percentage of unplanned closures, case duration accuracy, turnover time and excess staffing costs.

Alternatively, Arakelian, Gunningberg and Larsson (2008) emphasize that apart from cost-effectiveness, work in the OR should be organized to fulfil the demands on patient safety and high-quality care. From their perspective, OR departments must create efficient ways of planning and processing the work, while at the same time maintaining the quality of care. These authors also show that there are diverging perspectives among OR personnel on what efficiency and productivity entail.

The previous paragraphs illustrate that when speaking about OR performance optimization, different terminology is being used. Furthermore, although many studies focus on how to optimize or monitor certain aspects of the OR, studies

Table 1 OR performance includes four aspects: 1. Patient safety 2. Quality of care 3. Cost-effectiveness 4. Well-being healthcare professionals.

OR Performance	
Efficiency *Maximizing throughput and OR utilization while minimizing overtime and waiting time, without additional resources (16).*	Cost-effectiveness(17)
Quality	Quality of care(17) Patient Safety(17) Well-being healthcare professional(12)

on the impact of these changes on the quality and efficiency of the hospital as a whole appear to be lacking. This may lead to uncertain optimisation strategies that are difficult to substantiate with supporting evidence(15). Table 1 summarizes both quality and efficiency aspects of OR workflow and strives to align the methods and metrics to assess OR performance in terms of 1. Patient safety 2. Quality of care 3. Cost-effectiveness and 4. Healthcare professional well-being.

1.2 Method

A systematic literature review was conducted to make an inventory of metrics for optimization of the OR in literature. We used the search engines Scopus, Web of Science and PubMed with the search terms: "Operation Room" AND Optimization and Workflow AND Optimization AND Hospital. We limited the search to articles that discuss ways to optimize the OR as a system, not the performed medical interventions themselves. Furthermore, articles that were not written in the English language or did not belong to the category healthcare or medicine were excluded.

1.2.1 Analysis

An inventory of the topics of the articles was made by filtering out 1. the focus/aim of the study, 2. the method used and 3. the conclusion. Optimization strategies in other hospital departments might be transferable to the OR as well. Therefore, to gain insight in the distribution of optimization strategies on the different departments of the hospital, the articles were analysed by labelling the operational department the research is focussed on, which topic was investigated, and which method was used. After creating this overview, only data about the OR was used. To obtain OR performance metrics a second analysis was conducted: OR performance characteristics from the articles were split into aspects with their corresponding metrics.

Coding nodes

Overall categories for departments, topics and methods were identified based on the first 50 articles, as the authors felt a saturation rate for new categories was reached. The remaining articles were then labelled within these categories. To illustrate, Table 2 shows two sections that were both labelled as the metric T_3 and two sections that were labelled as the method M_8.

Table 2 Sections from articles that were labelled as T_3 and sections that were labelled as M_8, to illustrate when these sections fall in the same category.

I	Topic label T_3: Optimize patient flow
1	*"In most hospitals, patients move through their operative day in a linear fashion, starting at registration and finishing in the recovery room. Given this pattern, only 1 patient may occupy the efforts of the operating room team at a time. By processing patients in a parallel fashion, operating room efficiency and patient throughput are increased while costs remain stable" (18).*
2	*"The main objective of this work is to propose and to evaluate a Decision Support System (DSS) for helping medical staff in the automatic scheduling of elective patients, improving the efficiency of medical teams' work" (5).*
	Method label M_8: Computational
1	*"To solve the allocation of doctors to surgeries planning problem, also addressed in literature as Master Surgical Schedule (MSS), we propose a mathematical programming approach" (19).*
2	*"In this study, three optimization models were developed for optimizing operating room scheduling during unexpected events and accommodating emergency patient surgeries in the established schedule. The first model (Model I) schedules emergency patients in newly opened rooms, whereas the second model (Model II) aims to assign emergency patients to untapped ranges; the third model (Model III) re-sequences elective and emergency patients in the room with the greatest free margin" (20).*

Coding the articles

Some articles mention multiple topics or methods. If multiple topics were mentioned, the article was labelled for the topic which had the most emphasis. This is illustrated in Example 1, where both the topics patient throughput and costs are mentioned. However, the emphasis is on patient throughput. For topics the article was therefore labelled as T_3: Optimize patient flow.

Example 1: *"In most hospitals, patients move through their operative day in a linear fashion, starting at registration and finishing in the recovery room. Given this pattern, only 1 patient may occupy the efforts of the operating room team at a time. By processing patients in a parallel fashion, operating room efficiency and* **patient throughput** *are increased while* **costs** *remain stable"(18).*

When labelling the articles for their method, it occurred that an article investigates an optimization possibility and method by means of a literature study. The method of the article was then labelled as literature study.

In Example 2, the article investigates how workflow can be improved by identifying the potential failures of the system by means of a management tool.

Example 2: *"Failure mode and effects analysis (FMEA) is a valuable reliability* **management tool** *that can pre-emptively* **identify the potential failures of a system** *and assess their causes and effects, thereby preventing them from occurring. The use of FMEA in the healthcare setting has become increasingly popular over the last decade, being applied to a multitude of different areas. The objective of this study is to* **review comprehensively the literature** *regarding the application of FMEA for healthcare risk analysis"(21).*

However, the effects of the management system on workflow are investigated by a literature study. For methods the article was therefore labelled as M_1: Literature study. In the results the coded articles are displayed in 3 sunburst graphs: the first shows the distribution of methods and topics of all hospital departments, the second contains the distribution of methods and topics on the OR. To elucidate the OR data, the third graph shows a selection with the biggest categories of the second sunburst (categories with $N \geq 3$). Some of the smaller categories are illustrated with examples in the text.

Validation

The labelling was performed independently by two of the authors. Discrepancies were discussed and adjusted by obtaining consensus.

1.3 Results

In this section, the results of the inventory of OR performance metrics and the addressed OR performance topics in literature are shown.

1.3.1 Review statistics

Figure 1 shows the search engines, search terms and number of papers found.

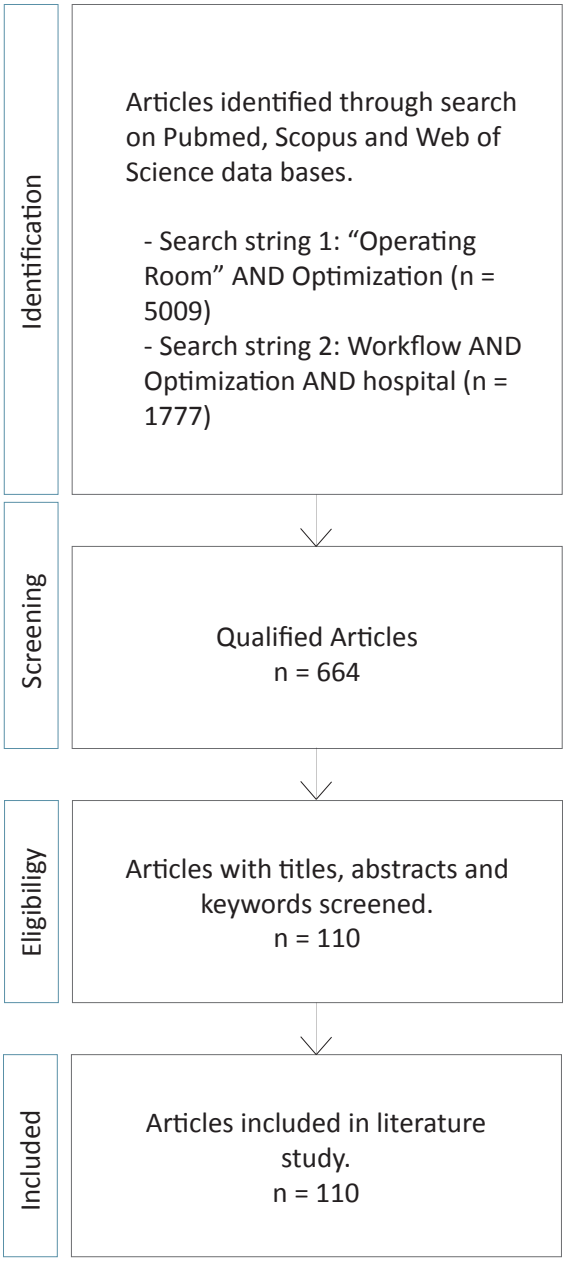


Figure 1 Literature search method used to make an inventory of the current literature on OR optimization.

1.3.2 OR performance metrics

Based on Table 1, the characteristics of OR performance (efficiency and quality) have been split up into aspects and were then further specified into metrics (Table 3).

Table 1 OR performance includes four aspects: 1. Patient safety 2. Quality of care 3. Cost-effectiveness 4. Well-being healthcare professionals.

Characteristic	*Aspect*	*Ref.*	*Metric*	*Ref.*
Efficiency	OR throughput	(16)	Number of operations per OR per month.	(22)
	OR utilization	(16)	Total utilization time per OR per month (hours).	(22)
	Time (overtime, waiting time)	(16)	Off-hours surgery per OR per month (hours) *(Results from urgent add-on cases or case over-runs).*	(3)
			Same-day cancellation rate per OR per month *(classify per cause and time of day.)*	(3)
			First case start-time accuracy per OR per month (%).	(3)
			OR use per OR per month (hours) *(Distinguish between overall utilization time (time something is occurring on the OR) and operating-specific utilization (time between first incision and final closure as a percentage of the room's overall "open" period.)*	(3)
			Percentage of unplanned closures per OR per month (%) *(may occur due to equipment deficits etc.).*	(3)
			Case duration accuracy per OR per month (%) *(useful to distinguish between true case time (from patient entry till patient exit) and turnover times).*	(3)
			Turnover time per OR per month (hours) *(from patient exit till next patient entry)*	(3)
			Excess staffing costs per OR per month (€) *(can be the result of both over-utilization (pay staff for overtime) and underutilization)*	(3)
	Resources	(16)	Procedural fees per OR per month (€)	(22)
			Total fees per OR per month (€)	(22)
Quality	Quality of care & patient safety	(17)	Number of problems per patient as a result of exposure to the healthcare system per OR per month	(12)

Well-being health care professionals	(12)	Workload (number of cases per OR staff member per month)	(12)
		Autonomy	(12)

1.3.3 Addressed OR performance topics in literature

Table 4 shows the categories used to analyse the articles, the corresponding labels and their names. In Appendix 1.1, Supp. Tab. 1, the topic category and their corresponding sources are presented.

Table 4 The categories used to analyse the articles, corresponding labels and names.

Category	*Label*	*Name*	*Description*
Department	D_1	OR	OR department
	D_2	ER	ER department
	D_3	Outpatient clinic	Outpatient clinic department
	D_4	Patient clinic	Patient clinic department
	D_5	Hospital	Hospital in general
Topic	T_1	Optimize role of surgeon	
	T_2	Reduce delays	
	T_3	Optimize patient flow	
	T_4	Reduce costs	
	T_5	Optimize management	Organisational management, risk management etc.
	T_6	Optimize teamwork	
	T_7	Reduce non operative time	
	T_8	Optimize anaesthesia procedure	Can be optimization of both medication and procedure.
	T_9	Define OR efficiency	
	T_10	Optimize scheduling	Scheduling of operations, medical staff etc.
	T_11	Optimize overall equipment effectiveness	Use equipment in a more effective way.
	T_12	Optimize workflow tracking systems	Such as an engineering perspective or VSM (Value Stream Mapping)

	T_13	Optimize overall productive capacity of a department	
	T_14	Optimize department design	Physical rearrangement or redesign of a department.
	T_15	Reduce workload	
Method	M_1	Literature review	
	M_2	Analysing data	
	M_3	Experiment with patients	
	M_4	Experiment with surgeons	

1.3.4 Distribution of the labels

Appendix 1.2, Supp. Fig. 1, shows a sunburst graph that illustrates the distribution of the labels per department (D_x). To give an overview that represents the distribution of departments in a hospital, only the data from the second search criteria (Workflow AND Optimization AND Hospital) was included in this graph. The inner circle contains the different departments, namely the OR, ER (emergency room), outpatient clinic, patient clinic and the hospital in general. The middle circle shows the corresponding methods, the outer circle shows the topics. Most articles focus on the OR (D_1, N = 16). The ER receives less attention (D_2, N = 2). There were no articles that were labelled for outpatient clinic (D_3).

In Appendix 1.2, Supp. Fig. 2 zooms in on methods and corresponding topics of just the OR. This graph includes all OR data from both search criteria and shows the methods, topics and number of articles in each category. In Figure 2, a selection of the OR sunburst graph is displayed. This selection contains the most frequent combination of period, method and topic (N ≥ 3). Most articles have the aim to optimize scheduling (N = 7), workflow tracking (N = 5) and patient flow (N = 4) by computational means such as machine learning.

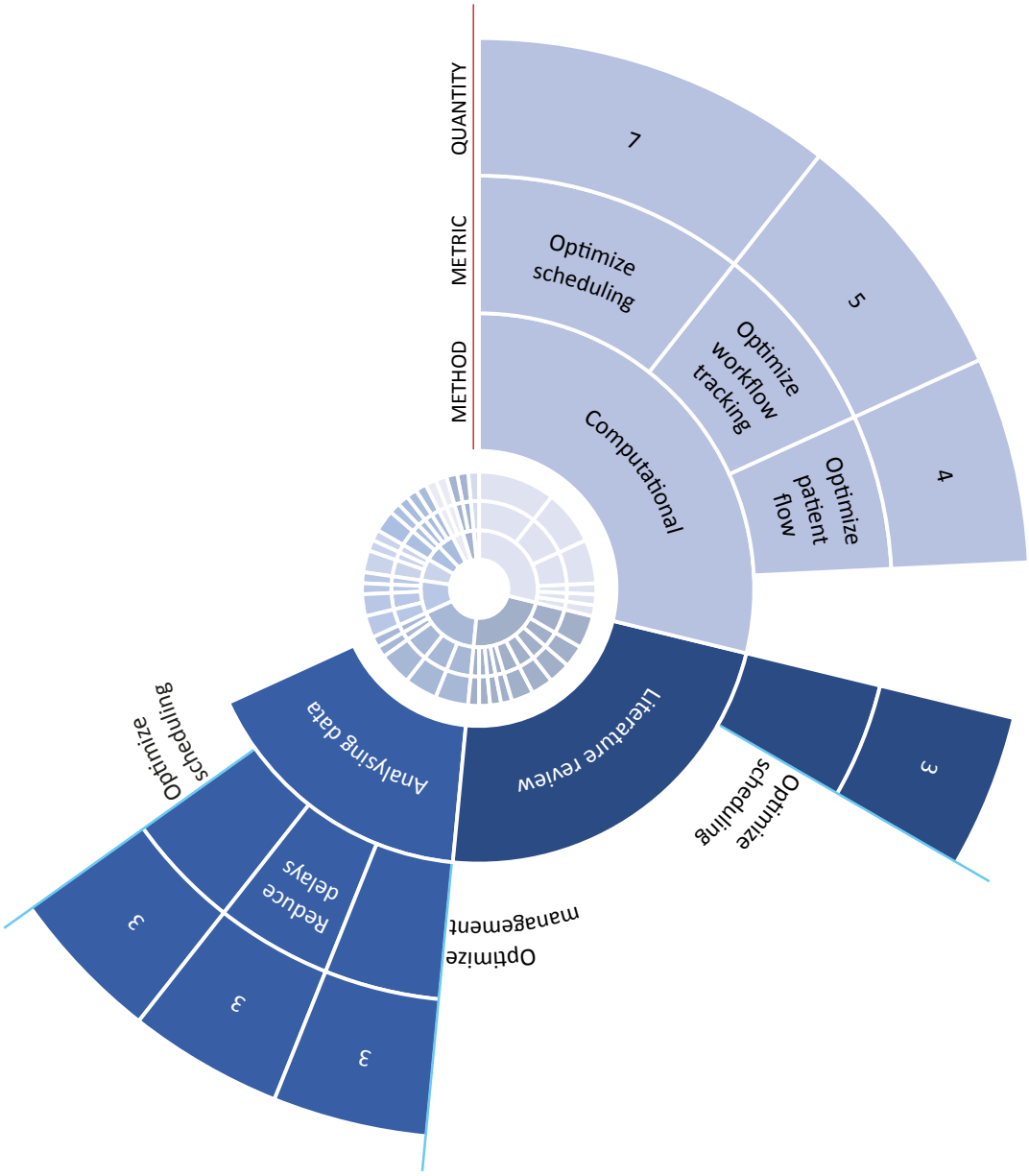


Figure 2 Selection of the sunburst graph, showing the seven main categories.

All data was then stratified by the means of a bar chart. Figure 3 shows the data while looking at different methods per topic. Computational methods (M_8) are used most frequently (N = 41). The methods that were used the least are experiments with the medical staff (M_7, N = 2) and system engineering (M_10, N = 2). The most investigated topics are patient flow (T_10, N = 18), OR scheduling (T_3, N = 17) and workflow tracking systems (T_5, N = 15).

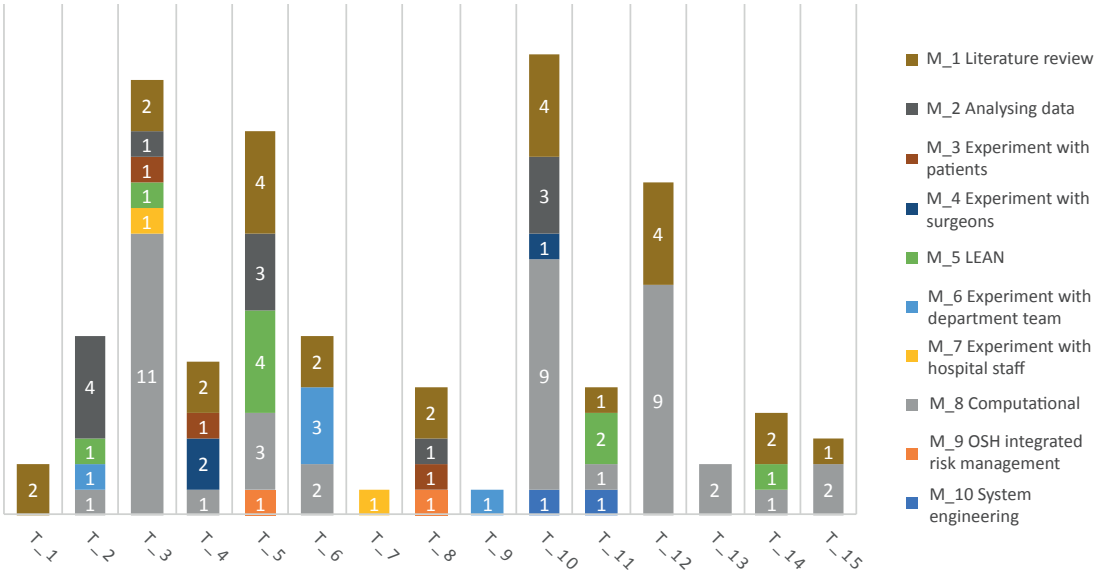


Figure 3 Bar chart with the different methods per topic.

1.4 Discussion

In this study we addressed what methods were used in other studies, what aspect of OR performance they focussed on, and for which department the effects were to be relevant. We aimed to investigate how the field approaches OR performance optimization and to create an overview of OR performance metrics for the categories of patient safety, quality of care, cost-effectiveness, and the well-being of healthcare professionals.

Most studies focused on patient safety, quality of care and cost-effectiveness. This might be explained by the fact that healthcare has a central focus on patient wellbeing and clinical outcome measures. One striking result from this study is

that the well-being of healthcare professionals is largely ignored in OR optimization studies. Ill-performing in these areas may contribute to staff shortages. Therefore, we deliberately added the well-being of healthcare professionals as a crucial aspect of OR performance as we feel that this is a subject that must be taken in account in OR optimisation.

By taking all four categories within OR performance as a starting point for the delineation of the ways to measure OR performance, we strive to create an all-encompassing overview of relevant metrics in literature. More metrics were found for efficiency than for quality aspects. This was as expected because efficiency tends to be easier to measure than quality aspects. Furthermore, quality metrics are often subjective. For instance, well-being of healthcare professionals, is linked to the metric autonomy (freedom to make your own choices, plan your workday etc.). This is a capacity that is difficult to quantify in a valid and reliable way.

Considering the research topics addressed in literature it was found that most articles have the aim to optimize OR scheduling, Workflow tracking or Patient flow by computational means, such as machine learning. Thanks to greater computing power, as well as the growing availability of large amounts of data, machine learning holds the promise to make sense of complex modelling tasks(24). Topics such as OR scheduling, Workflow tracking and Patient flow fit this picture. They are suitable for computational simulations and optimizations of complex systems such as the OR that are characterised by high variability in the timing and alignment of processes.

Categories that involve experiments with healthcare professionals (such as interventions in practice) were only limitedly represented in the literature. With AI on the rise, it seems a logical choice to use simulations to test optimizations instead of occupying the (often overworked) healthcare professionals. However, although simulated efficacy trials have generated many possible interventions to improve healthcare, their impact on practice and policy is limited so far(25). Establishing and conveying the credibility of computational modelling and simulation outcomes is a delicate task(26) and the step from simulation to implementation in practice turns out to be a difficult one.

Kessler & Glasgow point out that healthcare research must deal with “wicked” problems that are multilevel, multiply determined, complex and interacting. Re-

search tends to isolate, decontextualize and simplify issues in order to be able to investigate them. Consequently, the small number of studies with representative populations, staff and settings that substantiate optimisation approaches is in sheer contrast with the large number of papers that promote the potential of computational methods. Overall, similar to what Fong et al. (2016) report, timepoints, cost, methodology and outcome measures were inconsistent across the studies in this review, and it appears that multiple metrics can fit a topic. Nevertheless, the topics of the articles cited in this review give insightful handles of how to structure OR performance metrics. Increasing awareness about these topics and metrics amongst the people who work with them is therefore of value.

Awareness should also be increased about the definitions of the concepts of OR performance(17). It is important to realize that the term "OR performance" only describes a snapshot in time but extents across all topics. Some studies talk about performance, but do not always specify if there is change in this performance. Change can only be measured over time. When doing so, clear criteria are required to determine if the change is also an improvement. In one context something might be an improvement, in another it might worsen the situation(27). The ideal scenario would be to optimize an OR performance topic for all the metrics from Table 3. However, this may not always be attainable. A sensible approach is to apply relevant metrics both at the beginning of your project and after your

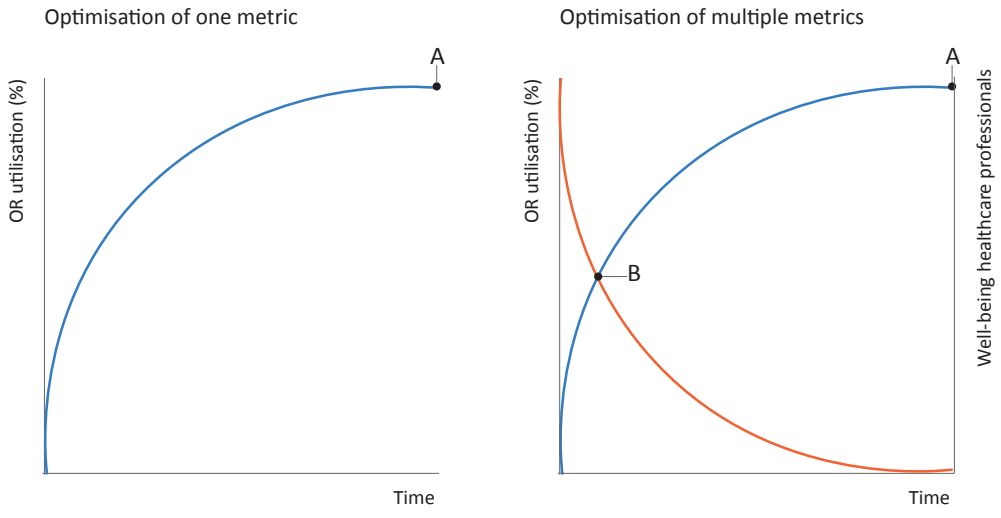


Figure 4 Two elements of OR performance optimization: optimize for a (set of) metric(s) and improve or conserve the overall balance of the metrics.

intervention in the system, and to evaluate the impact on all four categories of OR performance. By prioritizing and assigning weights to metrics acceptable ranges for the optimisation outcomes could be defined. When looking at optimization in this way, it should comprise two elements: improvement on a (set of) metric(s) and an improvement of the total system after your intervention.

This approach is illustrated in Figure 4, where on the left the hypothetical optimization of one metric is shown, and on the right the same change of the metric is shown, together with another metric of the system. When, for example, one chooses to optimize OR performance by increasing the metric Number of operations per OR per month, you aim for point A in Figure 4. However, Figure 4 also illustrates that an increase along one metric could mean a (unintended) decrease on another. When taking other metrics into account you can see it is actually point B you are aiming for. Therefore, measuring every metric before and after your intervention to monitor the impact on the total system is essential for a thorough validation of its appropriateness.

1.4.1 Modelling the metrics

Optimizing the system for a certain metric while also considering the other metrics should be part of the optimization strategy. Practical execution of this strategy is a roadmap with design steps in which the metrics are incorporated. In the following paragraphs this idea will be illustrated with Figure 5 and an example scenario for an optimization goal.

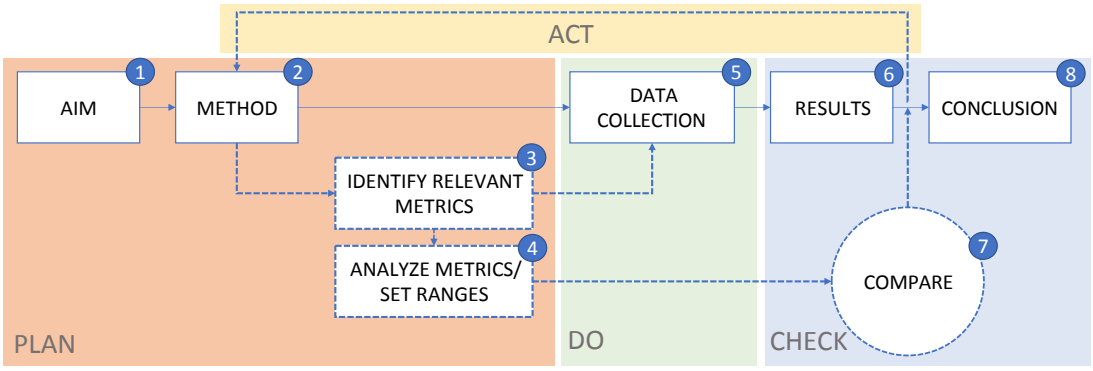


Figure 5 Suggestion for a research setup in which the whole system is taken into account by incorporating an analysis of the metrics. Based on the PDCA Cycle of Deming.

Figure 5 shows an example of the main steps of a research approach (aim, method, data collection, results, conclusion) with an emphasis on the phase between method and data collection. The approach is based on the Plan-Do-Check-Act method of Deming(28). In a fictitious scenario the aim of the project is to improve the well-being of healthcare professionals on the OR. This is the first step of the model in Figure 5. In second step it is determined that the method used to achieve the aim will be increasing the metric autonomy of the healthcare professionals. A questionnaire amongst the staff involved shows that the healthcare professionals would like to have more autonomy over when they work. A more open work schedule is therefore suggested. In the third step of the model the most important metrics that could be affected by this change are listed by the researchers:

- Excess staffing costs (often caused by over- or under-utilization of the OR).
- OR utilization
- Quality of care and patient safety
- Autonomy

In the fourth step the selected metrics are combined in logical sets as system optimisation metrics with assigned weights and acceptance ranges. As an example, we could look at optimizing OR utilization. In this case the constant consists of the metric off time per OR per month and the utility time per OR per month (see Equation 1).

(Eq. 1)

$$\frac{\frac{Toff}{\frac{OR}{month}}}{\frac{Tutility}{\frac{OR}{month}}} = \frac{Toff}{Tutility} = T*$$

Ranges of the constant are then given scores and weights to calculate the optimal value (Table 5). For example, if T* were to be greater than 1, there would be more off time per OR than utility time. That is an undesirable scenario. This range is therefore given a score of -1 and a weight of 2. When T* is low there is a high utility rate of the OR's. When T* is high there is a low utility rate. A more complete overview would be created when also plotting financial metrics and metrics concerning the well-being of the medical staff.

After data has been collected in step 5 of the model, the results of step 6 can be compared in step 7. One can then evaluate whether the intended innovation will

improve the system in such a way that it is worth the investment. And if not, consider carefully based on the metric overviews where adjustments to the intervention are required.

Table 5 The constant T* describes OR utility. To create insight in what values of T* are desirable and which are not, scores and weights are assigned to ranges of values of T*.

	Score	Weight	
$0 < T^* < 0.25$	2	2	Best
$0.25 < T^* < 1$	1	1	Acceptable
$1 < T^*$	-1	2	Worst

1.4.2 Limitations

This study has limitations. A major focus of this paper is the importance of seeing the whole picture when doing research. We have given examples of possibilities to bring this way of doing research into practice. However, despite the broad view of this study, we did not cover all aspects of healthcare. We looked at just the OR. Following our own philosophy, we want to stress that an even broader scope is relevant for successful optimization in healthcare. There is an intricate interplay between the different departments of a hospital. Increasing the efficiency of the OR might, for example, cause trouble in the timetable of the PACU (Post Anaesthesia Care Unit).

1.5 Concluding Remarks

In this study it was found that there are many different perspectives and approaches used to optimize OR performance. The metrics used to optimize OR performance are diverse. Based on our inventory of the metrics and methods used in literature we conclude that part of the crucial aspects of OR performance, such as the wellbeing of healthcare professionals, are underrepresented in the research field. The lack of studies that account for possible interactions between metrics of quality and efficiency have limited the impact of optimisation approaches. Too much focus on one metric potentially deteriorates other elements of the system you try to optimize. To obtain profitable OR optimization, a systems approach

that aligns metrics across functions and better representation of the wellbeing of healthcare professionals are needed.

1.5.1 Future research

An informative topic to investigate further is to test the effect of awareness of metrics when optimizing OR metrics in practice. The hypothesis here is that more awareness of OR performance metrics and their correlations amongst researchers could lead to better optimizing strategies. In this context, the model in Figure 5 might also be tested. Does it increase awareness? Do researchers use different approaches with the model than without? Does this lead to better outcomes?

Another direction is the continuous measuring of OR performance metrics to be able to monitor unintended interactions, in ways that not put a burden on healthcare professionals (i.e., increasing administrative tasks). Furthermore, technology can speed up and smoothen processes within the OR, but the impact on perioperative processes might not have been considered. An interesting way to put these thoughts to practice is investigating how the increase of technology on the OR has influenced the work of healthcare professionals such as OR nurses and supporting department.

References

1. Cassidy CE, Harrison MB, Godfrey C, Nincic V, Khan PA, Oakley P, et al. Use and effects of implementation strategies for practice guidelines in nursing: a systematic review. Implementation Science. 2021;16(1):1–29.
2. Hellström A, Lifvergren S, Quist J. Applying Process Management in Healthcare – Investigating Implementation Difficulties. J Quist - International Annual EurOMA . 2009;(June 2014):1–10.
3. Rothstein DH, Raval M V. Operating room efficiency. Seminars in Pediatric Surgery. 2018;27(2):79–85.
4. Wheelock A, Suliman A, Wharton R, Babu ED, Hull L, Vincent C, et al. The impact of operating room distractions on stress, workload, and teamwork. Annals of Surgery. 2015;261(6):1079–84.
5. Clavel D, Mahulea C, Albareda J, Silva M. A decision support system for elective surgery scheduling under uncertain durations. Applied Sciences (Switzerland). 2020;10(6):1–21.
6. Landon PM, Lazar J, Heylighen A, Dong H. Inclusive Designing. Springer International Publishing. 2014.
7. Bellini V, Guzzon M, Bigliardi B, Mordonini M, Filippelli S, Bignami E. Artificial Intelligence: A New Tool in Operating Room Management. Role of Machine Learning Models in Operating Room Optimization. Journal of Medical Systems. 2019;44(1):1–10.
8. Cima RR, Brown MJ, Hebl JR, Moore R, Rogers JC, Kollengode A, et al. Use of Lean and Six Sigma Methodology to Improve Operating Room Efficiency in a High-Volume Tertiary-Care Academic Medical Center. ACS. 2011;213(1):83–92.
9. Lovejoy WS, Li Y. Hospital operating room capacity expansion. Management Science. 2002;48(11):1369–87.
10. Boggs SD, Tan DW, Watkins CL, Tsai MH. OR Management and Metrics: How It All Fits Together for the Healthcare System. Journal of Medical Systems. 2019;43(6).
11. Matern U, Koneczny S. Safety, hazards and ergonomics in the operating room. Surgical Endoscopy and Other Interventional Techniques. 2007;21(11):1965–9.
12. SER. The Future of Dutch Healthcare: A Study. Social and Economic Council. 2020;2(1):1–13.
13. NOS. Helft jonge artsen denkt weleens aan stoppen door hoge werkdruk [Internet]. 2020 [cited 2021 Jul 26]. Available from: https://nos.nl/artikel/2343153-helft-jonge-artsen-denkt-weleens-aan-stoppen-door-hoge-werkdruk
14. Fong AJ, Smith M, Langerman A. Efficiency improvement in the operating room. Journal of Surgical Research. 2016;204(2):371–83.
15. Marang-van de Mheen PJ, Putter H, Bastiaannet E, Bottle A. Competing risks in quality and safety research: a framework to guide choice of analysis and improve reporting. BMJ Quality & Safety. 2021 Dec;30(12):1031–7.
16. Sandbaek BE, Helgheim BI, Larsen OI, Fasting S. Impact of changed management policies on operating room efficiency. BMC health services research. 2014;14:224.
17. Arakelian E, Gunningberg L, Larsson J. Job satisfaction or production? How staff and leadership understand operating room efficiency: A qualitative study. Acta Anaesthesiologica Scandinavica. 2008;52(10):1423–8.
18. Friedman DM, Sokal SM, Chang Y, Berger DL. Increasing Operating Room Efficiency Through Parallel Processing. Annals of Surgery •. 2006;243(1).
19. Assad DBN, Spiegel T. Maximizing the efficiency of residents operating room scheduling: A case study at a teaching hospital. Production. 2019;29.

20. Al-Refaie A, Chen T, Judeh M. Optimal operating room scheduling for normal and unexpected events in a smart hospital. Operational Research. 2018;18(3):579–602.
21. Liu HC, Zhang LJ, Ping YJ, Wang L. Failure mode and effects analysis for proactive healthcare risk evaluation: A systematic literature review. Journal of Evaluation in Clinical Practice. 2020;26(4):1320–37.
22. Tanaka M, Lee J, Ikai H, Imanaka Y. Development of efficiency indicators of operating room management for multi-institutional comparisons. Journal of Evaluation in Clinical Practice. 2013;19(2):335–41.
23. Rhee D, Zhang Y, Papandria D, Ortega G, Abdullah F. Agency for healthcare research and quality pediatric indicators as a quality metric for surgery in children: Do they predict adverse outcomes? Journal of Pediatric Surgery. 2012;47(1):107–11.
24. Yu K-H, Beam AL, Kohane IS. Artificial intellegence in healthcare. Nature Biomedical Engineering. 2018;(2):719–31.
25. Kessler R, Glasgow RE. A proposal to speed translation of healthcare research into practice: Dramatic change is needed. American Journal of Preventive Medicine. 2011;40(6):637–44.
26. Erdemir A, Mulugeta L, Ku JP, Drach A, Horner M, Morrison TM, et al. Credible practice of modeling and simulation in healthcare: Ten rules from a multidisciplinary perspective. Journal of Translational Medicine. 2020;18(1):1–18.
27. Austin PC, Ceyisakar IE, Steyerberg EW, Lingsma HF, Marang-Van De Mheen PJ. Ranking hospital performance based on individual indicators: Can we increase reliability by creating composite indicators? BMC Medical Research Methodology. 2019 Jun 26;19(1).
28. Taylor MJ, McNicholas C, Nicolay C, Darzi A, Bell D, Reed JE. Systematic review of the application of the plan-do-study-act method to improve quality in healthcare. BMJ Quality and Safety. 2014;23(4):290–8.
29. Duncan PG, Overdyk FJ, Harvey SC, Shippey F, Carolina S. Successful Strategies for Improving Efficiency at Academic Institutions. 1998;896–906.
30. Jreije K, Sachdeva S, Cull M, Diaz G, Romero J, Schweitzer J. Rewarding On Time Start Times in Operating Rooms Improves Efficiency. American Surgeon. 2020;86(10):1391–5.
31. Bas E. An integrated OSH risk management approach to surgical flow disruptions in operating rooms. Safety Science. 2018;109(September 2017):281–93.
32. Kaddoum R, Fadlallah R, Hitti E, El-Jardali F, El Eid G. Causes of cancellations on the day of surgery at a Tertiary Teaching Hospital. BMC Health Services Research. 2016;16(1):1–8.
33. Saha P, Pinjani A, Al-Shabibi N, Madari S, Ruston J, Magos A. Why we are wasting time in the operating theatre? International Journal of Health Planning and Management. 2009;24(3):225–32.
34. Aghaebrahim A, Granja MF, Agnoletto GJ, Aguilar-Salinas P, Cortez GM, Santos R, et al. Workflow Optimization for Ischemic Stroke in a Community-Based Stroke Center. World Neurosurgery. 2019;129:e273–8.
35. Venema E, Boodt N, Berkhemer OA, Rood PPM, Van Zwam WH, Van Oostenbrugge RJ, et al. Workflow and factors associated with delay in the delivery of intra-arterial treatment for acute ischemic stroke in the MR CLEAN trial. Journal of NeuroInterventional Surgery. 2018;10(5):424–8.
36. Nemati S, Shylo O V., Prokopyev OA, Schaefer AJ. The surgical patient routing problem: A central planner approach. INFORMS Journal on Computing. 2016;28(4):657–73.
37. Ajmi F, Zgaya H, Othman S Ben, Hammadi S. Agent-based dynamic optimization for

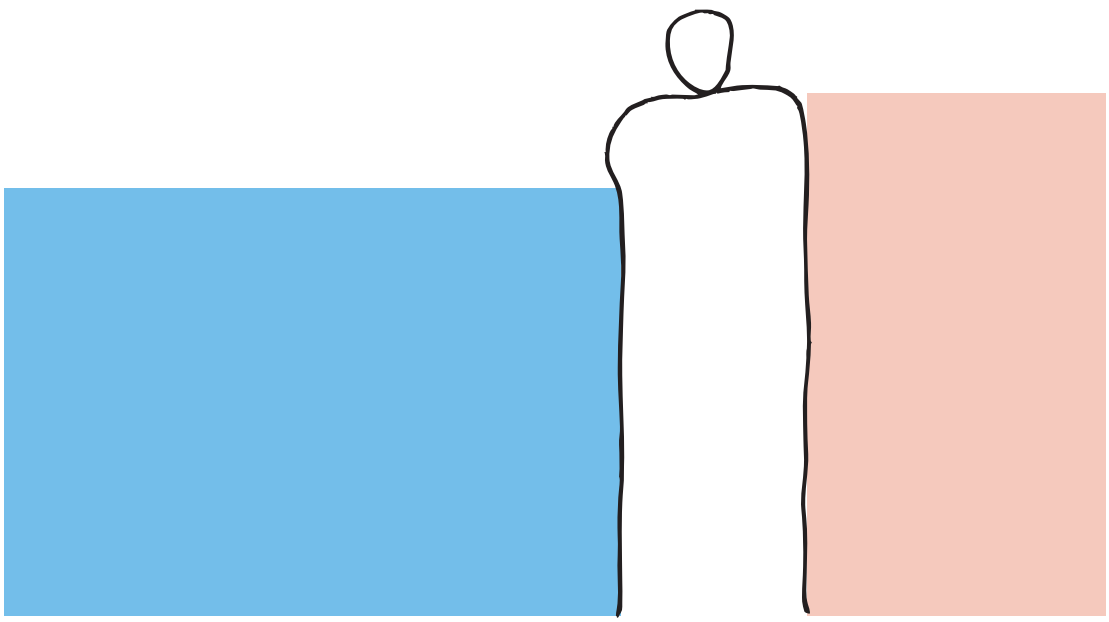
managing the workflow of the patient's pathway. Simulation Modelling Practice and Theory. 2019;96(May):101935.
38. Hur Y, Bard JF, Morrice DJ. Appointment scheduling at a multidisciplinary outpatient clinic using stochastic programming. Naval Research Logistics. 2021;68(1):134–55.
39. J. Morrice D, F. Bard J, M. Koenig K. Designing and scheduling a multi-disciplinary integrated practice unit for patient-centred care. Health Systems. 2020;9(4):293–316.
40. Tlapa D, Zepeda-Lugo CA, Tortorella GL, Baez-Lopez YA, Limon-Romero J, Alvarado-Iniesta A, et al. Effects of Lean Healthcare on Patient Flow: A Systematic Review. Value in Health. 2020;23(2):260–73. \
41. Markazi-Moghaddam N, Jame SZB, Tofighi E. Evaluating patient flow in the operating theater: An exploratory data analysis of length of stay components. Informatics in Medicine Unlocked. 2020;19:100354.
42. Baranova K, Torti J, Goldszmidt M. Explicit Dialogue about the Purpose of Hospital Admission Is Essential: How Different Perspectives Affect Teamwork, Trust, and Patient Care. Academic Medicine. 2019;94(12):1922–30.
43. Zhang H, Best TJ, Chivu A, Meltzer DO. Simulation-based optimization to improve hospital patient assignment to physicians and clinical units. Health Care Management Science. 2020;23(1):117–41.
44. Andersen AR, Nielsen BF, Reinhardt LB, Stidsen TR. Staff optimization for time-dependent acute patient flow. European Journal of Operational Research. 2019;272(1):94–105.
45. Kang CW, Imran M, Omair M, Ahmed W, Ullah M, Sarkar B. Stochastic-Petri net modeling and optimization for outdoor patients in building sustainable healthcare system considering staff absenteeism. Mathematics. 2019;7(6).
46. Berg E, Weightman AT, Druga DA. Emergency Department Operations II: Patient Flow. Emergency Medicine Clinics of North America. 2020;38(2):323–37.
47. Merchant RN. Slated versus actual operating room entry time in a British Columbia health authority. Canadian Journal of Anesthesia. 2020;67(6):726–31.
48. Yip K, Huang K, Chang S, Chui E. A mathematical optimization model for efficient management of Nurses' Quarters in a teaching and referral hospital in Hong Kong. Operations Research for Health Care. 2016;8:1–8.
49. Sasanfar S, Bagherpour M, Moatari-Kazerouni A. Improving emergency departments: Simulation-based optimization of patients waiting time and staff allocation in an Iranian hospital. International Journal of Healthcare Management. 2020;0(0):1–8.
50. Harvey LFB, Smith KA, Curlin H. Physician Engagement in Improving Operative Supply Chain Efficiency Through Review of Surgeon Preference Cards. The Journal of Minimally Invasive Gynecology. 2015;24(7):1116–20.
51. Lau H, Dadich A, Nakandala D, Evans H, Zhao L. Development of a cost-optimization model to reduce bottlenecks: A health service case study. Expert Systems. 2018;35(6):1–13.
52. Lee DJ, Ding J, Guzzo TJ. Improving Operating Room Efficiency. Current Urology Reports. 2019;20(6).
53. Halim UA, Khan MA, Ali AM. Strategies to Improve Start Time in the Operating Theatre: a Systematic Review. Journal of Medical Systems. 2018;42(9).
54. Glennie RA, Barry SP, Alant J, Christie S, Oxner WM. Will cost transparency in the operating theatre cause surgeons to change their practice? Journal of Clinical Neuroscience. 2019;60:1–6.
55. Xiang W, Li C. Surgery scheduling optimization considering real life constraints and comprehensive operation cost of operating room. Technology and Health Care. 2015;23(5):605–17.

56. Robinson ST. Lean Strategies in the Operating Room. Anesthesiology Clinics. 2015;33(4):713–30.
57. Ramos P, Bonfá E, Goulart P, Medeiros M, Cruz N, Puceh-leão P, et al. Perioperative Care and Operating Room Management First-case tardiness reduction in a tertiary academic medical center operating room : A lean six sigma perspective. Perioperative Care and Operating Room Management. 2016;5(December):7–12.
58. Pegoraro F, Portela Santos EA, de Freitas Rocha Loures E, Laus FW. A hybrid model to support decision making in emergency department management. Knowledge-Based Systems. 2020;203:106148.
59. Hu X, Barnes S, Golden B. Applying queueing theory to the study of emergency department operations: a survey and a discussion of comparable simulation studies. International Transactions in Operational Research. 2018;25(1):7–49.
60. Niñerola A, Sánchez-Rebull MV, Hernández-Lara AB. Quality improvement in healthcare: Six Sigma systematic review. Health Policy. 2020;124(4):438–45.
61. Sommer AC, Blumenthal EZ. Implementation of Lean and Six Sigma principles in ophthalmology for improving quality of care and patient flow. Survey of Ophthalmology. 2019;64(5):720–8.
62. Crown W, Buyukkaramikli N, Sir MY, Thokala P, Morton A, Marshall DA, et al. Application of Constrained Optimization Methods in Health Services Research: Report 2 of the ISPOR Optimization Methods Emerging Good Practices Task Force. Value in Health. 2018;21(9):1019–28.
63. Mitteregger M, Köhler G, Szyszkowitz A, Uranitsch S, Stiegler M, Aigner F, et al. Increasing Operating Room Efficiency with Shop Floor Management: an Empirical, Code-Based, Retrospective Analysis. Journal of Medical Systems. 2020;44(9).
64. Baccei SJ, Henderson SR, Lo HS, Reynolds K. Using Quality Improvement Methodology to Reduce Costs while Improving Efficiency and Provider Satisfaction in a Busy, Academic Musculoskeletal Radiology Division. Journal of Medical Systems. 2020;44(6).
65. Letelier P, Guzmán N, Medina G, Calcumil L, Huencho P, Mora J, et al. Workflow optimization in a clinical laboratory using Lean management principles in the pre-analytical phase. Journal of Medical Biochemistry. 2021;40(1):26–32.
66. Campbell K, Louie P, Levine B, Gililland J. Using Patient Engagement Platforms in the Postoperative Management of Patients. Current Reviews in Musculoskeletal Medicine. 2020;13(4):479–84.
67. Conley J, Bohan JS, Baugh CW. The Establishment and Management of an Observation Unit. Emergency Medicine Clinics of North America. 2017;35(3):519–33.
68. Stepaniak P, Vrijland W, de Quelerij M, de Vries G, Heij C. Working With a Fixed Operating Room Team on Consecutive Similar Cases and the Effect on Case Duration and Turnover Time. 2010;145(12):1165–70.
69. Reznick D, Niazov L, Holizna E, Keebler A, Siperstein A. Perioperative Care and Operating Room Management Dedicated teams to improve operative room ef fi ciency. Perioperative Care and Operating Room Management. 2016;3:1–5.
70. Volpin A, Khan O, Haddad FS. Theater Cost Is £16/Minute So What Are You Doing Just Standing There? Journal of Arthroplasty. 2016;31(1):22–6.
71. Durojaiye AB, Levin S, Toerper M, Kharrazi H, Lehmann HP, Gurses AP. Evaluation of multidisciplinary collaboration in pediatric trauma care using EHR data. Journal of the American Medical Informatics Association. 2019;26(6):506–15.
72. Hicks C, Petrosoniak A. The Human Factor: Optimizing Trauma Team Performance in Dynamic Clinical Environments. Emergency Medicine Clinics of North America. 2018;36(1):1–17.

73. Kawaguchi AL, Kao LS. Teamwork and Surgical Team–Based Training. Surgical Clinics of North America. 2021;101(1):15–27.
74. Nanah A, Bayoumi AB. The pros and cons of digital health communication tools in neurosurgery: a systematic review of literature. Neurosurgical Review. 2020;43(3):835–46.
75. Harders M, Malangoni MA, Weight S, Sidhu T. Improving operating room efficiency through process redesign. 2006;509–16.
76. Koçkaya G, Koçkaya PD, Özbariaçik Ö, Oba S. Improving cost-efficiency at a hospital by showing the time-saving effect of using different neuromuscular blockers for short operations. Journal of Pharmaceutical Health Services Research. 2014;5(1):61–6.
77. Lai HC, Chan SM, Lu CH, Wong CS, Cherng CH, Wu ZF. Planning for operating room efficiency and faster anesthesia wake-up time in open major upper abdominal surgery. Medicine (United States). 2017;96(7):1–5.
78. Navidi B, Kiai K. Efficiency and scheduling in the nonoperating room anesthesia suite: Implications from patient satisfaction to increased revenue operating room: A common (Dollars and Sense) approach. Current Opinion in Anaesthesiology. 2019;32(4):498–503.
79. Abouleish A, Hudson M, Whitten C. Measuring Clinical Productivity of Anesthsiology Groups. Anesthesiol. 2019;130(2):336–48.
80. Boggs SD, Barnett SR, Urman RD. The future of nonoperating room anesthesia in the 21st century: Emphasis on quality and safety. Current Opinion in Anaesthesiology. 2017;30(6):644–51.
81. Fairley M, Scheinker D, Brandeau ML. Improving the efficiency of the operating room environment with an optimization and machine learning model. Health Care Management Science. 2019;22(4):756–67.
82. Ringoir J, Van Biesen S, Pauwels J, Pannier E, Wouters P, Van de Velde M, et al. Improving compliance with hospital accreditation standards for anesthesia through repetitive feedback and education: a cross-sectional study. Acta Anaesthesiologica Belgica. 2019;70(3):119–28.
83. Ramme AJ, Hutzler LH, Cerfolio RJ, Bosco JA. Applying systems engineering to increase operating room efficiency. Bulletin of the Hospital for Joint Diseases. 2020;78(1):26–32.
84. Heider S, Schoenfelder J, McRae S, Koperna T, Brunner JO. Tactical scheduling of surgeries to level bed utilization in the intensive care unit. IISE Transactions on Healthcare Systems Engineering. 2020;5579:1–14.
85. Zhu S, Fan W, Yang S, Pei J, Pardalos PM. Operating room planning and surgical case scheduling: a review of literature. Journal of Combinatorial Optimization. 2019;37(3):757–805.
86. Morris AJ, Sanford JA, Damrose EJ, Wald SH, Kadry B, Macario A. Overlapping Surgery: A Case Study in Operating Room Throughput and Efficiency. Anesthesiology Clinics. 2018;36(2):161–76.
87. Bai M, Pasupathy KS, Sir MY. Pattern-based strategic surgical capacity allocation. Journal of Biomedical Informatics. 2019;94(August 2018):103170.
88. Wiyartanti L, Lim CH, Park MW, Kim JK, Kwon GH, Kim L. Resilience in the surgical scheduling to support adaptive scheduling system. International Journal of Environmental Research and Public Health. 2020;17(10).
89. Gür Ş, Eren T. Application of Operational Research Techniques in Operating Room Scheduling Problems: Literature Overview. Journal of Healthcare Engineering. 2018;2018.
90. Watanabe Y, Noguchi H, Nakata Y. How efficient are surgical treatments in Japan?

The case of a high-volume Japanese hospital. Health Care Management Science. 2020;23(3):401–13.
91. Agnetis A, Coppi A, Corsini M, Dellino G, Meloni C, Pranzo M. Long term evaluation of operating theater planning policies. Operations Research for Health Care. 2012;1(4):95–104.
92. Park HS, Kim SH, Bong MR, Choi DK, Kim WJ, Ku SW, et al. Optimization of the Operating Room Scheduling Process for Improving Efficiency in a Tertiary Hospital. Journal of Medical Systems. 2020;44(9).
93. Fügener A, Schiffels S, Kolisch R. Overutilization and underutilization of operating rooms - insights from behavioral health care operations management. Health Care Management Science. 2017;20(1):115–28.
94. Devi SP, Rao KS, Sangeetha SS. Prediction of surgery times and scheduling of operation theaters in optholmology department. Journal of Medical Systems. 2012;36(2):415–30.
95. Ayala R, Ruiz G, Valdivielso T. Automatizing a nonscripting TPS for optimizing clinical workflow and reoptimizing IMRT/VMAT plans. Medical Dosimetry. 2019;44(4):409–14.
96. Neumuth T. Surgical process modeling. Innovative Surgical Sciences. 2020;2(3):123–37.
97. Tan A, Durbin M, Chung FR, Rubin AL, Cuthel AM, McQuilkin JA, et al. Design and implementation of a clinical decision support tool for primary palliative Care for Emergency Medicine (PRIM-ER). BMC Medical Informatics and Decision Making. 2020;20(1):1–11.
98. Wang C, Zhu X, Hong JC, Zheng D. Artificial Intelligence in Radiotherapy Treatment Planning: Present and Future. Technology in cancer research & treatment. 2019;18:1–11.
99. Souza TA, Roehe Vaccaro GL, Lima RM. Operating room effectiveness: a lean healthcare performance indicator. International Journal of Lean Six Sigma. 2020;11(5):987–1002.
100. Nino V, Claudio D, Valladares L, Harris S. An enhanced kaizen event in a sterile processing department of a rural hospital: A case study. International Journal of Environmental Research and Public Health. 2020;17(23):1–20.
101. del Carmen León-Araujo M, Gómez-Inhiesto E, Acaiturri-Ayesta MT. Implementation and Evaluation of a RFID Smart Cabinet to Improve Traceability and the Efficient Consumption of High Cost Medical Supplies in a Large Hospital (Journal of Medical Systems, (2019), 43, 6, (178), 10.1007/s10916-019-1269-6). Journal of Medical Systems. 2019;43(12).
102. Ahmadi E, Masel DT, Metcalf AY, Schuller K. Inventory management of surgical supplies and sterile instruments in hospitals: a literature review. Health Systems. 2019;8(2):134–51.
103. Briatte I, Allix-Béguec C, Garnier G, Michel M. Revision of hospital work organization using nurse and healthcare assistant workload indicators as decision aid tools. BMC Health Services Research. 2019;19(1):1–9.
104. Antunes RS, Seewald LA, Rodrigues VF, Da Costa CA, Gonzaga L, Righi RR, et al. A survey of sensors in healthcare workflow monitoring. ACM Computing Surveys. 2018;51(2).
105. Koch A, Burns J, Catchpole K, Weigl M. Associations of workflow disruptions in the operating room with surgical outcomes: A systematic review and narrative synthesis. BMJ Quality and Safety. 2020;29(12):1033–45.
106. Chadebecq F, Vasconcelos F, Mazomenos E, Stoyanov D. Computer Vision in the Surgical Operating Room. Visceral Medicine. 2020;43–5.

107. Padoy N. Machine and deep learning for workflow recognition during surgery. Minimally Invasive Therapy and Allied Technologies. 2019;28(2):82–90.
108. Perez B, Lang C, Henriet J, Philippe L, Auber F. Risk prediction in surgery using case-based reasoning and agent-based modelization. Computers in Biology and Medicine. 2021;128(October 2020):1–11.
109. Tellis R, Starobinets O, Prokle M, Raghavan UN, Hall C, Chugh T, et al. Identifying Areas for Operational Improvement and Growth in IR Workflow Using Workflow Modeling, Simulation, and Optimization Techniques. Journal of Digital Imaging. 2021;34(1):75–84.
110. Wang Y, Yan F, Lu X, Zheng G, Zhang X, Wang C, et al. IILS: Intelligent imaging layout system for automatic imaging report standardization and intra-interdisciplinary clinical workflow optimization. EBioMedicine. 2019;44:162–81.
111. Spini G, van Heesch M, Veugen T, Chatterjea S. Private Hospital Workflow Optimization via Secure k-Means Clustering. Journal of Medical Systems. 2020;44(1).
112. Overmann K, Wu D, Xu C, Bindhu S, Barrick L. Real-time locating systems to improve healthcare delivery: A systematic review. Journal of the American Medical Informatics Association. 2021;
113. Kawamoto K, McDonald CJ. Designing, Conducting, and Reporting Clinical Decision Support Studies: Recommendations and Call to Action. Annals of internal medicine. 2020;172(11):S101–9.
114. Shailam R, Botwin A, Stout M, Gee MS. Real-Time Electronic Dashboard Technology and Its Use to Improve Pediatric Radiology Workflow. Current Problems in Diagnostic Radiology. 2018;47(1):3–5.
115. Badilla-Murillo F, Vargas-Vargas B, Víquez-Acuña O, García-Sanz-Calcedo J. Analysis of the installed productive capacity in a medical angiography room through discrete event simulation. Processes. 2020;8(6).
116. Marjamaa RA, Torkki PM, Hirvensalo EJ, Kirvelä OA. What is the best workflow for an operating room? A simulation study of five scenarios. Health Care Management Science. 2009;12(2):142–6.
117. Neumann J, Angrick C, Höhn C, Zajonz D, Ghanem M, Roth A, et al. Surgical workflow simulation for the design and assessment of operating room setups in orthopedic surgery. BMC Medical Informatics and Decision Making. 2020;20(1):1–20.
118. Benitez GB, Da Silveira GJC, Fogliatto FS. Layout Planning in Healthcare Facilities: A Systematic Review. Health Environments Research and Design Journal. 2019;12(3):31–44.
119. Fogliatto FS, Tortorella GL, Anzanello MJ, Tonetto LM. Lean-oriented layout design of a health care facility. Quality Management in Health Care. 2019;28(1):25–32.
120. Katz JD. Control of the Environment in the Operating Room. Anesthesia and Analgesia. 2017;125(4):1214–8.
121. Mcleod R, Myint-Wilks L, Davies S, Elhassan H. The impact of noise in the operating theatre: a review of the evidence. The Annals of The Royal College of Surgeons of England. 2021;103(2):83–7.
122. Kim JH, Parameshwara N, Guo W, Pasupathy KS. The Impact of Interrupting Nurses on Mental Workload in Emergency Departments. International Journal of Human-Computer Interaction. 2019;35(3):206–17.
123. Fishbein D, Nambiar S, McKenzie K, Mayorga M, Miller K, Tran K, et al. Objective measures of workload in healthcare: a narrative review. International Journal of Health Care Quality Assurance. 2019;33(1):1–17.



II

RESA

Redefining Effective Surgery Assistance: Impact of Operating Room Technology on Intra-operative Nurses' Workload and Job Satisfaction: an Observational Study

The integration of medical technology in the operating room has transformed surgical workflows and team dynamics but coincides with a global nursing shortage and high turnover, affecting care quality, nurse well-being, and hospital finances. This study investigates how technological complexity impacts the workload and job satisfaction of intra-operative nurses during open, minimally invasive, and robotic-assisted gynecological surgeries in a Dutch academic hospital. Using a mixed-methods approach, we combined 5 interviews, 28 validated questionnaires, automated video analysis of 35 surgeries, and hospital data from 411 cases collected in 2022 and 2023. Results show that open procedures yield the highest job satisfaction through active involvement and manageable workloads; minimally invasive surgeries, though less physically demanding, lead to reduced engagement and lower satisfaction; and robotic-assisted surgeries pose the most challenges, marked by increased workload, decreased involvement, and stress due to complex preparation and shifting team dynamics. While technological advancements enhance surgical outcomes, they often overlook their effect on intra-operative nurses. This study highlights the role of communication gaps, equipment difficulties, and insufficient training in driving burnout and turnover, and advocates for supportive OR environments that prioritize nurses' well-being. It also demonstrates the value of automated video analysis in objectively assessing nursing roles, reinforcing the need to balance technological progress with human-centered care.

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2.1 Introduction

Technology has become indispensable in the operating room (OR) (Zhang et al., 2021). The advancement of medical technology is illustrated by the shift from traditional surgical methods, open surgery and minimally invasive surgery, to robotic-assisted surgery (Sheetz et al., 2020). When comparing robotic-assisted surgery to open surgery and minimally invasive surgery, literature shows that robotic-assisted surgery typically takes longer, requires larger teams, and involves more complex equipment. Likewise, open surgery and minimally invasive surgery each require distinct skills and team dynamics (Zheng et al., 2015). Consequently, each type of surgery functions within a unique working environment and demands specific skill sets (Gjeraa et al., 2016).

The surge in medical technology brings advantages: the primary goals when developing medical technology for the operating room are to enhance patient outcomes, increase time efficiency, and improve surgeons' well-being (Schouten et al., 2023). However, the adoption of technology has also introduced new challenges for the surgical team as it increases the complexity of procedural workflows. Several papers address the impact of the use of technology on team composition and communication, as well as the influence of experiences of individual operating room team members (L Cao et al., 2004; Webster & Cao, 2006). For example, certain aspects of the altered working environment, such as longer surgery durations and more intricate procedures, are associated with heightened stress and workload for the surgical team. (Gillespie et al., 2021).

Despite significant changes in their work, there is a paucity in literature on the effects of technology on the work of nurses (Schuessler et al., 2020). Meanwhile, there is a growing concern that the nursing profession is facing labour shortages due to a high turnover and inequitable workforce distribution. The causes related to the nursing shortage are numerous and impacting patient care quality, nurses' well-being, and hospital finances (Lee et al., 2020). In particular, the recruitment and retention of intra-operative nurses are challenging, due to the need to collaborate with various health professionals in a fast-paced, high-tech environment with high patient turnover (Björn et al., 2015). Compared to other nursing specialties, intra-operative nurses report less favorable working conditions, such as limitations of communication in the team, feeling of isolation, blocking of vision due to large equipment, unexpected device errors and malfunctions, fear and anxiety due to lack of technical knowledge and burnout due to lack of trained nurses

(Celik et al., 2023). Smith & Palesy (2018) introduced the concept of "technology stress" in perioperative nursing – the idea that the influx of advanced technology, while improving certain tasks, can also create stress as nurses strive to master new devices and systems. They argue that in many hospitals, perioperative nurses often become "super users" of new OR technologies, rapidly learning the equipment and then training their colleagues. This expanded role means that nurses not only deliver patient care but also serve as on-the-spot technical experts and troubleshooters for complex machines. Smith & Palesy have noted an ongoing tension between technical and caring aspects of nursing practice in the OR, as nurses balance operating sophisticated devices with their traditional patient-focused duties.

To enhance and maintain a robust intra-operative nursing workforce, it is necessary to cultivate a work environment that inspires and motivates nurses (Lambrou et al., 2010). A supportive and engaging atmosphere encourages job satisfaction and enhances overall team performance. This not only ensures that nurses feel valued and appreciated but also strengthens their commitment to delivering high-quality care during surgical procedures (Gusar et al., 2020). It is therefore important to understand the relationships between the characteristics of their working environment, job satisfaction, and workload (Lee et al., 2020). Most perioperative nursing research, however, does not differientiate between levels of technological complexity in operating room environments (Kelvered et al., 2012; Sørensen et al., 2014). Literature highlights the need for comparative studies between high-tech and low-tech operating rooms to, for example, better understand how nurses allocate attention between patients and technology (Bull & FitzGerald, 2006; Göras et al., 2019).

In this study, we investigate the impact of medical technology on the workload and job satisfaction of intra-operative nurses by comparing these factors across open surgery, minimally invasive surgery, and robotic-assisted surgery. The study design follows a mixed-methods approach, combining a qualitative analysis of interviews with a focused quantitative analysis using questionnaires, video recordings, and hospital data (Figure 2). By conducting interviews and administering validated questionnaires we obtain insight in how nurses perceive and experience the working conditions in surgical environments with different technological complexity. We hypothesize that nurses prioritize the physical and emotional aspects of patient care above a focus on handling medical technolo-

gy and that such interactions positively influence their job satisfaction. Next to this qualitative research approach, we explore the potential of automated video analysis to quantify the role and tasks of intra-operative nurses across the afore mentioned types of surgery. Automated video analysis offers key advantages over traditional methods like direct observation or self-reports. It reduces recall and observer bias, minimizes disruption in the operating room, and provides objective, consistent, and detailed data. This allows for more accurate comparisons across surgery types and enables retrospective analysis to validate findings from other sources (Gabriel et al., 2024).

2.2 Method

At the Leiden University Centre (LUMC) in the Netherlands, we collected three types of data within the gynaecology department in 2022 and 2023: interviews

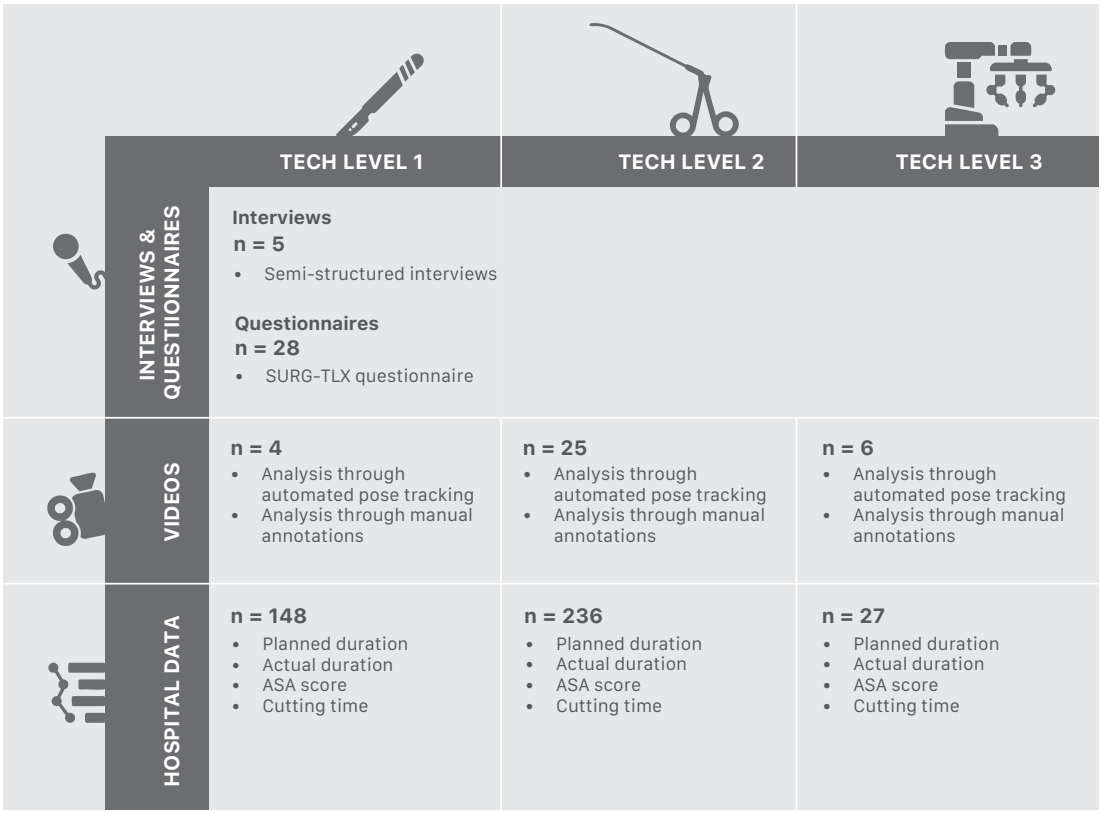

Figure 1 Analysis of three levels of surgical technology within the gynecology department at LUMC, based on three data sources: interviews and questionnaires with nurses experienced in all three technology levels, video recordings, and hospital data from 2023.

and questionnaires with intra-operative nurses, video recordings of gynecology surgeries, and hospital datasets of gynecology surgeries. The surgeries were categorized into three levels of technology: open surgery as the lowest level, minimally invasive surgery as the second level, robotic-assisted surgery as the highest level. Figure 1 gives an overview of the collected data used for the analysis of the three technology levels.

In the study, five surgical approaches used in gynecology were incorporated: (1) open surgery, (2) vaginal surgery, (3) hysteroscopic surgery, (4) laparoscopic surgery, and (5) robotic-assisted surgery. These approaches were distributed across the three technology levels as follows:

- Tech level 1: Open surgery- Open surgical procedures.
- Tech level 2: Minimally invasive surgery - Includes vaginal surgery, hysteroscopic surgery, and laparoscopic surgery.
- Tech level 3: Robotic-assisted surgery - Procedures performed with robotic assistance.

2.2.1 Study design

The study design follows a mixed-methods approach, integrating qualitative interviews with a focused quantitative analysis based on questionnaires, video recordings, and hospital data (Figure 2). The questionnaire consisted of two parts: the first part was analyzed qualitatively to identify factors influencing workload and job satisfaction, while the second part—based on the SURG-TLX—was ana-

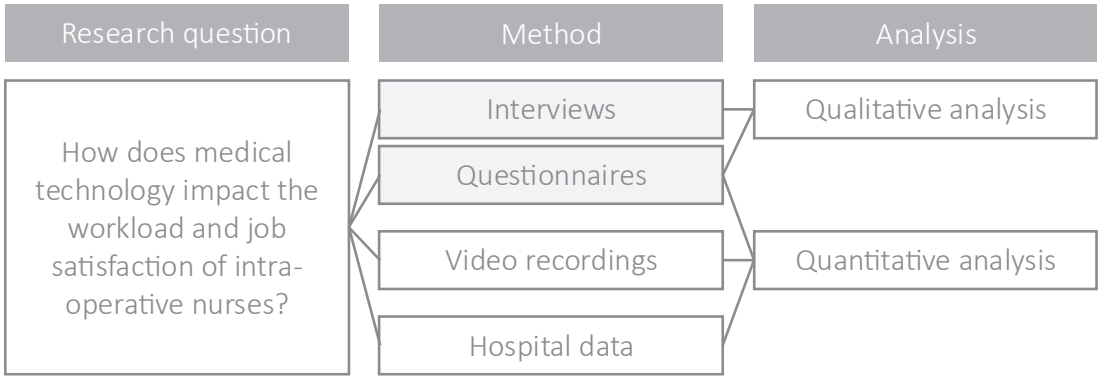

Figure 2 Flowchart with study design

lyzed quantitatively to compare perceived workload and satisfaction across different surgery types and phases.

II

2.2.2 Interviews and questionnaires

We conducted interviews and questionnaires based on the validated survey structure of SURG-TLX (Wilson et al., 2011) for each type of surgery (open surgery, minimally invasive surgery and robotic-assisted surgery), to identify factors that influence workload and job satisfaction. Participants included intra-operative nurses with experience in all three types of surgery. Five nurses participated in semi-structured interviews, while 28 completed a paper-based questionnaire. Of these, 19 nurses fully completed the SURG-TLX section. Participation was voluntary. For the questionnaire, one of the researchers was present in the operating room cafeteria, and nurses filled in the form when they had time. The questionnaire was filled out anonymously.

First, intra-operative nurses completed the questionnaire individually. To gain a better impression of overall practices, they were asked to reflect on their general experiences with the three types of surgery, rather than on a specific procedure they had recently assisted in. This approach also encouraged a broader range of responses and helped increase the response rate. In the first section of the questionnaire, we gathered general information about the participants, such as their age, years of experience, and specialty. An open-ended question asked participants to identify at least three factors that contribute to their job satisfaction and three factors that influence their perceived workload. In the second section, participants were required to complete a SURG-TLX based survey, developed for this study.

The original SURG-TLX evaluates six aspects on a scale of 20: mental demands, physical demands, temporal demands, task complexity, situational stress and distractions. To capture both workload and job satisfaction, we added a seventh aspect, job satisfaction, to the SURG-TLX. This is, to our knowledge, the first time that job satisfaction has been integrated into the SURG-TLX framework. As such, this represents an initial construct and an exploratory application of the tool. The job satisfaction aspect was measured using the same 20-point scale to assess how nurses perceive their satisfaction during surgeries, enabling us to explore the potential relationship between workload and job satisfaction in the operating

room. Given the novelty of this addition, the outcomes related to job satisfaction should be interpreted as indicative rather than definitive—providing direction for future research rather than serving as hard statistical conclusions.

To facilitate comparisons among open surgery, minimally invasive surgery, and robotic-assisted surgery for each aspect, we added a separate scale for each surgery type (see Supplementary Figure 1 in Appendix 2.1). All aspects are scored this way for three clinical phases (corresponding with the registered timestaps of the hospital) of the surgery: (Phase 1) patient entry to first incision; (Phase 2) first incision to closing; (Phase 3) closing to patient exit.

In individual semi-structured interviews with five intra-operative nurses, we delved deeper into the questionnaire questions to gain a richer understanding of their perspectives. Interviews were conducted following email invitations, with participants selected based on recommendations from the staff team leader. Participants were asked to explain the context behind the factors they considered important for their job satisfaction and workload. The interview responses were transcribed using WisperAI (v20231117) (WisperAI Inc., 2023). To analyze the data, we used inductive categorization, a method where patterns and themes emerge directly from the data without relying on pre-existing frameworks. This approach allowed us to group the factors identified by participants into overarching themes that reflect their insights into workload and job satisfaction.

2.2.3 Video analysis

To quantify the factors identified in the interviews and questionnaires, we analyzed video recordings of surgeries. Over the course of a year, gynecological surgeries were filmed in two ORs using multiple cameras mounted on the ceiling. The videos were collected on computers running Noldus Observer XT software (Noldus Information Technology, 2023). The research setup consisted of the operating room with two Axis wide-view cameras mounted on the ceiling. These cameras were connected via ceiling-mounted cables to the recording computer in an adjacent room. The second operating room had four cameras installed in a similar manner, connected to a second recording computer. Before the filming process began, the study setup was ethically approved by the scientific review committee of the LUMC.

Procedures were filmed only if all members of the surgical team consented to participate and if the patient had signed a consent form at least 24 hours in advance. To ensure privacy, the faces of the staff and the entire body of the patient were blurred. The videos were stored and analyzed in the LUMC hospital, according to the data compliance plan in Appendix 2.2. Surgeries that deviated from the planned procedure, such as those impacted by complications, were excluded from the study.

Manual annotations

To estimate the frequency of critical factors influencing work satisfaction and workload, we selected the same camera viewpoint for all videos and manually annotated the actions of nurses, the overall operating room team, and the room conditions using Noldus software. The annotation scheme used is detailed in Supplementary Table 1, Appendix 2.3. The annotations in Noldus were exported to Microsoft Excel (Microsoft Corporation, 2023) for quantitative data analysis.

Automated pose tracking

We used automated human-pose detection to extract movements and locations of the staff during surgery. Detection of staff in the videos was accomplished with AlphaPose (Fang et al., 2023), which is an open-source framework for human pose estimation that uses deep learning models. It estimates human poses by identifying the positions of joints such as shoulders, elbows, and knees in images or videos. Specifically, AlphaPose was used to detect staff poses in individual video frames. A version of BYTE (Butler et al., 2025), adapted to leverage pose data, was employed to track individual staff members between video frames. To quantify the time staff spends actively at the operating table, we monitored the presence of three specific pose subsets in designated annotated areas, as shown in Figure 3. This metric was chosen because we hypothesized that the time spent actively at the operating table could serve as an indicator of the nurse's active involvement during surgery. To identify this involvement, we required both wrists to be near the patient, both shoulders to be positioned above the wrists, and the head (defined as a subset of ears, eyes, and nose) to be in a third area above the shoulders. These latter two pose subsets were included to mitigate the impact of camera perspective, ensuring that a wrist from someone not actively working at the operating table would not be misclassified as involvement.

In addition to positional constraints, movement thresholds were implemented to prevent false positives from staff merely passing by the operating table without interacting with it. Movement speed was measured in pixels by analyzing the positions of key points in the poses across consecutive frames. If the movement of the shoulders and head exceeded a threshold of 17.5 pixels over 5 frames, the individual was classified as not being active at the operating table. Wrist motion was not taken in account, as the wrists are expected to move during activity. Also, leg motion was not computed as it is difficult to detect them accurately in this setting due to the wearing of surgical aprons and camera angles. Data analysis was performed using R (R Core Team, 2023).

2.2.4 Hospital data

To provide an objective context for the interview and questionnaire findings, we analyzed hospital data from 686 gynecology procedures conducted between January 2, 2023, and December 29, 2023. The dataset included details such as staff composition, procedure indications, patient ASA scores, emergency classifications, and the planned duration of each procedure phase, as recorded in the hos-

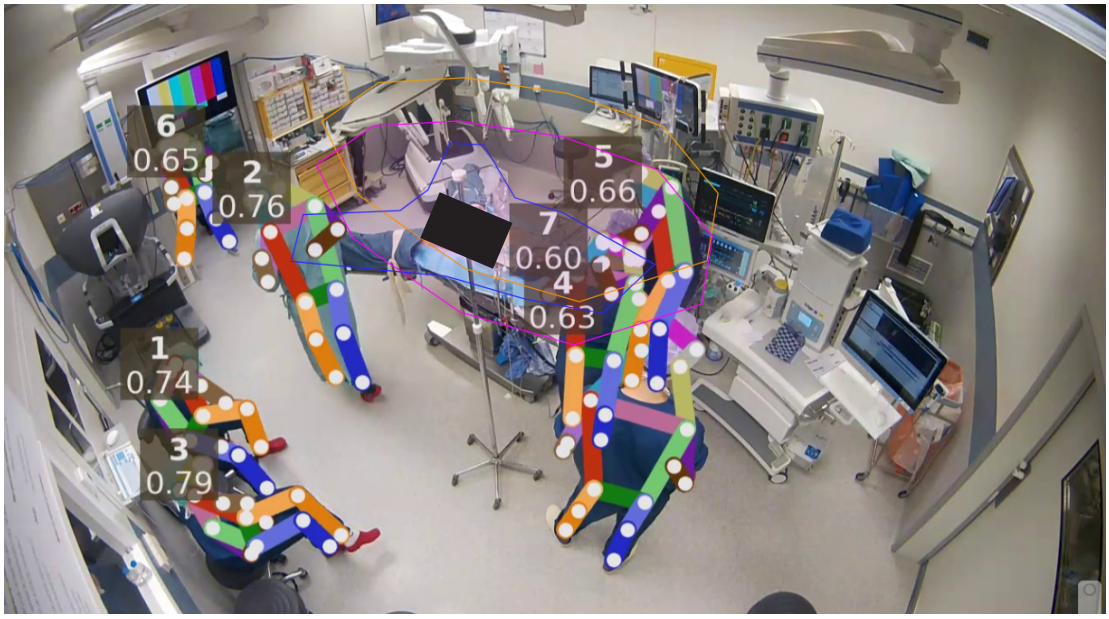

Figure 3 Frame of one of the recorded videos in which the poses of the staff (1-7) and the operation table area have been annotated. If the hands of a staff member are in the blue-line marked area, the shoulders in the pink area and the head in the orange area, it was counted as “active at the operation table”.

pital information system HIX 6.3 (Chipsoft, 2023). This analysis aimed to quantify how often the factors mentioned by nurses in the interviews and questionnaires occurred.

2.2.5 Handling of missing data

Missing values were handled as follows: for the SURG-TLX questionnaire, only fully completed responses were included in the quantitative analysis (n = 19). Partially completed questionnaires were excluded from the analysis of that specific section but included in the qualitative analysis of the open-ended questions, where applicable. No imputation techniques were used. For the hospital data and video recordings, only complete cases with full information were included in the corresponding analyses.

2.2.6 Ethics

Approval for this research was obtained from the Human Research Ethics Committee (HREC) on March 25, 2024, under application number 3822.

2.2.7 Statistical analysis

For the SURG-TLX outcomes, a non-parametric Friedman test was performed on the data to assess whether there were statistically significant differences in the importance of the SURGTLX domains. If the Friedman test indicated a statistically significant difference ($p < 0.05$), post-hoc analysis using the Nemenyi test was conducted to identify which specific domains differed from each other. Effect sizes were reported using partial eta squared (η^2) to indicate the strength of associations. Statistical analyses were conducted using IBM SPSS Statistics (Version 29.0.0.0 (241)) (IBM SPSS Statistics, 2023) to determine the statistical significance of the findings.

2.3 Results

This section begins with the presentation of the interview and questionnaire results, followed by the findings from the automated pose detection analysis of the video data. Finally, the results of the hospital data analysis are presented.

2.3.1 Interviews and questionnaire results

We conducted five semi-structured interviews and administered 28 questionnaires. The demographic characteristics of the participants are shown in Table 1. The SURG-TLX results showed significant differences in mental demand, temporal demand, distractions, and job satisfaction across procedure types (Figure 4a). Robotic-assisted surgery was associated with higher perceived mental and temporal demand compared to minimally invasive and open procedures, while open surgery was linked to the highest job satisfaction. Full descriptive statistics and effect sizes are provided in Table 2.

In terms of overall workload, mean SURG-TLX scores for the six original domains were 32.60 for open surgery, 30.32 for minimally invasive surgery, and 40.82 for robotic-assisted surgery. While the literature indicates that scores exceeding 50 are potentially detrimental to individuals, it is notable that scores for all procedure types in this study remained below this threshold. Nevertheless, robotic-assisted surgery exhibited consistently higher scores relative to both open surgery and minimally invasive surgery, indicating a greater perceived workload for robotic-assisted procedures.

Regarding the differences between scores for the 3 different phases of the surgery, a significant difference was observed in the mental demand domain, with phase 1 (patient entry to first incision) scoring higher than phase 2 (First incision to closing) ($p=0.033$), indicating that nurses found phase 2 more mentally demanding than phase 1 (see Figure 4b). Descriptive statistics and effect size are provided in Table 3.

Table 1 Demographic characteristics of the participants.

Characteristic	Mean	SD	Min	Max
Number of women	26 (93%)	-	-	-
Age (years)	36.4	5.2	25	50
Total work experience (years)	14.18	9.92	1	40
Experience with robotic surgery (years)	4.19	2.76	0	10
Working hours per week	30.71	4.30	24	36

II

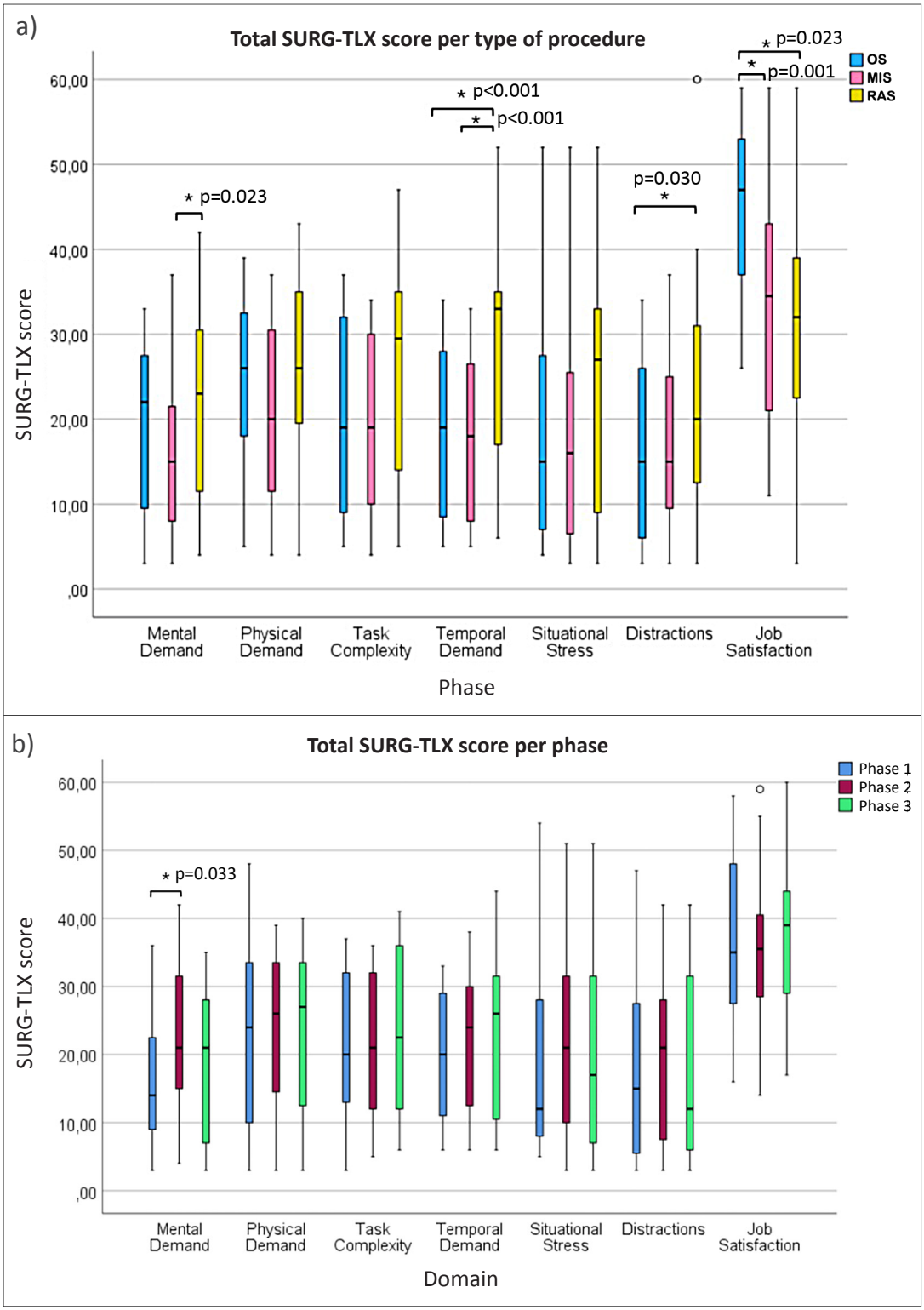
a)
Total SURG-TLX score per type of procedure
SURG-TLX score
60,00
50,00
40,00
30,00
20,00
10,00
,00
* p=0.023
* p<0.001
* p<0.001
p=0.030
*
* p=0.023
* p=0.001
OS
MIS
RAS
Mental Demand
Physical Demand
Task Complexity
Temporal Demand
Situational Stress
Distractions
Job Satisfaction
Phase
b)
Total SURG-TLX score per phase
SURG-TLX score
60,00
50,00
40,00
30,00
20,00
10,00
,00
* p=0.033
Phase 1
Phase 2
Phase 3
Mental Demand
Physical Demand
Task Complexity
Temporal Demand
Situational Stress
Distractions
Job Satisfaction
Domain

Table 2 Descriptive statistics and effect sizes for SURG-TLX domains with significant differences by procedure type (open surgery OS, minimally invasive surgery MIS and robotic-assisted surgery RAS).

Domain	Procedure type	Mean (SD)	Significat differences	Effect size (partial η^2)
Mental demand	OS	18.95 (10.96)	RAS > MIS(p = 0.023)	~0.06 (small–moderate)
	MIS	16.00 (10.42)		
	RAS	22.58 (11.41)		
Temporal demand	OS	20.26 (11.39)	RAS > OS, MIS (p < 0.001)	~0.09 (moderate)
	MIS	19.68 (10.27)		
	RAS	25.37 (12.43)		
Distractions	OS	16.16 (10.87)	RAS > OS (p = 0.030)	~0.07 (moderate)
	MIS	16.84 (10.23)		
	RAS	23.05 (14.40)		
Job satisfaction	OS	46.47 (8.53)	OS > MIS (p = 0.023), OS > RAS (p = 0.001)	~0.12 (moderate–large)
	MIS	34.53 (13.83)		
	RAS	31.95 (14.27)		
Working hours per week	30.71	4.30	24	36

LEFT: Figure 4 a) Boxplot illustrating the SURG-TLX scores for each surgical procedure type: open surgery (OS), minimally invasive surgery (MIS), and robot assisited surgery (RAS). The scores are derived by summing the scores for each procedure type across all surgical phases (Phase 1, Phase 2, Phase 3). This figure emphasizes the variations in perceived workload and job satisfaction across the three procedure types, with * indicating statistically significant differences. b) Boxplot illustrating the SURG-TLX scores for each surgical phase (Phase 1, Phase 2, and Phase 3). The scores represent the sum of individual scores across all procedure types.

Table 3 SURG-TLX Mental Demand Scores per Surgical Phase (summed across surgery types).

Surgical phase	Mean (SD)	Significat differences	Effect size (partial η^2)
Phase 1 (Entry to Incision)	16.42 (10.53)	Phase 1> Phase 2 (p = 0.033)	~0.07 (moderate)
Phase 2 (Incision to Closure)	22.68 (10.86)		
Phase 3 (Closure to Patient Exit)	18.42 (12.16)		

2.3.2 Factors influencing workload and job satisfaction

Using inductive categorization, the factors identified by the 28 participants in question 10 and 11 of the questionnaire were grouped into seven main categories affecting workload and job satisfaction. The development of these categories, as well as the interpretation of their content, was guided by insights from the interview data to ensure alignment with the lived experiences and language of intra-operative nurses. These categories and their corresponding subcategories are detailed in this section and illustrated with quotes from the interviews. Supplementary Figure 2, Appendix 2.4, illustrates the frequency with which nurses mentioned the factors.

1. Team Dynamics

The dynamics within the surgical team play a central role in shaping both workload and job satisfaction. Nurses consistently emphasized that the skill level and demeanor of their colleagues influenced their experience. Skilled and pleasant colleagues could ease workload and contribute positively to the work atmosphere, while less experienced or incompatible team members often increased stress and complexity.

A recurring theme was the influence of the surgeon's personality on the overall team atmosphere. Surgeons who communicated well and maintained a supportive tone helped foster a positive working environment, especially in high-pressure settings. Teamwork emerged as a critical factor: when collaboration was smooth and roles were clearly coordinated, nurses experienced lower workload and greater job satisfaction.

One nurse noted, *"It makes a big difference if, at the end of the day, everyone is thanked for their hard work as a team."*

2. Procedural Characteristics

The type of surgical procedure itself also shaped nurses' experiences. Participants expressed a preference for open abdominal surgeries over miminally invasive or robotic-assisted procedures. Open surgeries were often described as more engaging and dynamic, offering greater opportunities for nurses to think along and remain active throughout the procedure. As one nurse put it, "*Open abdominal surgeries are much more enjoyable than robot and laparoscopic surgeries. They are more challenging for us because you can think along, stay busy, and keep moving*."

Robotic-assisted procedures, in contrast, were sometimes perceived as monotonous or passive, particularly when the nurse's tasks were limited. Long procedures with little direct involvement could increase perceived workload despite fewer physical demands. Visibility and engagement were particularly low during certain robotic phases, leading to reduced job satisfaction. The smoothness of a procedure—how well it flowed without interruptions or confusion—was also key. Chaotic or poorly managed procedures increased mental demands and stress. Finally, variety played a dual role: while variation in tasks and cases could increase satisfaction, rotating across different specialties or shifting between robotic and minimally invasive surgeries in a single day often elevated workload due to the preparation and cognitive switching required. One nurse noted, *"If we have to switch between different types of surgeries like laparoscopic, robotic-assisted surgery, and then laparoscopic again, it becomes very inconvenient. Each change requires extra preparation, elevating workload."*

3. Preparation and Equipment

Preparation was a consistent determinant of both workload and satisfaction. Nurses highlighted that when setups were incomplete or plans unclear, they had to compensate under pressure, increasing their workload and reducing satisfaction. Robotic-assisted surgeries, in particular, required more extensive preparation.

One nurse explained, *"The preparation for robotic-assisted surgery procedures is more than for an open or laparoscopic procedure."*

Technology-related challenges—especially with robotic systems—further added to workload. Equipment malfunctions or delays in system readiness were frequent stressors and led to feelings of frustration and inefficiency. These issues contributed to lower satisfaction and, in some cases, made nurses feel disconnected from the surgical process.

4. Working Environment

Physical elements of the OR environment, such as lighting, sound, and space, also impacted nurse experiences. Dim lighting, often used in minimally invasive and robotic surgeries, was noted to increase strain and reduce comfort. While background music could create a relaxed atmosphere, excessive or disruptive noise elevated stress levels. Crowding in the operating room—whether from additional personnel, observers, or equipment—was another challenge. This was especially prevalent in robotic-assisted surgeries, where large consoles and robot arms took up significant space, reducing nurses' freedom to move and increasing physical and mental workload.

5. Organizational Factors

Beyond the immediate OR setting, broader organizational factors also influenced nurses' workload and job satisfaction. Poor OR scheduling, including back-to-back complex procedures or inadequate breaks, led to fatigue and reduced morale. High work pressure, often stemming from staff shortages or urgent cases, compounded these issues. Some participants also cited salary disparities as a demotivating factor, with several colleagues leaving for better-paying agency jobs. The ability to take breaks during procedures—particularly during long robotic cases—was another point of concern. Nurses reported that being unable to step out of the OR, even briefly, negatively impacted both workload and job satisfaction.

6. Appreciation and Recognition

Feelings of appreciation played a major role in shaping job satisfaction. Nurses described how simple gestures of recognition could have a significant impact on their morale. As one participant explained, *"A simple 'Hey guys, we worked really hard together today, thank you so much' can have a large impact."* Conversely, a lack of appreciation—especially when coupled with dismissive comments from surgeons—could deeply affect motivation and self-worth.

One nurse recalled, *"A specialist once commented on my work: 'Even a monkey could learn to do that.'"*

Nurses also reported higher satisfaction when they were actively involved and their contributions were valued. This sense of personal satisfaction was especially present during open surgeries, where their engagement in the procedure was often more hands-on and continuous.

7. Physical Demand

Finally, physical strain played a role in how nurses experienced different surgeries. Open procedures typically involved prolonged standing, which could be tiring. However, many participants reported that the engaging nature of these procedures made the physical demands more manageable.

As one nurse noted, *"Open surgery generally means standing longer, but you hardly notice it because the work is so engaging."*

In contrast, robotic-assisted surgeries often involved sitting for long periods, which some nurses found physically easier but mentally more draining. Heavy lifting of robotic equipment or positioning the robotic arms also added to the physical workload, particularly during setup and takedown phases. By identifying these themes and their associated factors, we gain insight into what impacts the workload and job satisfaction of operating room nurses. To understand how frequently these factors occur—and thereby assess the urgency of the challenges they represent—we analyzed hospital data and video recordings.

2.3.3 Video analysis

The results of the video analysis encompassed a total of 4 open surgeries with a cumulative duration of 16 hours and 32 minutes, 24 minimally invasive surgery totaling 53 hours and 37 minutes, and 6 robotic-assisted surgery with a total duration of 17 hours and 30 minutes. One procedure was excluded due to complications.

Manual annotations

Figure 5 shows the percentage of nurses' activity time during each surgery phase, expressed relative to the average total duration of the phase (with the induction of anesthesia and surgical preparations combined into phase 1 of the SURG-TLX, phase 2 corresponding with the cutting phase and phase 3 corresponding with the emergence from anesthesia) and the SURG TLX scores for job satisfaction.

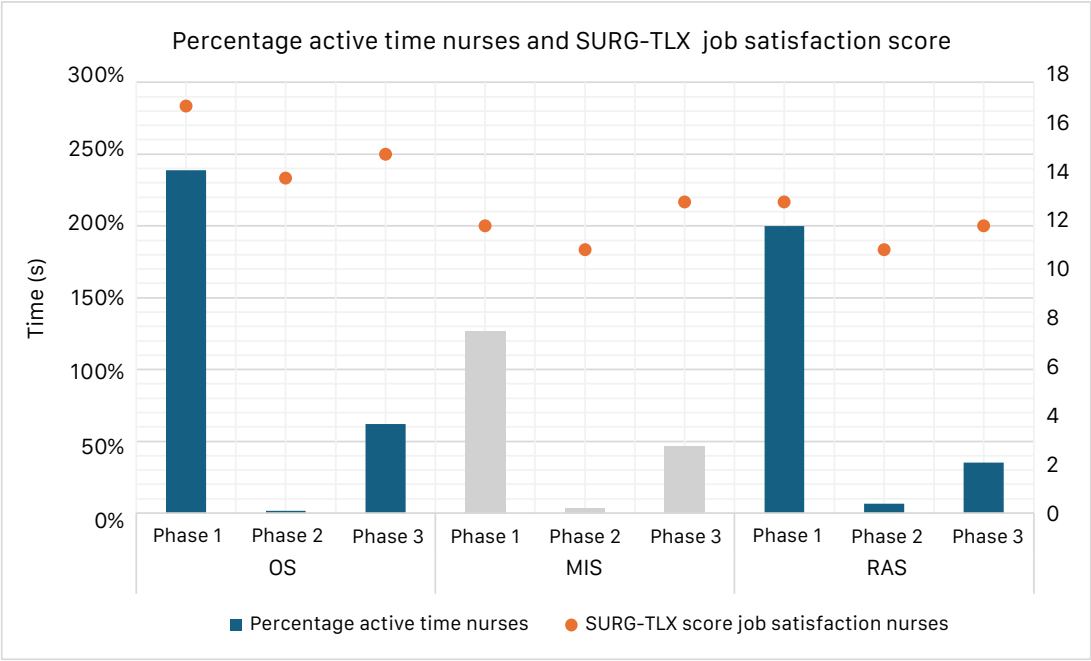

Figure 5 Percentage of nurses' activity time during each surgery phase, expressed relative to the average total duration of the phase and corresponding SURG TLX job satisfaction scores. Since the percentage reflects the combined activity of all active nurses, values may exceed 100%. Phase 1 includes the induction of anesthesia and surgical preparations, Phase 2 corresponds to the cutting phase, and Phase 3 corresponds to the emergence from anesthesia. The left axis represents time in seconds, while the right axis represents the SURG TLX job satisfaction score scale.

For open surgery and robotic-assisted surgery, the highest measured activity levels align with higher job satisfaction scores in the SURG-TLX. Similarly, minimally invasive surgery follows this pattern in phases 1 and 2. However, in phase 3, minimally invasive surgery shows higher job satisfaction despite lower activity levels compared to phase 1, indicating a deviation from the observed relationship in other phases.

Results automated pose tracking

Supplementary Figure 3, Appendix 2.5, presents the percentage of measured movement for each procedure type. This percentage represents the proportion of movement relative to the total duration of the procedure. To enable comparison between procedures of varying lengths, we calculated these percentages. Additionally, to illustrate the variation in the lengths of the 34 procedures, the x-axis of the figure displays the surgery duration. Overall, the values for all procedure types remain low, with movement rarely exceeding 10%, indicating minimal movement during procedures. A distinct difference emerges between robotic-assisted surgery and the other two procedure types, with robotic-assisted surgery showing lower movement percentages. In contrast, minimally invasive surgery displays more variability in movement patterns among these procedures. Still, it is important to note that minimally invasive surgery also includes considerably more data points than robotic-assisted surgery and open surgery. Also, open surgery had one notably longer surgery compared to the other procedures, which may have influenced the data.

Figure 6a presents the average movement percentage calculated for each surgery phase. The surgery phases were extracted through manual annotation. Overall, movement percentages are higher during the second phase compared to other phases. Figure 6b displays the average interaction percentages in the surgery table area per surgical phase for each surgery type, where interaction refers to the number of people actively engaged around the surgical table area. In robotic-assisted surgery, interaction decreases during the surgery phase and remains lower across all phases compared to minimally invasive surgery and open surgery.

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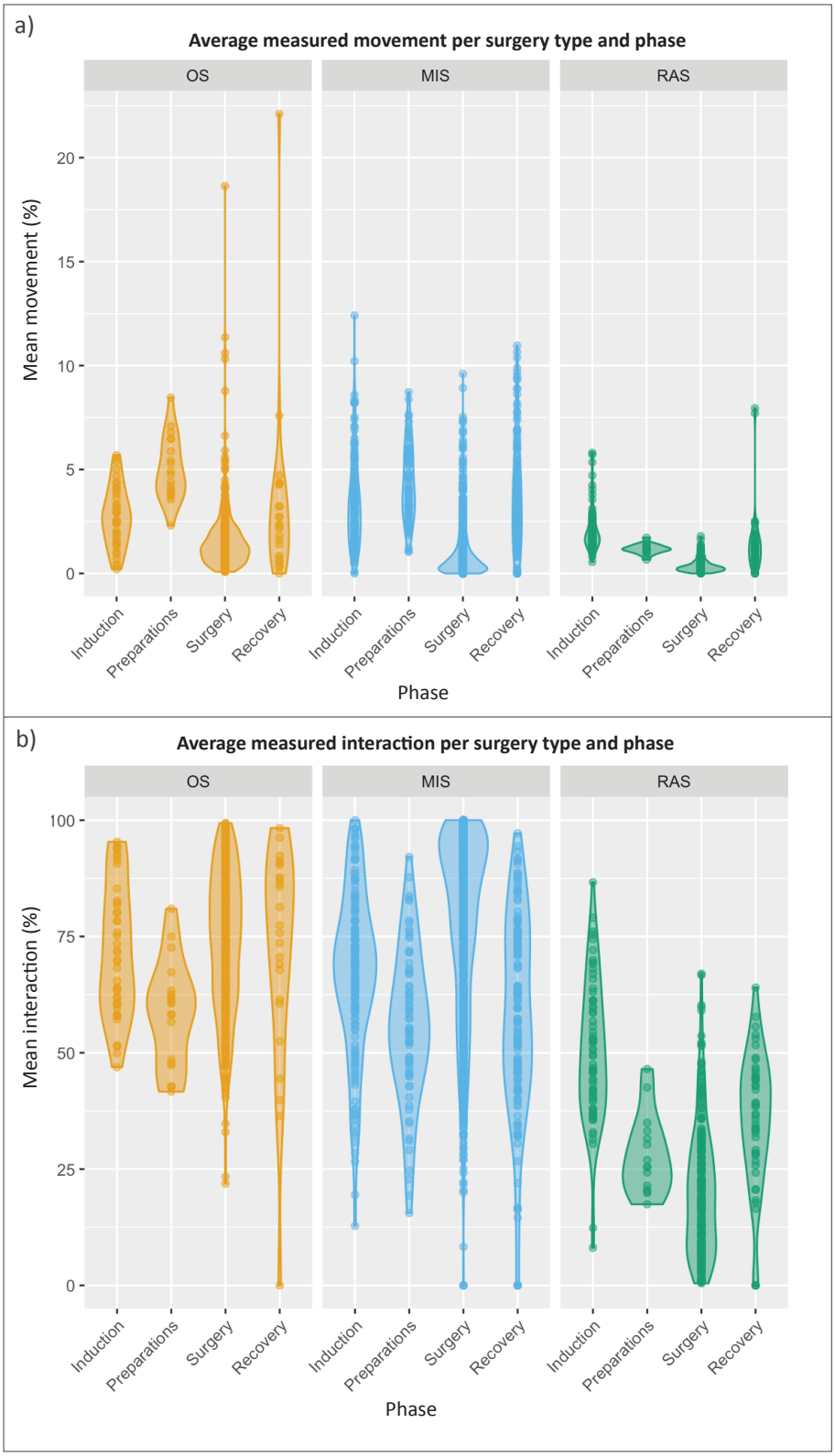

a)
Average measured movement per surgery type and phase
OS
MIS
RAS
Mean movement (%)
0
5
10
15
20
Induction
Preparations
Surgery
Recovery
Phase
b)
Average measured interaction per surgery type and phase
OS
MIS
RAS
Mean interaction (%)
0
25
50
75
100
Induction
Preparations
Surgery
Recovery
Phase

2.3.4 Hospital Data

Supplementary Table 2, Appendix 2.6, presents a summary of metrics related to the gynecological procedures performed in 2023. The data includes total procedure duration, deviations from planned durations, ASA scores of patients, and the time spent in the dark—defined as the periods during which the dim lights are turned on, primarily occurring during the cutting phase (phase 2) of the surgery.

Minimally invasive surgery procedures had the shortest operating times, while robotic-assisted surgery and open procedures had similar durations. During Phase 2 of the procedure (from first incision to closing), which involves dim lighting, robotic-assisted surgery required more time compared to minimally invasive surgery, a factor nurses indicated negatively affects job satisfaction, linking to questionnaire outcomes.

Open procedures often finished ahead of schedule, minimally invasive procedures stayed closer to planned durations, and robotic-assisted procedures tended to run longer, with the cumulative effect of small delays becoming significant over multiple surgeries. Patients undergoing open procedures generally had higher ASA scores, indicating greater preoperative risk, while robotic-assisted procedures were performed on healthier patients, with minimally invasive surgery falling in between. Additionally, open and robotic-assisted procedures typically required more personnel in the operating room compared to minimally invasive surgery.

2.4 Discussion

This research employed a multi-method approach—questionnaires, interviews, hospital data and video recording analysis—to evaluate the relation between operating room technology use and intra-operative nurses' workload and job satisfaction in the Netherlands. Our study identified several key influencing factors among which are team dynamics, procedural characteristics, preparation and

LEFT: Figure 6 Average Measured Movement and interaction per Surgery Phase by Procedure Type. a) Illustrating the percentage of average duration attributed to measured movement during open surgery (OS), minimally invasive surgery (MIS) and robotic-assisted surgery (RAS) across different surgical phases. b) Illustrating the percentage of average duration attributed to measured interaction in OS, MIS and RAS across different surgical phases.

equipment, work environment, organizational support, appreciation, and physical demands.

In this study, we extended the original SURG-TLX by adding a seventh aspect: job satisfaction. To our knowledge, this is the first time job satisfaction has been integrated into the SURG-TLX framework, marking an exploratory adaptation of the tool. By measuring job satisfaction on the same 20-point scale, we aimed to gain insights into how nurses experience satisfaction during different types of surgeries and how this relates to workload. As this is a first construct, the findings related to job satisfaction should be considered exploratory. They offer a valuable starting point for further investigation but should not be interpreted as conclusive statistical outcomes.

2.4.1 Open surgeries

Intra-operative nurses consistently rated open procedures as the most satisfying, correlating with higher job satisfaction scores on the SURG-TLX. Despite their longer duration, nurses reported staying actively engaged, contributing to a manageable workload. One nurse explained that the continuous involvement in open surgeries enhances satisfaction. At LUMC, open procedures, often involving higher-risk (ASA score) and emergency patients, were preferred for their challenges and hands-on engagement. Additionally, open surgeries typically end sooner than planned, reducing overruns and associated stress. The simpler equipment and well-lit environment in open surgeries further ease workload and stress (Sonoda et al., 2018). Video data supports these findings, showing higher Interaction with Operating Table scores, suggesting greater team engagement.

2.4.2 Minimally invasive surgeries

Minimally invasive procedures generally involve a lower workload than robotic-assisted procedures but also yield lower job satisfaction than open surgeries. The reduced workload is likely due to the higher frequency of minimally invasive surgery cases, allowing nurses to gain familiarity and efficiency. Shorter procedure times and fewer people in the operating room contribute to a more favorable working environment. Video data also shows higher Movement and Interaction with Operating Table scores than robotic-assisted surgery, suggesting more active involvement by team members. However, job satisfaction scores for minimally invasive surgery remain lower than for open procedures. This may be due

to the typically lower ASA and emergency scores, which suggest less complex cases, reducing engagement opportunities. Nurses reported feeling less involved due to limited visibility of the surgical site and noted that dim lighting, while less frequent than in robotic-assisted surgery, still impacted satisfaction.

2.4.3 Robotic-Assisted surgeries

Robot-Assisted procedures place a higher workload on intra-operative nurses than open and minimally invasive surgery and are associated with lower job satisfaction compared to open surgeries. The preparation phase of robotic-assisted procedures is particularly demanding, in contrast with the other procedures. Interviews revealed that nurses face significant stress preparing complex instruments and managing unexpected issues, aligning with previous findings (Sonoda et al., 2018). In the interviews, nurses report a lack of sufficient technical knowledge for troubleshooting, which increases their workload. Additionally, the lower frequency of robotic-assisted surgery cases means nurses have less hands-on experience, compounding stress and workload.

SURG-TLX assessments show robotic-assisted procedures impose greater temporal demands than other surgeries, with actual durations often exceeding estimates. This discrepancy adds to nurse workload. The robotic-assisted surgery work environment, characterized by dim lighting, elevated noise from extra equipment, and a crowded OR, contributes to increased distraction scores and lower satisfaction. More personnel are typically present, increasing noise and reducing space, while robotic-assisted procedures attract additional observers, further contributing to distractions.

Lower job satisfaction in robotic-assisted surgery cases may be partly due to reduced engagement; nurses report limited visibility of the surgical site and fewer tasks, especially in phase 2 (first incision to closing). This diminished involvement can lead to under-arousal, impacting both performance and satisfaction. Additionally, robotic-assisted surgery patients typically have lower ASA scores, presenting less complexity and fewer challenges, which may also lower engagement and satisfaction. Video data supports these insights, showing that robotic-assisted procedures have lower Movement and Interaction with Operating Table scores compared to open surgeries and minimally invasive surgery, reflecting reduced activity and involvement. However, during the cutting phase, video

analysis shows slightly higher activity levels in robotic-assisted surgery than in open surgery and minimally invasive surgery. This contrasts with findings suggesting fewer tasks for nurses during the cutting phase in robotic-assisted surgery. While robotic-assisted procedures generally have longer durations than minimally invasive surgery, potentially leading to longer periods of inactivity for nurses, the average durations of open surgery are comparable to those of robotic-assisted surgery.

The nurses' reports of fewer tasks during robotic-assisted surgery may instead reflect the nature of these tasks, as they also described them as less engaging. It is important to note the limited number of recorded videos in this study. Larger datasets are necessary to obtain more reliable and generalizable results.

2.4.4 Reccomendations

Our findings point to several strategies to improve working conditions for intra-operative nurses. From a management perspective, scheduling should aim to reduce frequent transitions between surgical setups while still offering variety in tasks. Grouping similar procedures and allowing sufficient time between cases may help lower setup-related workload and increase engagement. From an engineering perspective, the physical presence of robotic systems often disrupts nurses' workflows. Future designs should prioritize compact solutions, such as ceiling-mounted systems, to reduce floor clutter. Additionally, systems that function under normal lighting conditions could improve visibility and comfort for the surgical team. Finally, reduced nurse engagement during robotic-assisted procedures remains a concern. Ensuring nurses have a clear, active role in these workflows—through design or team protocols—will be key to maintaining job satisfaction.

2.4.5 Limitations

This study was conducted at LUMC, a university hospital with medical trainees who may take on tasks usually performed by intra-operative nurses, potentially biasing results. The study does not differentiate between scrub and circulating nurses, who share roles at LUMC, though research suggests these roles may perceive teamwork differently (Sonoda et al., 2018). Circulating nurses, who bear more physical demands (e.g., fetching equipment), reported higher frustration levels.

Focused on gynecological procedures, the study did not distinguish workload variations across specializations, though atmosphere and demands vary (Catchpole et al., 2016). In LUMC's gynecology department, nurses are not expected to change robotic arms, unlike in urology, potentially reducing involvement during robotic-assisted procedures. Analysis of specialization differences was limited by nurses frequently working across departments and selecting multiple specializations in questionnaires. Physiological workload measures (e.g., EMG, EEG) weren't included, so findings rely on subjective assessments and video analysis, which may limit workload evaluation comprehensiveness. Workload and job satisfaction are subjective, varying by factors such as age and hierarchy tolerance. A small sample size limits statistical reliability, as illustrated by variability in workload perceptions across domains. Five interviews were conducted, reducing generalizability and limiting the interpretive scope. With no statistically significant domain differences, SURG-TLX results were left unweighted, potentially limiting sensitivity (Olthof et al., 2018). Another potential limitation of this study is the modification of the SURG-TLX questionnaire by adding an additional domain: job satisfaction. While this adjustment was made to capture an important aspect of the participants' experiences that is not addressed in the original tool, it deviates from the validated structure of the SURG-TLX. This could potentially impact the comparability of our findings with previous studies using the unmodified version. Future research should consider validating the modified tool or employing complementary methods to assess job satisfaction independently.

Procedure classification was manual, with challenges from varying data formats and ambiguous cases (e.g., "research under anesthesia"). Vaginal procedures (e.g., hysteroscopies) were grouped with laparoscopies, though further separation may be warranted. Inconsistent data across procedures may also introduce bias, especially in emergency classifications and personnel records.

Additional observers during robotic-assisted procedures reportedly increased workload perception due to added vigilance needs. Observer data was absent, preventing analysis of how their presence impacts workload. Patient factors beyond ASA and emergency classifications, such as BMI, were unavailable, though they may influence workload; one nurse noted that robotic arms struggle with obese patients. Dim lighting in phase 2 (first incision to closing) of robotic-assisted surgery and minimally invasive surgery potentially confounded responses, as nurses noted increased workload in low-light settings.

We explored the potential of automated video analysis to extract objective measurements of nurse activities. Positively, these measurements aligned closely with manual annotations, demonstrating the promise of this approach for reliably tracking nurse activities. However, the algorithm metrics primarily captured lower body movements, missing finer actions such as handovers, which are crucial for understanding workload and skill demands (Quinn et al., 2023).

Additionally, the video analysis algorithm encountered challenges, including obstructions, dim lighting, and an inability to differentiate procedural phases, which limited its capacity to provide detailed insights into specific workload demands. The limited variety of recorded procedures (4 open, 6 robotic-assisted surgery, 25 minimally invasive surgery) further introduced potential biases, requiring cautious interpretation of the results. These findings highlight the need for further refinement of the algorithm to capture a broader range of activities and address contextual challenges.

2.4.6 Future research

This study highlights how surgical modality influences intra-operative nurses' workload and job satisfaction, but further research is needed to unpack the underlying factors contributing to these differences. Future studies should investigate how elements such as procedural complexity, perceived stress, and quality of treatment influence workload and satisfaction across different types of surgery. In particular, real-time measures of stress (e.g., physiological indicators or observational stress markers) could provide deeper insight into how nurses experience various surgical environments.

Moreover, while this study emphasizes the importance of creating supportive operating room environments, future research should explore concrete strategies to achieve this. This includes evaluating the effectiveness of targeted interventions such as team-based communication training, stress management workshops, and role-specific technical training programs tailored to different surgical technologies. Additionally, ergonomic improvements—such as adaptable OR layouts, more intuitive equipment interfaces, or support tools to reduce physical strain—should be systematically tested for their impact on both nurse well-being and workflow efficiency.

Investigating the interplay between organizational practices, technology use, and human factors will be essential to developing sustainable improvements in surgical care. Longitudinal studies or intervention-based research could help determine how such changes influence nurse retention, performance, and ultimately, patient safety.

2.5 Conclusions

This study used a multi-method approach to assess the workload and job satisfaction of intra-operative nurses at LUMC. Key factors influencing workload and job satisfaction included team dynamics, procedural characteristics, preparation and equipment, working environment, organizational factors, recognition and appreciation, and physical demands.

Generally, nurses found their workload acceptable and were satisfied with their jobs. Open procedures led to the highest job satisfaction due to continuous engagement and a manageable workload. Conversely, minimally invasive procedures, while less demanding, resulted in lower job satisfaction due to reduced involvement, simpler cases, higher frequency, and shorter durations. Robotic-assisted procedures were associated with increased workload and decreased job satisfaction, mainly due to preparation requirements, technological challenges, diminished involvement, and a less pleasant work environment (Figure 7).

These findings suggest that job satisfaction among intra-operative nurses is not solely determined by workload intensity but also by the level of engagement and perceived contribution to patient care. Minimally invasive and robotic-assisted procedures, despite their technological advancements, may unintentionally reduce nurses' sense of professional fulfillment. This underscores the importance of optimizing workflow and team dynamics in these procedures to enhance job satisfaction and maintain high-quality patient care.

Acknowledgements

We extend our heartfelt gratitude to all the nurses and patients who participated in this study. Your time, insights, and cooperation have been invaluable in advancing our understanding of the operating room environment. This research would not have been possible without your generous contributions and dedication. Thank you for sharing your experiences and for your commitment to improving surgical care.

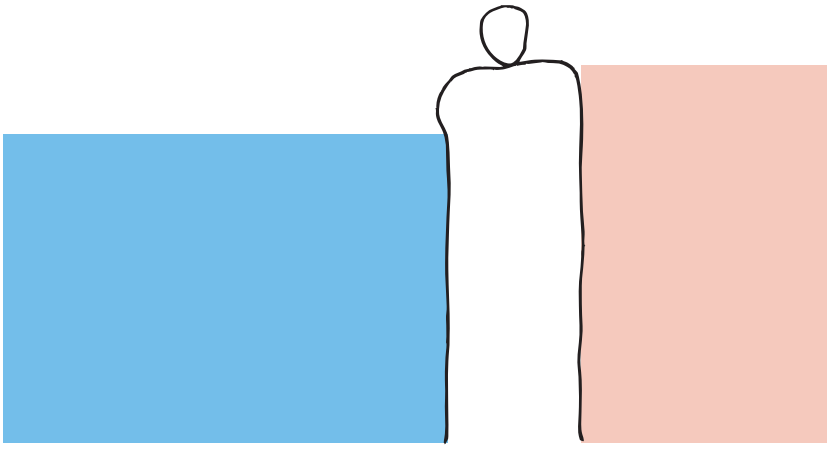


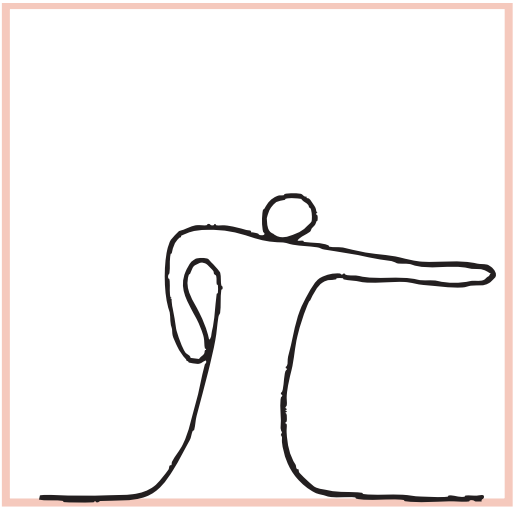
Figure 7 OR nurses sometimes feel caught between technologies.

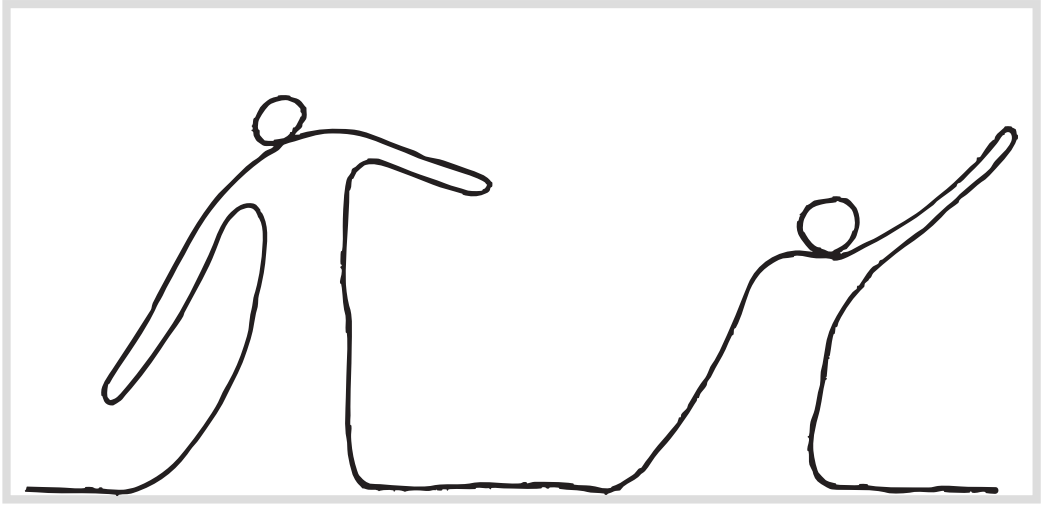
References

1. Björn, C., Josephson, M., Wadensten, B., & Rissén, D. (2015). Prominent attractive qualities of nurses' work in operating room departments: A questionnaire study. Work, 52(4), 877–889. https://doi.org/10.3233/WOR-152135
2. Bull, R., & FitzGerald, M. (2006). Nursing in a technological environment: Nursing care in the operating room. International Journal of Nursing Practice, 12(1), 3–7. https://doi.org/10.1111/j.1440-172X.2006.00542.x
3. Butler, R. M., Vijfvinkel, T. S., Frassini, E., van Riel, S., Bachvarov, C., Constandse, J., van der Elst, M., van den Dobbelsteen, J. J., & Hendriks, B. H. W. (2025). 2D human pose tracking in the cardiac catheterisation laboratory with BYTE. Medical Engineering & Physics, 135, 104270. https://doi.org/10.1016/j.medengphy.2024.104270
4. Catchpole, K., Perkins, C., Bresee, C., Solnik, M. J., Sherman, B., Fritch, J., Gross, B., Jagannathan, S., Hakami-Majd, N., Avenido, R., & Anger, J. T. (2016). Safety, efficiency and learning curves in robotic surgery: a human factors analysis. Surgical Endoscopy, 30(9), 3749–3761. https://doi.org/10.1007/s00464-015-4671-2
5. Chipsoft. (2023). HIX (6.3).
6. Fang, H. S., Xu, Y., Wang, W., Liu, X., & Zhu, C. (2023). AlphaPose. Https://Github.Com/MVIG-SJTU/AlphaPose.
7. Gabriel, P., Rehani, P., Troy, T., Wyatt, T., Choma, M., & Singh, N. (2024). Continuous Patient Monitoring with AI: Real-Time Analysis of Video in Hospital Care Settings.
8. Gillespie, B. M., Gillespie, J., Boorman, R. J., Granqvist, K., Stranne, J., & Erichsen-Andersson, A. (2021). The Impact of Robotic-Assisted Surgery on Team Performance: A Systematic Mixed Studies Review. In Human Factors (Vol. 63, Issue 8, pp. 1352–1379). SAGE Publications Inc. https://doi.org/10.1177/0018720820928624
9. Gjeraa, K., Spanager, L., Konge, L., Petersen, R. H., & Østergaard, D. (2016). Non-technical skills in minimally invasive surgery teams: a systematic review. Surgical Endoscopy, 30(12), 5185–5199. https://doi.org/10.1007/s00464-016-4890-1
10. Göras, C., Olin, K., Unbeck, M., Pukk-Härenstam, K., Ehrenberg, A., Tessma, M. K., Nilsson, U., & Ekstedt, M. (2019). Tasks, multitasking and interruptions among the surgical team in an operating room: a prospective observational study. BMJ Open, 9(5), e026410. https://doi.org/10.1136/bmjopen-2018-026410
11. Gusar, I., Lazinica, A., & Klarin, M. (2020). Work motivation, job satisfaction, and nursing record-keeping: do they differ in surgery and internal disease departments? Central European Journal of Nursing and Midwifery, 11(4), 163–170. https://doi.org/10.15452/cejnm.2020.11.0028
12. IBM SPSS Statistics. (2023). SPSS (29.0.0.0 (241)).
13. Kelvered, M., Öhlén, J., & Gustafsson, B. Å. (2012). Operating theatre nurses' experience of patient-related, intraoperative nursing care. Scandinavian Journal of Caring Sciences, 26(3), 449–457. https://doi.org/10.1111/j.1471-6712.2011.00947.x
14. L Cao, C. G., Khalid, H., Helander, M., Yeo, A., Cao, C. G., & Taylor, H. (2004). Effects of New Technology on the Operating Room Team Work with Computing Systems 2004 Effects of New Technology on the Operating Room Team. https://www.researchgate.net/publication/235098737
15. Lambrou, P., Kontodimopoulos, N., & Niakas, D. (2010). Motivation and job satisfaction among medical and nursing staff in a Cyprus public general hospital. Human Resources for Health, 8(1), 26. https://doi.org/10.1186/1478-4491-8-26
16. Lee, S. E., MacPhee, M., & Dahinten, V. S. (2020). Factors related to perioperative nurses' job satisfaction and intention to leave. Japan Journal of Nursing Science, 17(1). https://

doi.org/10.1111/jjns.12263
17. Microsoft Corporation. (2023). Microsoft Excel.
18. Noldus Information Technology. (2023). Noldus Observer XT. https://www.noldus.com/the-observer-xt
19. Olthof, M., Stevens, M., Dijkstra, B., Bulstra, S. K., & Van Den Akker-Scheek, I. (2018). Actual and perceived nursing workload and the complexity of patients with total hip arthroplasty. Applied Nursing Research, 39, 195–199. https://doi.org/10.1016/j.apnr.2017.11.023
20. Quinn, K. M., Chen, X., Runge, L. T., Pieper, H., Renton, D., Meara, M., Collins, C., Griffiths, C., & Husain, S. (2023). The robot doesn't lie: real-life validation of robotic performance metrics. Surgical Endoscopy, 37(7), 5547–5552. https://doi.org/10.1007/s00464-022-09707-8
21. R Core Team. (2023). R.
22. Schouten, A. M., Flipse, S. M., van Nieuwenhuizen, K. E., Jansen, F. W., van der Eijk, A. C., & van den Dobbelsteen, J. J. (2023). Operating Room Performance Optimization Metrics: a Systematic Review. In Journal of Medical Systems (Vol. 47, Issue 1). Springer. https://doi.org/10.1007/s10916-023-01912-9
23. Schuessler, Z., Scott Stiles, A., & Mancuso, P. (2020). Perceptions and experiences of perioperative nurses and nurse anaesthetists in robotic-assisted surgery. Journal of Clinical Nursing, 29(1–2), 60–74. https://doi.org/10.1111/jocn.15053
24. Senol Celik, S., Ozdemir Koken, Z., Canda, A. E., & Esen, T. (2023). Experiences of perioperative nurses with robotic-assisted surgery: a systematic review of qualitative studies. In Journal of Robotic Surgery (Vol. 17, Issue 3, pp. 785–795). Springer Nature. https://doi.org/10.1007/s11701-022-01511-9
25. Sheetz, K. H., Claflin, J., & Dimick, J. B. (2020). Trends in the Adoption of Robotic Surgery for Common Surgical Procedures. JAMA Network Open, 3(1). https://doi.org/10.1001/jamanetworkopen.2019.18911
26. Smith, J., & Palesy, D. (2018). Technology stress in perioperative nursing: An ongoing concern. Journal of Perioperative Nursing, 31(2). https://doi.org/10.26550/2209-1092.1028
27. Sonoda, Y., Onozuka, D., & Hagihara, A. (2018). Factors related to teamwork performance and stress of operating room nurses. Journal of Nursing Management, 26(1), 66–73. https://doi.org/10.1111/jonm.12522
28. Sørensen, E. E., Olsen, I. Ø., Tewes, M., & Uhrenfeldt, L. (2014). Perioperative nursing in public university hospitals: an ethnography. BMC Nursing, 13(1), 45. https://doi.org/10.1186/s12912-014-0045-7
29. Webster, J. L., & Cao, C. G. L. (2006). Lowering Communication Barriers in Operating Room Technology. Human Factors: The Journal of the Human Factors and Ergonomics Society, 48(4), 747–758. https://doi.org/10.1518/001872006779166271
30. Wilson, M. R., Poolton, J. M., Malhotra, N., Ngo, K., Bright, E., & Masters, R. S. W. (2011). Development and validation of a surgical workload measure: The surgery task load index (SURG-TLX). World Journal of Surgery, 35(9), 1961–1969. https://doi.org/10.1007/s00268-011-1141-4
31. WisperAI Inc. (2023). WisperAI ((v20231117)). WisperAI Inc. https://www.wisperai.com
32. Zhang, W., Li, H., Cui, L., Li, H., Zhang, X., Fang, S., & Zhang, Q. (2021). Research progress and development trend of surgical robot and surgical instrument arm. International Journal of Medical Robotics and Computer Assisted Surgery, 17(5). https://doi.org/10.1002/rcs.2309
33. Zheng, B., Fung, E., Fu, B., Panton, N. M., & Swanström, L. L. (2015). Surgical team com-

position differs between laparoscopic and open procedures. Surgical Endoscopy, 29(8), 2260–2265. https://doi.org/10.1007/s00464-014-3938-3





III

OPUS I

Operating Room Planning and Utilization Strategies of University Medical Centers: an Observational Study

Hospitals are under increasing pressure due to workforce shortages and rising patient demand, making efficient OR planning crucial. While research often focuses on short-term decisions, long-term planning and resource management receive less attention. Challenges such as late blueprint issuance, staff availability, and lack of transparency hinder effective scheduling. This study examines bottlenecks and opportunities for improvement in OR planning, based on structured interviews with 54 stakeholders from all eight academic hospitals in the Netherlands. Findings reveal that OR planning varies, with long-term scheduling remaining a bottleneck due to staff shortages and unrealistic schedules. Despite emerging data-driven tools and capacity centers, adoption is slow as stakeholders prioritize transparency over automation. The absence of clear OR planning policies complicates decision-making. To improve efficiency, hospitals should focus on: (1) leveraging data for greater transparency, (2) gradually integrating automation into established systems like EHRs, and (3) developing standardized OR planning policies to ensure consistency and accountability.

This chapter is under review as:
A.M. Schouten *(1st)*, L. Horenberg *(1st)*, S.M. Flipse, F.W. Jansen, E.Y. Sarton, A.C. van der Eijk, J.J. van den Dobbelsteen. OPUS I - Operating Room Planning and Utilization Strategies of University Medical Centers: an Observational Study

3.1 Background

Hospitals face growing economic and workforce related pressures, due to an aging population and a shortage of healthcare workers. This creates an urgent need for process optimization to control costs and improve service delivery (Rais & Viana, 2011). The operating theatre, as a complex and high-cost hospital environment, is central to these optimization efforts (Lee et al., 2019). Hospital managers aim to enhance OR performance by delivering high-quality services, ensuring patient satisfaction and safety, and achieving exemplary care outcomes, while simultaneously addressing budget constraints and prioritizing staff well-being. This necessitates efficient surgery schedules that minimize overtime (Fei et al., 2010).

As examples to improve OR scheduling efficiency, we found that researchers have proposed diverse strategies, including computational planning and scheduling techniques such as machine learning (Al Amin et al., 2025; Harris & Claudio, 2022a; Rahimi & Gandomi, 2021; Schouten et al., 2023; Zhu et al., 2019). Bellini et al. (2024) discuss the growing adoption of Artificial Intelligence (AI) in healthcare management and note challenges in implementing AI for OR scheduling, including data accessibility, privacy concerns, and limited validation research. Oliveira et al. (2023) explores the potential of extended OR hours to address surgery backlogs, while Pasquer et al. (2024) highlights organizational factors, such as specialty-dedicated rooms and teams, that enhance surgical performance. Additional systematic reviews on OR scheduling generally classify research based on patient characteristics (e.g., in/outpatient, emergency status), decision types (e.g., medical vs. non-medical), decision-making levels (strategic, tactical, operational), uncertainties (e.g., patient arrival times, surgery duration, cancellations), methodologies (e.g., simulations), and practical applications (e.g., theoretical or real-life data, implementation testing) (Cardoen et al., 2010; Harris & Claudio, 2022; Hulshof et al., 2012; Koushan et al., 2021; Samudra et al., 2016; Zhu et al., 2019).

We found that most research focuses on operational-level scheduling—where elective surgery planning takes place—rather than on the strategic and tactical levels that involve long-term staffing and OR time allocation (Zhu et al., 2019). There appears to be less emphasis on strategies to address workforce shortages in OR planning, while staff shortages at the operational level remain a significant cause of surgery cancellations, and Koushan et al. (2021) argue that these

shortages are symptoms of inadequate capacity management. They suggest that simply expanding the workforce is insufficient unless the underlying issues in capacity planning are addressed.
Implementing interventions or innovations in hospitals often fails (Jacobs et al., 2015), and there is a notable gap in applied research within OR scheduling (Harris & Claudio, 2022; Pasquer et al., 2024; Samudra et al., 2016). Few studies report on successfully implemented scheduling interventions.

Among those that do, Hwang & Barton (2016), Riise et al. (2016), and Visintin et al. (2017) investigated tools designed to improve master scheduling systems. A master scheduling system is a framework used to allocate OR resources at the tactical level, determining the distribution of surgical time blocks to different specialties or services over a planning horizon (e.g., weeks or months). Dios et al. (2015) studied the implementation of a decision support system for scheduling patients into the OR, while Zenteno et al., (2015, 2016) examined the use of open time slots dedicated for emergency cases and data-driven scheduling approaches that consider downstream bed occupancy. Rowse et al. (2015) also researched an OR scheduling system that takes bed occupancy into account to reduce surgery cancellations. Calegari et al. (2020) evaluated a heuristic approach for sequencing surgeries that integrates both upstream and downstream resources. These studies provide valuable insights into the practical application of scheduling interventions, yet they remain relatively rare within the broader body of OR scheduling research.

We acknowledge that hospitals are inherently complex organizations (Glouberman & Mintzberg, 2001). While individual aspects of surgery planning might seem straightforward, integrating these elements into the broader organizational and social context reveals significant challenges. This lack of cohesion across various components and processes complicates OR planning, as it involves multiple stakeholders with sometimes conflicting interests (Cardoen et al., 2010). Poor inter-professional collaboration can hinder patient care and OR planning effectiveness (van Veen-Berkx et al., 2015). Additionally, many studies focus on isolated aspects of OR planning, lacking a comprehensive system-wide perspective (Toub et al., 2022). Such narrow perspectives can impede the successful implementation of medical technologies or interventions, which require a holistic understanding of the broader context to ensure relevance and feasibility in clinical practice.

In the Netherlands, the University Medical Centers (UMCs) adopt a collaborative approach through the Benchmarking OR initiative, where the operating theaters of all seven UMCs work together to share information, identify best practices, enhance organizational learning, and conduct joint research. Building on this initiative, this study seeks to map the involvement of individuals and departments throughout the different phases of the OR planning process. By identifying common bottlenecks, current practices, and emerging trends, we create a comprehensive overview that integrates insights on challenges and best practices. With this overview we aim to provide a structured framework for understanding and improving OR planning across all seven UMCs in the Netherlands. Such insights will contribute to more effective planning processes and addressing healthcare workforce shortages, ultimately enhancing both operational efficiency and patient care.

3.1.1 Theoretical framework

The OR planning overview combines and adaptation of the Functional Resonance Analysis Method (FRAM) model (Hollnagel, 2017) with the positioning framework of Hans et al., 2007. Actions from stakeholders that contribute to the OR planning, referred to as functions in the FRAM model, are plotted in stakeholder-specific swimming lanes against a timeline ranging from a year in advance to the day of surgery. We also indicate the planning levels outlined by Hans et al. (2007): strategic planning (long-term decisions such as capacity dimensioning and resource allocation), tactical planning (medium-term decisions, including resource allocation and scheduling over months to a year), and offline and online operational planning (short-term decisions involving week-to-week and day-to-day planning and scheduling).

The original FRAM model, typically used to analyze complex systems, is build up by functions. A function represents a set of activities performed by the system. Functions are visualized as hexagons with six aspects: input, output, time, resource, control and precondition. Input is what the function needs to start, output is what the function produces. Preconditions must be met before the function can be performed and resources are tools or information that are required to perform the function. Control comprises supervisory aspects that influence how the function is performed. Time represents temporal constraints.

By linking the functions, the model shows couplings and dependencies, helping to understand how changes in one part of the system can impact other parts.

3.2 Method

To create detailed overviews of the hospitals' planning processes, we conducted a series of interviews with stakeholders. During these interviews, stakeholders were asked to describe the actions they perform in their segment of the planning process, the individuals or departments they collaborate with, and the ways they communicate (e.g., through structured meetings). The interviews were guided by a printed schematic that included a timeline and stakeholder-specific swim lanes. The methodology for developing these overviews, including participant selection and the interview setting, is described in detail in this section, following the COREQ checklist (Tong et al., 2007). Although the overviews aim to capture the current situation, participants were also encouraged to share how they would prefer to work differently. These preferences were documented as *"wish lists"*.

3.2.1 Study design

In our adaptation of the FRAM model, we have made four significant changes (Figure 1). First, since we place the functions on a timeline, we excluded time as a separate aspect connected to the function. Second, we plot the functions in stakeholder-specific swimming lanes to clearly delineate responsibilities. Third, we indicate which functions take place during meetings of the involved stakeholders. Fourth, we differentiate between functions and subfunctions. A subfunction, represented as a small black dot, is used when a stakeholder contributes to a function by, for example, acting as a resource, but does not execute the action themselves. This choice helps maintain an overview, as the processes we describe are extensive.

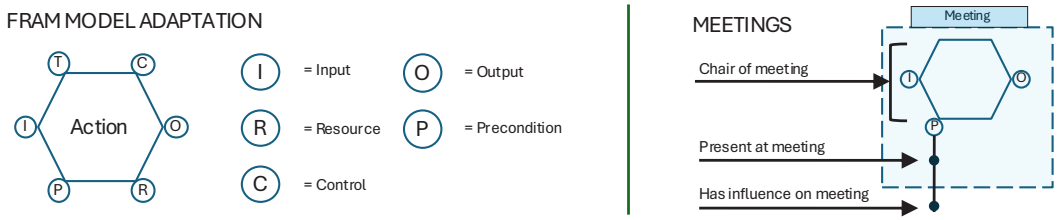


Figure 1 FRAM model adaptations.

Figure 2 shows a simplified example of the overview. In this overview, we include advance scheduling (Cardoen et al., 2010), which involves setting a surgery date for a patient, and allocation scheduling, which specifies the operating room and the start time of the procedure on the designated surgery day. Additionally, we cover OR staff planning, which encompasses scheduling for individual physicians, operating assistants, and anesthesia assistants. However, we do not cover resource scheduling, which involves identifying and reserving necessary equipment and materials for surgery. In our overviews, the term "resource" specifically refers to staff resources.

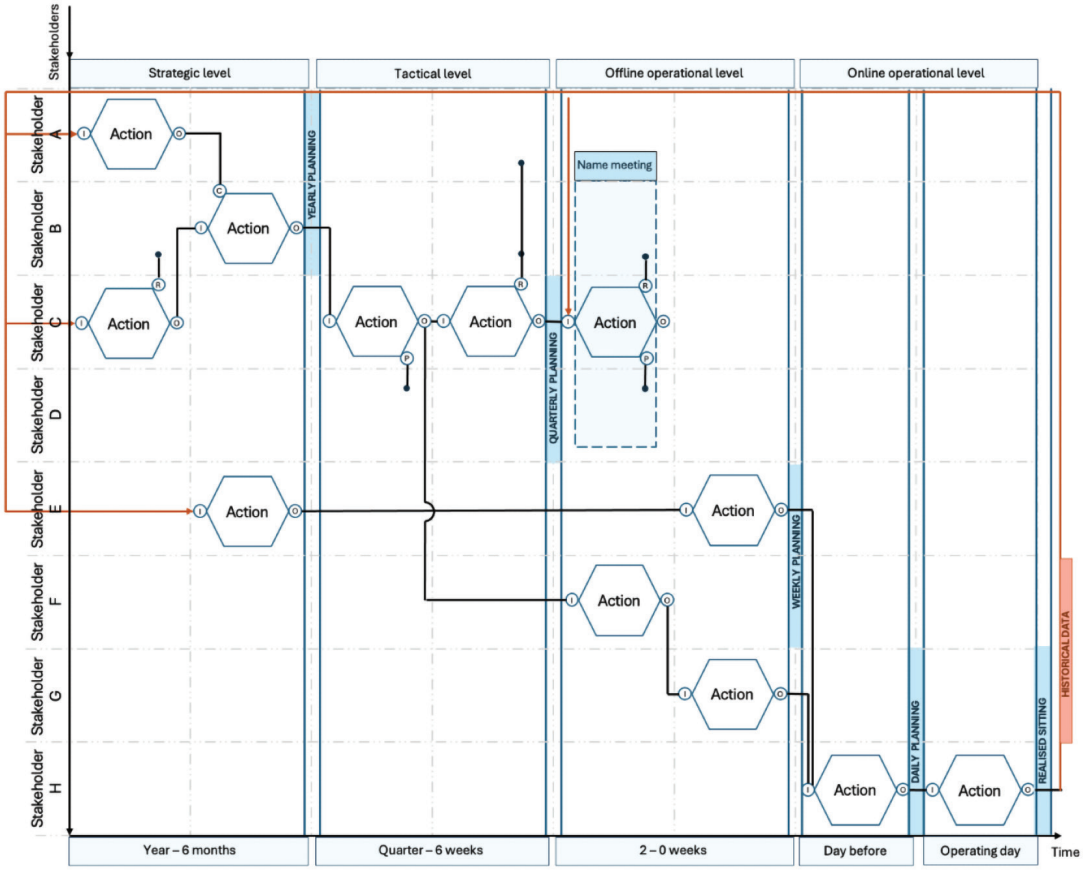


Figure 2 Simplified example of the OR planning process overview layout.

3.2.2 Participant selection

All seven Dutch University Medical Centers are part of the OR Benchmarking initiative and participated in this study. One of these hospitals is currently in

the process of merging from initially two university medical centers. Therefore, we considered them as one entity, but due to the ongoing nature of the merger, particularly at the operational level, we decided to create separate overviews for each of the two originally separate centers. This required interviewing additional stakeholders and resulted in eight overviews for seven hospitals.

We conducted interviews with at least seven stakeholders per hospital, totaling 54 participants. The interviewed stakeholders included members of the board of directors, OR managers, Capacity Center staff, senior planners, medical specialists, OR staff planners (who plan OR nurses and anesthesia nurses), OR team leaders, planning office employees, medical coordinators, and program coordinators. We did not interview health insurance providers, staff from recovery, function departments, nursing wards, or the intensive care unit (ICU). While these groups play a role in coordinating bed availability across hospital departments, they do not directly contribute to OR planning and were therefore excluded from the scope of our study.

Of the 54 participants, three stakeholders were unable to complete the entire study because of time constraints, pregnancy leave, and long-term sick leave. We found a replacement for one of these stakeholders. For the remaining two, we chose to include their incomplete information if it could be verified by the other participants in the study.

3.2.3 Setting

The first round of interviews was conducted on-site at the hospital where the stakeholders work, with only the two researchers (authors AS and LH) and the participant present. Once all interviews in the first round were completed, the findings were consolidated into a single comprehensive overview. To validate this overview, a second round of interviews was conducted online. Each stakeholder was presented with the same version of the overview, and the researchers refrained from sharing any knowledge or insights previously gathered from other stakeholders. This approach ensured consistency in the way information was collected. A third and final validation was completed via email. All interviews were conducted in 2023 and 2024, using the standard consent form format provided by the University of Leiden, which all participants were required to sign.

3.2.4 Data collection

The overview was constructed in three stages:

1. Initial Draft (V0): When available, the initial draft is created based on the hospital's OR regulations document, though not all hospitals have such a document, and its content can vary. This draft is then reviewed by at least seven stakeholders during individual interviews, where they can annotate and provide feedback on a printed copy of the V0 draft. In cases where no regulations document exists, an empty overview is used as a starting point, which is then collaboratively filled in with input from the stakeholders.
2. Revised Draft (V1): The feedback from the initial interviews is incorporated into a second draft. In a second round of individual interviews with the same stakeholders, the V1 draft is re-evaluated.
3. Final Version (V2): The finalized version of the overview is sent to the stakeholders via email for a final review.

The study design was pilot tested in the LUMC hospital with three stakeholders, with different occupations. During the interviews, no audio or visual recordings were made. One researcher guided the participant through the draft of the overview, and the second researcher made field notes. This way, the researchers and the interviewee visually updated the drafts of the scheduling process. Both researchers asked the participant to elaborate on certain parts of the planning process when necessary.

To achieve data saturation, a minimum of seven stakeholders were interviewed. Recurring meetings—defined as structured discussions or regular collaborative gatherings within the planning process—were included in the overview only if at least three different stakeholders independently mentioned them. The overviews derived from the interview results were created by author AS and cross-checked by author LH against the notes taken during the interviews to ensure accuracy and consistency.

3.2.5 Analysis and findings

To analyze quantitative aspects of the overviews, such as the number of actions performed by each stakeholder per hospital and the distribution of actions across decision levels, the overviews were digitized in Microsoft Excel 2024 (Microsoft

Corp.). This involved populating columns with data on the (sub-)function, corresponding coordinates, stakeholder, relevant aspects, decision level, timestamp, hospital, whether the action occurred during a meeting, and whether it resulted in a planning outcome. The participants' wish lists were documented in Microsoft Excel 2024, organized by profession, and independently labeled and categorized by AS and LH. Any differences in labeling were discussed and resolved collaboratively.

3.3 Results

The supplementary files contain the eight produced overviews of the seven hospitals included in this study. This section presents the analysis of these overviews. First, an overview of the stakeholders and their roles within the hospital context is provided. Next, a comprehensive overview of OR planning in Dutch UMCs is described, with key differences between hospitals highlighted. Finally, participants' perspectives on potential improvements to the OR planning process are discussed.

3.3.1 Overview of participants and their context in the hospital

Table 1 shows an overview of the roles of the 54 participants, and how many participants per role were interviewed. Note that some participants fulfill multiple roles. Figure 3 displays the participant roles placed in the context of the relevant hospital departments.

Table 1 Overview of the roles of the participants in the hospital and how many participants per role were interviewed.

Role in hospital	Description	n
Operating Room manager	Oversees the entire OR center.	7
Medical coordinator	Typically an anesthesiologist, responsible for coordinating surgeries on the scheduled day alongside the program coordinator. Together, they manage emergency surgeries, delays, and other issues. The medical coordinator is accountable for medical decisions.	8
Program coordinator	Usually an OR nurse who takes on this role a few days a week. Works with the medical coordinator to manage emergencies, delays, and schedule gaps caused by staffing shortages.	7
Operating Room team leader	Leads the team of OR nurses.	7
Planning office	Each medical specialty generally has its own office responsible for scheduling patients. In some cases, one office may handle scheduling for multiple specialties.	5
Medical specialist	Often, a lead medical specialist is responsible for overseeing the planning aspects for their specialty.	5
Capacity center	Develops an annual budget cycle that includes financial, production, and capacity planning. This cycle determines the patient care to be provided by the hospital and the required capacity.	7
Board of directors	Responsible for overseeing the organization's overall strategic direction, ensuring high standards of patient care, financial stability, and regulatory compliance.	1
Senior planner	Responsible for the distribution budgeted surgery hours across specific ORs and days.	3
Staff planner	Develops staff planning for OR nurses and anesthesia nurses.	4

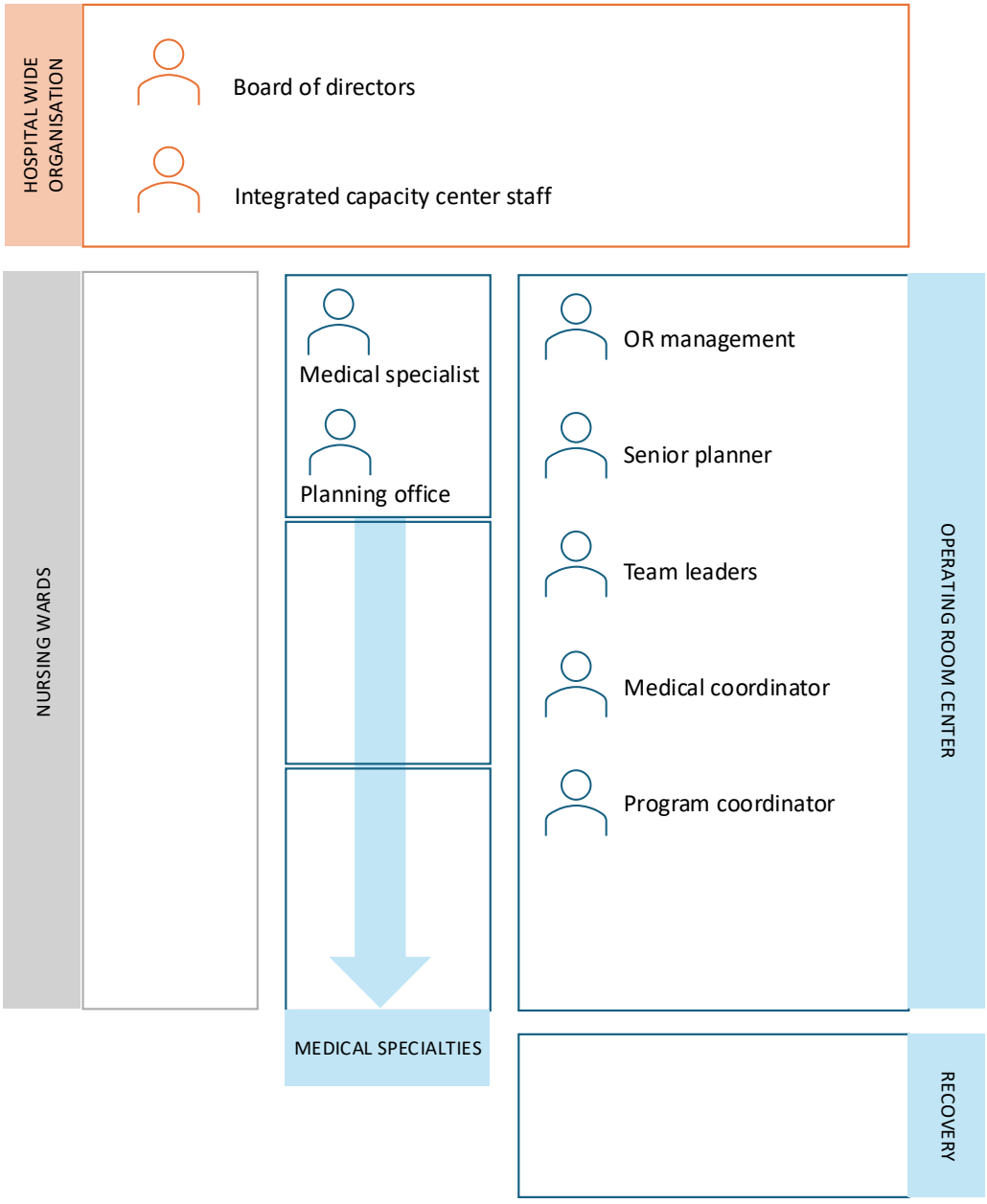


Figure 3 The general structure of the relevant departments of the hospitals and corresponding participant roles.

3.3.2 Overview of OR planning in Dutch UMCs

To quantify the differences between hospitals, Figure 4 illustrates the number of actions at each planning level for each hospital. The number of actions at the online operational level is relatively consistent across hospitals. However, the focus on tactical-level planning varies and is often quite low. Notably, interviews revealed fewer reported bottlenecks in operational planning when the number of actions at the tactical level was higher. This trend suggests that hospitals with more robust tactical planning may experience less need for adjustments to their original plans.

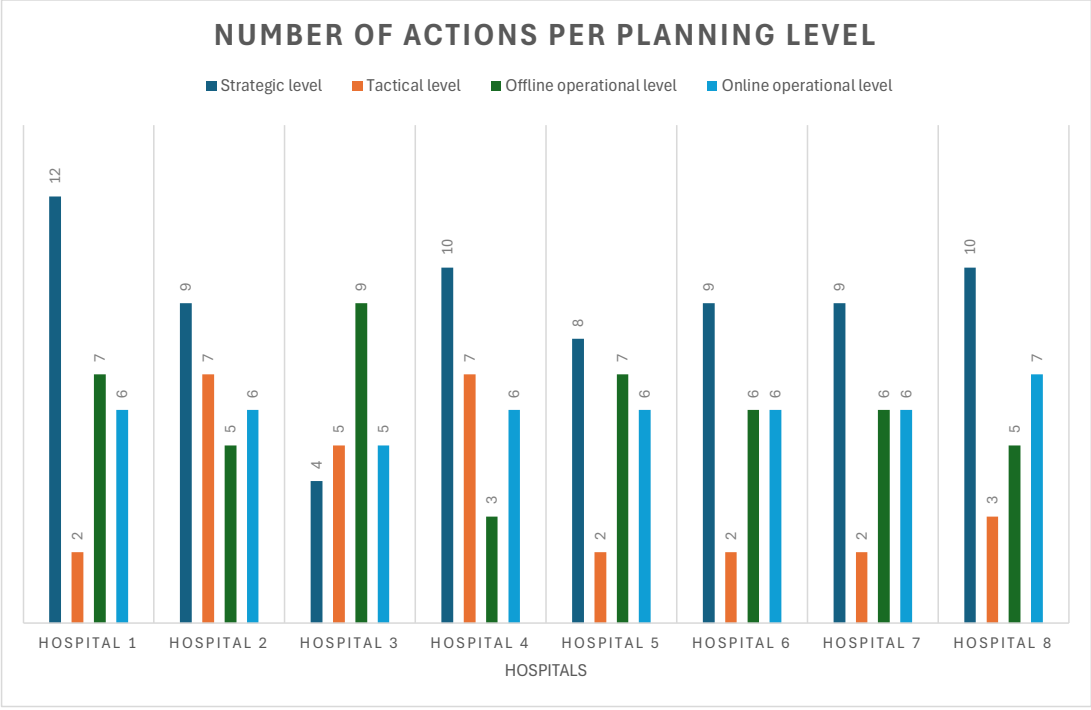


Figure 4 Bar chart illustrating the number of planning actions across strategic, tactical, and operational levels for each hospital.

Figure 5 presents the number of actions performed by each stakeholder across different hospitals. There is variation among stakeholders with the same role across hospitals. For instance, while the number of actions for program coordinators is relatively consistent in most hospitals, the program coordinators in hospitals 2 and 3 exhibit a significantly higher number of actions.

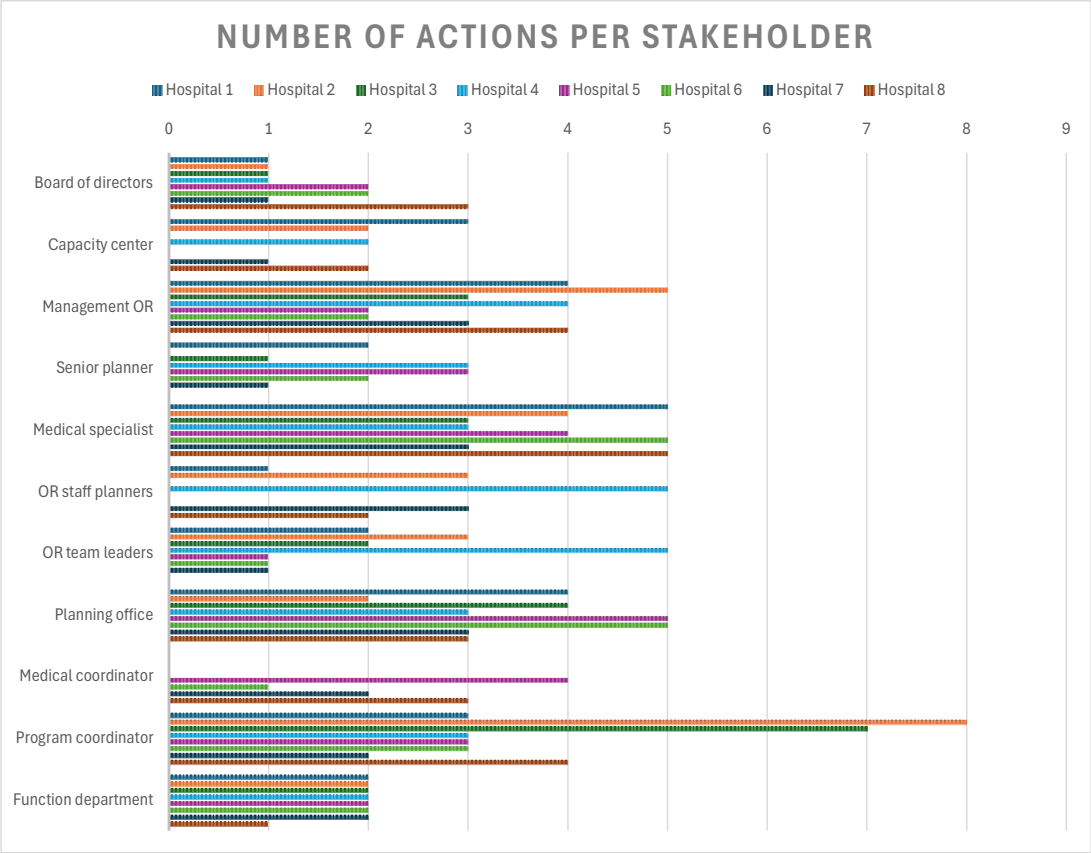


Figure 5 Bar chart showing the number of actions performed by each stakeholder across hospitals.

3.3.3 Strategic level

A year in advance, the board of directors formulates a hospital vision and strategy, which is influenced by negotiations with external stakeholders such as healthcare insurance providers and the government. Simultaneously, medical specialties develop their own strategies. The interaction between these strategic levels varies by hospital, affecting the degree of collaboration between the board of directors, medical specialists, and OR management. Surgery hours are allocated to medical specialties based on these strategies (Figure 6). The allocation process differs among hospitals: in two, the board of directors supervises the process, typically delegating execution to the finance and control department; in another two, a capacity center determines allocations based on data from the previous year; and in four, the responsibility lies with the OR management team.

The allocated hours are then presented to the medical specialties, which can sometimes request changes, potentially leading to several iterations. This process is a zero-sum game—if one specialty receives more hours, another receives fewer.

III

In seven out of eight hospitals, the newly allocated hours are distributed throughout the year in four-week cycles, including reduction weeks—periods when the operating room operates on a reduced schedule, often due to holidays or lower patient demand. This distribution is commonly referred to as the yearly blueprint. Five hospitals use the previous year's blueprint as a baseline, adjusting it based on the newly budgeted hours, except in cases of structural changes, such as OR center remodeling or shifts in healthcare provision. The remaining three hospitals take a more flexible approach, developing their blueprint from scratch each year.

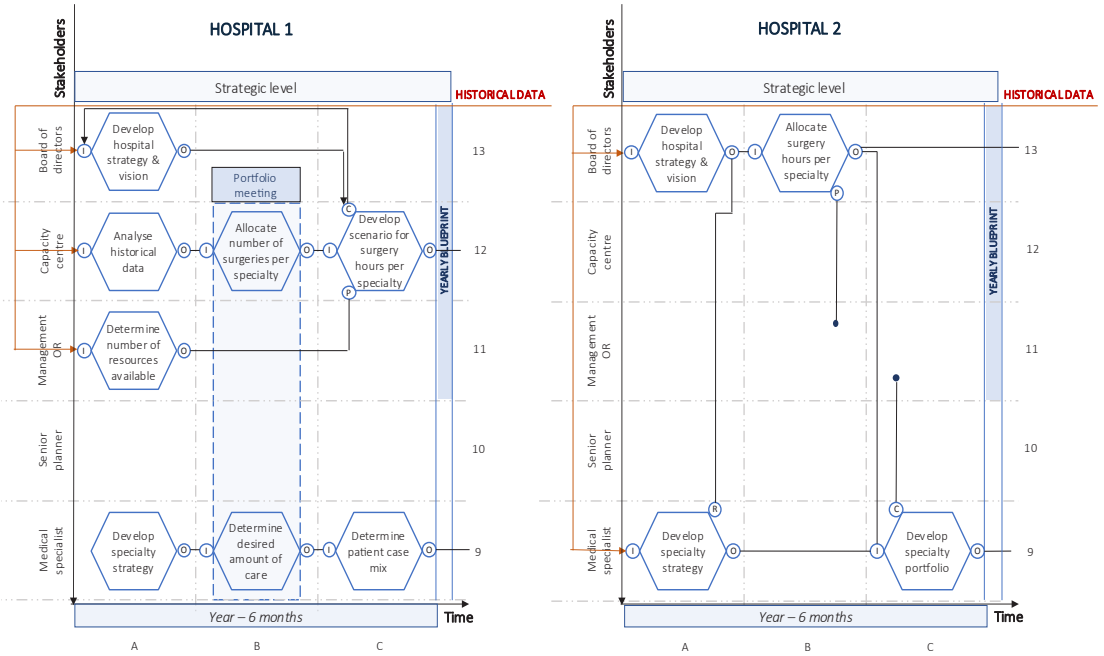


Figure 6 Selection of the strategic level from two different hospitals, illustrating the strategies used for allocating surgery hours per medical specialty. The numbers on the x-axis and the y-axis (right) represent the coordinates of actions within the overview, corresponding to their positions in the original overviews.

3.3.4 Tactical level

Approximately six months in advance, the availability of OR staff is determined (Figure 7). In six hospitals, OR management oversees this process, while in two, OR staff team leaders and planners take on a more significant role. Every month, three months ahead of time, the alignment between OR staff capacity and the yearly blueprint is reviewed. Hospitals employ different strategies to reconcile any discrepancies. One hospital uses flexible ORs, reallocating them based on historical data to specialties with the greatest need after the initial planning. Three other hospitals designate specific timeslots as pro-memorie sessions, meaning that if adjustments are required, patients scheduled in these slots will be the first to be canceled.

Once the staff budget and yearly blueprint are aligned, a senior planner distributes the budgeted hours across specific ORs and days. The staff budget refers to the availability of operating room assistants and anesthesia nurses. In five hospitals, the capacity center supports this process by analyzing historical data, such as the utilization of medical specialists in previous months. Four hospitals reported that the results of this step are reviewed in a tactical planning meeting, while others communicate them via email.

Larger medical specialties often have more involvement than smaller ones. Medical specialties can request extended operating times for specific procedures, with the timing of these requests varying by hospital. In some hospitals, this occurs at the tactical level, while others handle it more ad hoc at the operational level. The result of the tactical level planning is the yearly planning, where the filled-in blueprint sessions are published in the Electronic Health Record (EHR) per month, three months in advance.

Parallel to the development of the yearly planning, OR staff planning begins. Six months in advance, operating room assistants and anesthetic nurses communicate their availability for the coming months. Based on their availability, OR staff planners develop and publish a duty roster with the working hours.

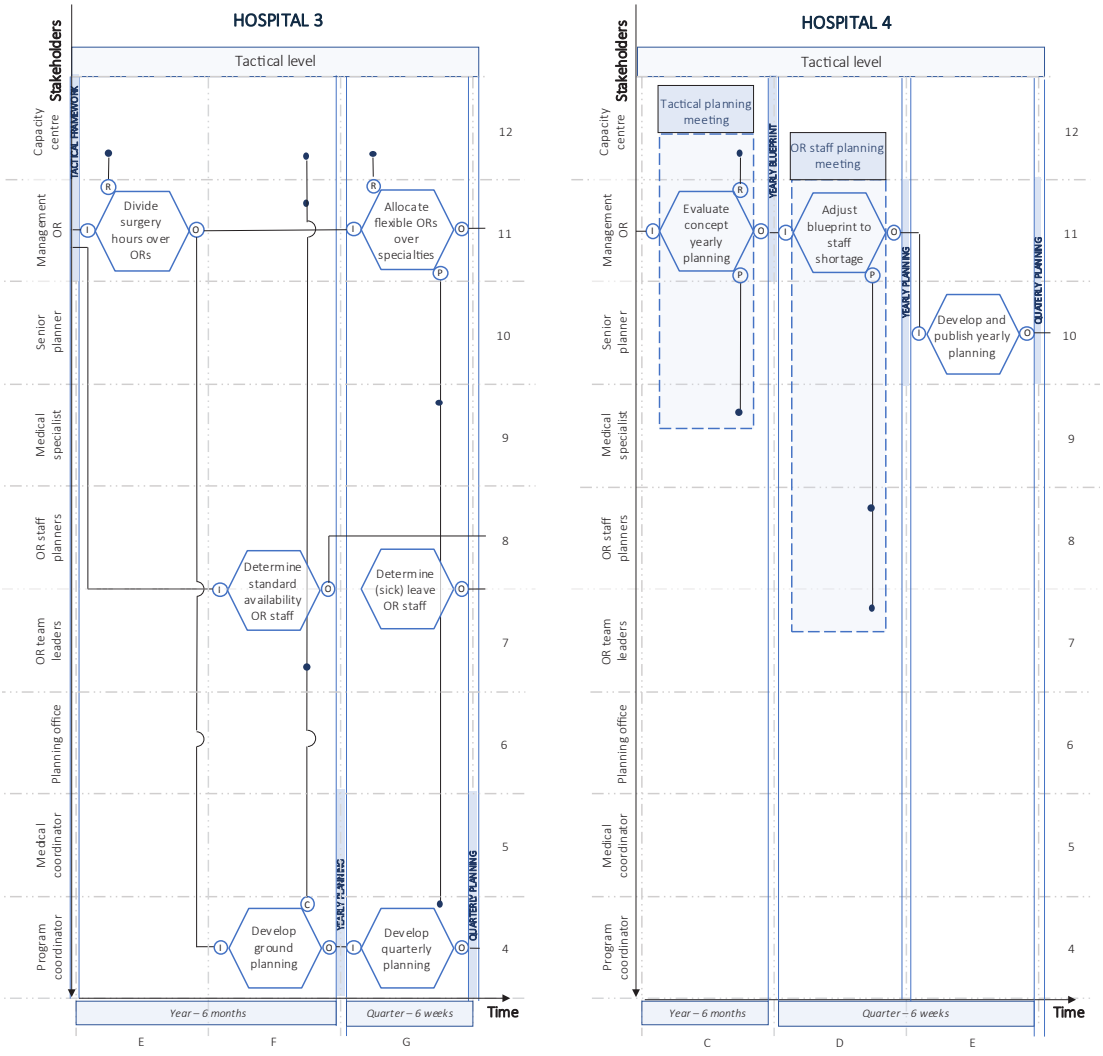


Figure 7 Selection of the tactical level of two different hospitals that illustrates the used to align the yearly blueprint with staff capacity. Both hospitals first divide the surgery hours over the OR and compensate for staff availability by making use of flexible ORs (Hospital 3) or pro-memorie ORs (Hospital 4). The numbers on the x-axis and the y-axis (right) represent the coordinates of actions within the overview, corresponding to their positions in the original overviews.

3.3.5 Offline operational level

Once the yearly planning is published in the EHR, planning offices or specialty-specific planners begin scheduling patients from the waiting list into designated OR sessions for their specialty. They follow guidelines to maintain flexibility for emergency patients and optimal utilization. For instance, planners aim to schedule longer surgeries at the beginning of the day and shorter ones towards

the end. This approach allows for adjustments if a longer surgery overruns, as the shorter surgery can be moved to another OR with more efficient planning. In five hospitals it was reported that planners typically develop a decentralized concept plan, relying on their own judgment, before entering it into the EHR. The advance planning timeline varies by specialty and surgery type; for example, trauma surgery typically plans patients on a shorter-term basis than more routine procedures.

All patients must be scheduled approximately one week in advance, with (elective) trauma specialties being an exception. To verify and approve the plans made by the planners, six hospitals hold a multidisciplinary meeting and a weekly program meeting. The multidisciplinary meeting, which can be specialty-specific or combined across specialties, involves the OR management, medical coordinators, and other relevant disciplines discussing the planning (Figure 8). The multidisciplinary meeting, which may be specific to a single specialty or involve multiple specialties, includes OR management, medical coordinators, and other relevant disciplines who collaborate on the surgical planning. The anesthesiologist assesses whether the patient is fit for surgery, determines the sedation technique, and addresses specific needs, such as scheduling diabetic patients early. The surgeon decides on the procedure, such as full mastectomy or breast-conserving surgery in breast oncology, based on the cancer's characteristics, which also affects surgery duration.

Following this, the weekly program meeting checks if the planning is realistic in terms of OR staff availability and if all necessary materials, such as 3D-printed equipment, are ready. It also ensures there are enough ICU and recovery beds. This results in a final weekly plan, and the OR assistants and anesthetic nurses are then scheduled according to this plan. After staff scheduling, the planning is evaluated at the day level. Before finalizing the day plan, planning offices can make adjustments, such as adding semi-emergency patients to time slots intentionally left empty for emergencies or delays. These timeslots are typically a strategic choice of the planning office rather than hospital policy. The day before surgeries, the day plan is finalized and locked at a specific time, usually early in the afternoon. After this point, changes are not permitted without approval from the medical and program coordinators. The strictness of enforcing this locked planning policy varies by hospital.

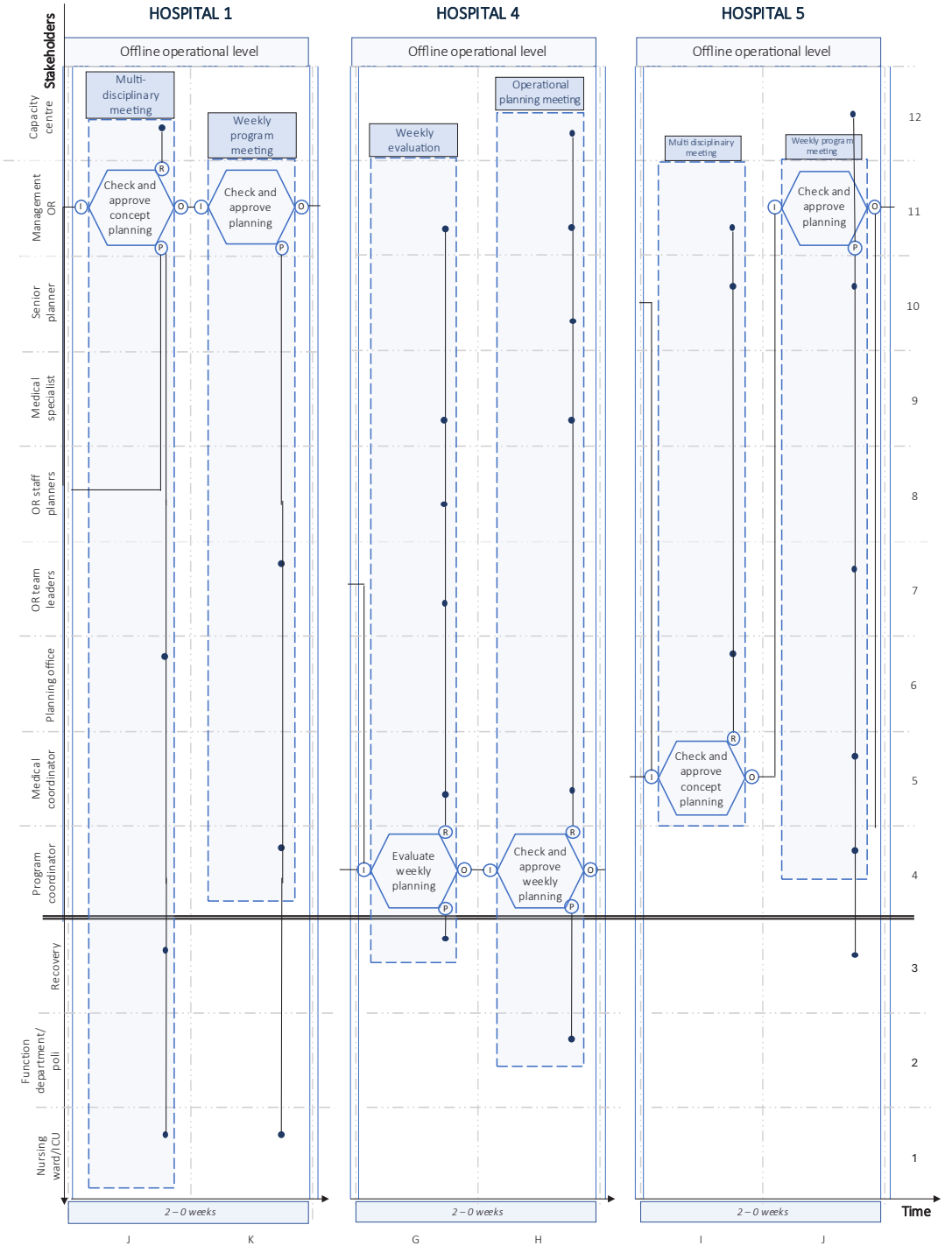


Figure 8 Three examples of hospitals who have similar multi-disciplinary meetings and weekly evaluation meetings on an offline operational level. In these meetings the weekly planning is evaluated, checked and approved by a broad range of stakeholders. The numbers on the x-axis and the y-axis (right) represent the coordinates of actions within the overview, corresponding to their positions in the original overviews.

3.3.6 Online operational level

On the day of surgery, the medical and program coordinators review the emergency waiting list, which often includes cases that came in overnight. All hospitals have multiple dedicated emergency ORs. Adding patients to the emergency waiting list is typically done by the medical specialist, who contacts the medical and program coordinators, with assistance from the planning office in some cases.

The medical coordinator, usually an anesthesiologist, makes medical decisions regarding the priority of emergency patients and whether the elective schedule needs to be adjusted for additional emergency surgeries. The program coordinator ensures that the ORs are prepared for these surgeries and that the necessary staff and equipment are available. A medical specialist can also cancel a surgery if the patient develops a fever or becomes too ill for the procedure. In such cases, the specialist must notify both the medical and program coordinators. It is not uncommon for the coordinators to close a session due to staff shortages, surgery delays, or emergency surgeries. When a surgery is canceled, either coordinator will inform the medical specialist and adjust the final planning.

3.3.7 Historical data

After surgery, data is stored, but the extent to which hospitals use this historical data to improve planning varies. A growing trend across hospitals is the development of capacity centers, which are expanding in (staff) size, influence, and gaining broader acceptance and appreciation. However, in most hospitals, data analysis is not yet performed consistently; instead, it is typically conducted on an ad-hoc basis, often in response to specific questions from OR management.

3.3.8 Stakeholder perspectives

Stakeholders involved in OR planning across various hospitals expressed a range of wishes and concerns, highlighting both challenges and areas for improvement. A common theme is the need for better long-term planning, with stakeholders preferring realistic and transparent blueprints that align with current capacity and avoid over-scheduling. For example, three stakeholders suggested issuing final blueprints earlier—ideally 8–12 weeks in advance instead of the current 4–6 weeks—to allow more time for preparation, particularly for large or complex surgeries.

Eight stakeholders emphasized the need to account for staffing shortages in the planning process, with one suggestion being to consider 80% capacity as the new 100% to create more realistic and achievable schedules.

Communication and coordination are significant pain points. Decentralized planning often requires excessive back-and-forth communication, leading to inefficiencies. For instance, one stakeholder noted that medical specialists sometimes call anesthesia directly instead of coordinating through the OR office, creating inconsistencies. Another example involves the clustering of similar procedures, where specialties independently schedule many small surgeries on the same day, causing bottlenecks. Nine stakeholders suggested standardizing communication protocols and fostering better collaboration between specialties and departments, particularly to address issues such as emergency cases and cancellations.

Data-driven approaches and enhanced tools were frequently mentioned as critical improvements. Ten stakeholders wished to integrate historical data into planning systems to improve resource prediction and scheduling accuracy. For example, five stakeholders proposed using historical data to determine procedure times at the surgeon and anesthetist levels and implementing AI tools to optimize schedules. Twelve stakeholders also highlighted the limitations of current EHR systems, noting that they do not effectively track schedule changes. They emphasized the need for a more user-friendly EHR system that enables real-time updates and transparent tracking. Furthermore, four stakeholders identified significant value in the ability to create a draft schedule within the EHR that remains hidden from patients until finalized.

Twelve stakeholders also emphasized the importance of feedback and adherence to planning rules. They called for structured evaluations of planning outcomes and the establishment of clearer guidelines to ensure consistency across specialties. For instance, seven stakeholders highlighted the need for stricter policies to lock schedules, minimizing last-minute changes after the operational planning meeting. Four stakeholders proposed conducting weekly planning reviews with all relevant departments to promote transparency and alignment.

Ultimately, stakeholders desire a planning process that is proactive, transparent, and responsive to their needs. Specific improvements include issuing earlier and more realistic blueprints, integrating advanced data tools, streamlining commu-

nication, and aligning planning processes more closely with operational realities, such as accounting for downstream impacts like recovery room and bed availability.

3.4 Discussion

This study aimed to identify bottlenecks, current practices, and emerging trends in OR planning. The findings show variability in planning practices across Dutch hospitals, particularly in the number of strategic, tactical, and operational actions, as well as in how responsibilities are distributed among stakeholders. Differences in the number of actions at each decision level can be attributed to variations in hospital locations, leading to distinct case-mix compositions. Additionally, hospital size plays a role in shaping planning approaches. A hospital's strategic priorities also influence its planning focus; for instance, a hospital prioritizing emergency cases in the region may adopt a more operationally driven planning strategy. The distribution of responsibilities among stakeholders often reflects their own preferences and organizational dynamics.

3.4.1 Bottlenecks

Stakeholders involved in OR planning have highlighted bottlenecks that impede efficiency. One major challenge is long-term planning, with blueprints often issued too late—4–6 weeks in advance—providing insufficient preparation time, especially for complex surgeries. Stakeholders have proposed issuing blueprints 8–12 weeks earlier and designing more realistic schedules that account for staffing constraints, such as planning at 80% capacity to better match available resources. This challenge aligns with the Case-Mix Planning Problem described in the literature, which focuses on determining the optimal combination of surgeries to perform within a specific period (Cardoen et al., 2010). The aim is to balance resource utilization—such as staff, ORs, and beds—while achieving desired outcomes like financial efficiency or improved patient throughput, all within the constraints of surgeon availability and patient prioritization (Kim et al., 2018).

Communication and coordination remain critical challenges in OR planning. Decentralized planning often results in inefficiencies, such as excessive back-and-forth communication and inconsistent practices. Poor coordination between specialties can lead to bottlenecks, such as the clustering of small procedures on

the same day. Standardized communication protocols and improved cross-specialty collaboration could mitigate these issues. However, stakeholders emphasized that while centralized planning is desirable, current EHR systems lack the functionality to support it. A significant concern is that concept plans in EHRs are immediately visible to patients, potentially causing confusion. Additionally, stakeholders reported that the way information is presented in EHRs often lacks clarity, making it difficult to maintain an overview during the planning process. Despite these limitations, EHR systems are frequently cited in the literature as successful hospital innovations that significantly enhance patient care coordination (Omaghomi et al., 2024). This suggests that developing an EHR system tailored to standardized OR planning – where planning is conducted using the same system and follows consistent rules across departments, without centralizing all decisions – could be a valuable improvement for hospitals, addressing existing challenges and enhancing planning efficiency.

Stakeholders also emphasized the need for planning systems that integrate historical and real-time data to enhance scheduling accuracy, with suggestions for using data-driven methods to predict procedure times at both the surgeon and anesthetist levels. While the literature describes numerous systems with such functionalities, implementation remains challenging due to fragmented hospital data storage, financial constraints, and resistance from staff to adopt yet another system (Cardoen et al., 2010). However, modern EHR systems are increasingly capable of integrating historical and real-time data. A more structured approach to data storage, combined with the continued development of systems already embedded in clinical workflows, is likely the most effective path forward. The financial constraints hospitals face in acquiring more advanced EHR systems must be considered (Nguyen et al., 2022). Due to the high costs of vendor-based EHRs, open-source alternatives are emerging. However, these open-source systems often lack systematic evaluation based on a standardized reference model, raising concerns about their reliability and integration into clinical workflows (Shaikh et al., 2022).

Additionally, stakeholders report that feedback mechanisms and adherence to planning rules are insufficient, with inconsistent evaluations and frequent last-minute changes undermining the planning process. Clearer, universally applied rules were suggested to improve consistency and efficiency. This could be in the form of more elaborate OR regulation documents, in which plan rules and

regulations are documented. These documents should be available and used by all stakeholders that contribute to the planning. It is also reported in literature that more structured management policies can reduce variability and increase predictability, thereby improving operating room efficiency (Sandbaek et al., 2014).

An open question remains whether formalizing proven planning strategies into hospital policies would lead to greater uniformity in OR planning across institutions. However, while standardization can enhance efficiency, variation is not inherently negative. We advocate for well-substantiated variation, ensuring that differences in planning approaches are intentional, evidence-based, and tailored to the specific needs of each hospital rather than resulting from ad hoc decisions or inconsistent practices.

Finally, current planning sometimes overlooks downstream factors, such as recovery room and bed availability, which can result in delays and resource mismatches. The challenge of integrating upstream and downstream scheduling is well-documented in the literature, highlighting the need for comprehensive approaches to address this complexity (Calegari et al., 2020). Incorporating data-driven approaches may offer a potential solution. For instance, Shehadeh & Padman (2022) discuss the modeling of surgery scheduling problems constrained by downstream capacity and propose stochastic optimization methods to improve efficiency.

3.4.2 Emerging trends

Although historical data is routinely collected, its application to improve OR planning remains inconsistent. Capacity centers are emerging as valuable tools for data-driven optimization, but they have not yet been universally adopted. This hesitancy aligns with findings in the literature, which indicate that implementing innovations in hospital settings often fails (Jacobs et al., 2015). This study also revealed that stakeholders value transparency and a clear overview of the processes they are involved in. The lack of such overview may contribute to their reluctance to delegate tasks to data-driven tools. At present, it appears that the primary value of hospital data lies in enhancing transparency for stakeholders rather than automating processes or reducing workloads and responsibilities.

3.4.3 Key recommendations

Based on our findings, we propose three key actions to help hospitals strengthen their OR planning in an ecosystem marked by severe workforce shortages and an increasingly demanding population due to factors such as aging and obesity:

1. *Leverage hospital data to enhance process transparency*; Stakeholders need a clear overview of OR planning processes to foster trust, collaboration, and efficiency. Regular data analysis can support this.
2. *Introduce automation only after transparency is established;* Once processes are well understood, automation – preferably integrated into existing systems like EHRs—can be gradually introduced to optimize OR planning.
3. *Establish clear, written OR planning policies*; While many hospitals possess informal knowledge of effective planning strategies, documenting these guidelines will accelerate the learning curve for new staff, promote accountability, and ensure that all stakeholders – regardless of hierarchy – have a voice. Although deviations from standard regulations will sometimes be necessary, a universally accepted framework will greatly enhance transparency and fairness in OR planning.

By prioritizing these steps, hospitals can build a more resilient and adaptive OR planning system, ensuring both operational efficiency and equitable decision-making.

3.4.4 Limitations

This study included only the process components explicitly mentioned by stakeholders, which may result in some overviews missing certain parts of the planning process if stakeholders did not bring them up. Future research could mitigate this limitation by providing stakeholders with comprehensive overviews of all hospital processes. Such an approach could help stakeholders identify elements they may have overlooked when describing their own planning processes. Additionally, while the overviews aim to provide a complete picture, they lack detail in certain areas, particularly the integration of resource planning and the involvement of hospital departments outside the OR center. These limitations constrain the scope of the findings and their applicability to broader hospital operations.

Furthermore, it is important to acknowledge that the overviews created for this study represent a snapshot of the processes in the interviewed hospitals, as these institutions are continuously evaluating and refining their workflows.

3.5 Conclusions

This study aimed to explore the bottlenecks, current practices, and emerging trends in OR planning. The findings highlight variability in planning approaches across Dutch hospitals, particularly in the number of strategic, tactical, and operational actions and the distribution of responsibilities among stakeholders.

Long-term planning remains a critical bottleneck, with blueprints often issued too late and insufficiently accounting for resource constraints such as staffing shortages. Additionally, enhancing EHR systems to better support centralized OR planning and integrating real-time and historical data are promising strategies for improvement. However, the successful implementation of these technologies requires a structured, stepwise approach.

Emerging trends include the gradual adoption of capacity centers and the potential for data-driven tools to optimize scheduling. However, the current primary value of hospital data may lie in increasing transparency rather than directly automating processes (Figure 9).

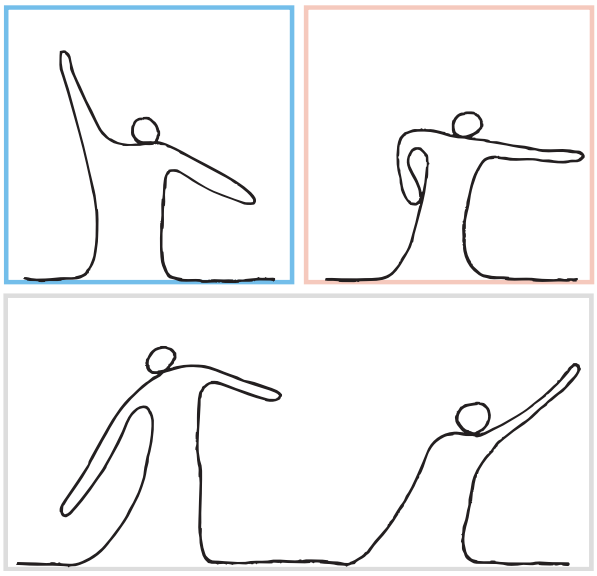


Figure 9 Planning perspectives can point in different directions.

The lack of clarity in data-driven approaches underscores the need for tools that provide stakeholders with a clear understanding of their roles and the broader planning process.

Additionally, a lack of feedback mechanisms and inconsistent adherence to planning rules create inefficiencies, with frequent last-minute changes disrupting workflows. The implementation of clear, universally applied rules and the development of comprehensive OR regulation documents accessible to all stakeholders could improve consistency. However, standardization should not eliminate flexibility—rather, we advocate for well-substantiated variation, ensuring that planning differences across hospitals are intentional and evidence-based, rather than the result of ad hoc decision-making. To strengthen OR planning in an ecosystem marked by workforce shortages and increasing patient demand, hospitals should focus on three key recommendations:

1. *Leverage hospital data to enhance process transparency*; Stakeholders need a clear overview of OR planning processes to foster trust, collaboration, and efficiency. Regular data analysis can support this.
2. *Introduce automation only after transparency is established;* Once processes are well understood, automation – preferably integrated into existing systems like EHRs—can be gradually introduced to optimize OR planning.
3. *Establish clear, written OR planning policies*; While many hospitals possess informal knowledge of effective planning strategies, documenting these guidelines will accelerate the learning curve for new staff, promote accountability, and ensure that all stakeholders – regardless of hierarchy – have a voice. Although deviations from standard regulations will sometimes be necessary, a universally accepted framework will greatly enhance transparency and fairness in OR planning.

Addressing these challenges and bottlenecks requires a comprehensive and phased approach that prioritizes transparency, structured automation, and clear policy frameworks. By implementing these steps, hospitals can improve efficiency, reduce bottlenecks, ultimately creating a more resilient and adaptive OR planning system.

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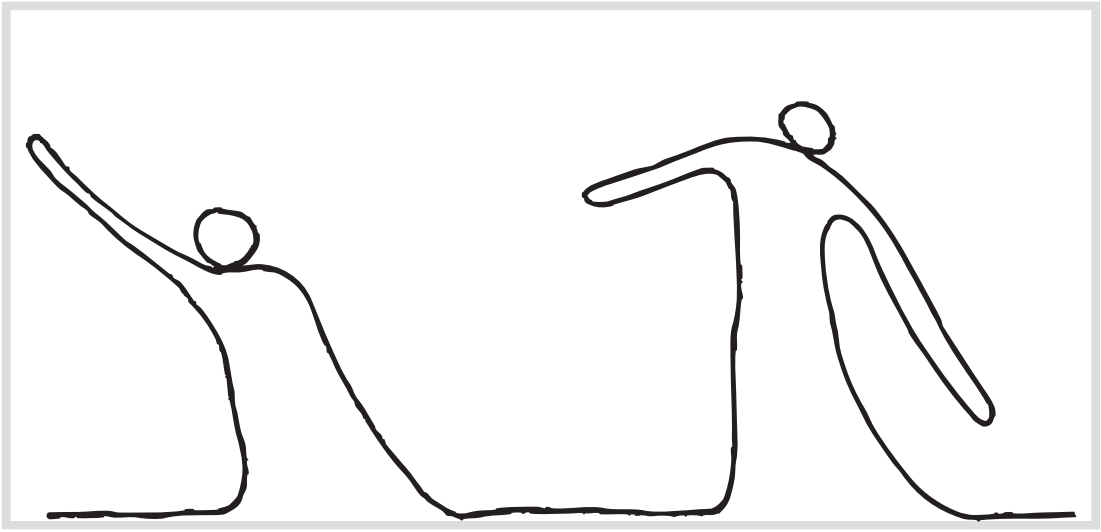
References

1. Al Amin, M., Baldacci, R., & Kayvanfar, V. (2025). A comprehensive review on operating room scheduling and optimization. Operational Research, 25(1), 3. https://doi.org/10.1007/s12351-024-00884-z
2. Bellini, V., Russo, M., Domenichetti, T., Panizzi, M., Allai, S., & Bignami, E. G. (2024). Artificial Intelligence in Operating Room Management. Journal of Medical Systems, 48(1), 19. https://doi.org/10.1007/s10916-024-02038-2
3. Calegari, R., Fogliatto, F. S., Lucini, F. R., Anzanello, M. J., & Schaan, B. D. (2020). Surgery scheduling heuristic considering OR downstream and upstream facilities and resources. BMC Health Services Research, 20(1), 684. https://doi.org/10.1186/s12913-020-05555-1
4. 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
5. Dios, M., Molina-Pariente, J. M., Fernandez-Viagas, V., Andrade-Pineda, J. L., & Framinan, J. M. (2015). A Decision Support System for Operating Room scheduling. Computers & Industrial Engineering, 88, 430–443. https://doi.org/10.1016/j.cie.2015.08.001
6. Fei, H., Meskens, N., & Chu, C. (2010). A planning and scheduling problem for an operating theatre using an open scheduling strategy. Computers and Industrial Engineering, 58(2), 221–230. https://doi.org/10.1016/j.cie.2009.02.012
7. Glouberman, S., & Mintzberg, H. (2001). Managing the Care of Health and the Cure of Disease—Part I: Differentiation. Health Care Management Review , 26, 56–69.
8. Hans, E. W., Herroelen, W., Leus, R., & Wullink, G. (2007). A hierarchical approach to multi-project planning under uncertainty. Omega, 35(5), 563–577. https://doi.org/10.1016/j.omega.2005.10.004
9. Harris, S., & Claudio, D. (2022a). Current Trends in Operating Room Scheduling 2015 to 2020: a Literature Review. Operations Research Forum, 3(1), 21. https://doi.org/10.1007/s43069-022-00134-y
10. Harris, S., & Claudio, D. (2022b). Current Trends in Operating Room Scheduling 2015 to 2020: a Literature Review. Operations Research Forum, 3(1), 21. https://doi.org/10.1007/s43069-022-00134-y
11. Hollnagel, E. (2017). FRAM: The Functional Resonance Analysis Method. CRC Press. https://doi.org/10.1201/9781315255071
12. Hulshof, P. J. H., Kortbeek, N., Boucherie, R. J., Hans, E. W., & Bakker, P. J. M. (2012). Taxonomic classification of planning decisions in health care: a structured review of the state of the art in OR/MS. Health Systems, 1(2), 129–175. https://doi.org/10.1057/hs.2012.18
13. Hwang, H., & Barton, A. (2016). Computer randomized scheduling for general surgery: a novel tool for resource sharing at two regional hospitals in British Columbia. BCMJ, 58, 19–24.
14. Jacobs, S. R., Weiner, B. J., Reeve, B. B., Hofmann, D. A., Christian, M., & Weinberger, M. (2015). Determining the predictors of innovation implementation in healthcare: a quantitative analysis of implementation effectiveness. BMC Health Services Research, 15(1), 6. https://doi.org/10.1186/s12913-014-0657-3
15. Kim, S.-H., Whitt, W., & Cha, W. C. (2018). A Data-Driven Model of an Appointment-Generated Arrival Process at an Outpatient Clinic. INFORMS Journal on Computing, 30(1), 181–199. https://doi.org/10.1287/ijoc.2017.0773
16. Koushan, M., Wood, L. C., & Greatbanks, R. (2021). Evaluating factors associated with

the cancellation and delay of elective surgical procedures: a systematic review. International Journal for Quality in Health Care, 33(2). https://doi.org/10.1093/intqhc/mzab092
17. Lee, D. J., Ding, J., & Guzzo, T. J. (2019). Improving Operating Room Efficiency. Current Urology Reports, 20(6), 28. https://doi.org/10.1007/s11934-019-0895-3
18. Nguyen, K.-H., Wright, C., Simpson, D., Woods, L., Comans, T., & Sullivan, C. (2022). Economic evaluation and analyses of hospital-based electronic medical records (EMRs): a scoping review of international literature. Npj Digital Medicine, 5(1), 29. https://doi.org/10.1038/s41746-022-00565-1
19. Oliveira, M., Bélanger, V., Ruiz, A., & Santos, D. (2023). A systematic literature review on the utilization of extended operating room hours to reduce surgical backlogs. Frontiers in Public Health, 11. https://doi.org/10.3389/fpubh.2023.1118072
20. Omaghomi, T. T., Oluwafunmi Adijat Elufioye, Jane Osareme Ogugua, Andrew Ifesinachi Daraojimba, & Opeoluwa Akomolafe. (2024). INNOVATIONS IN HOSPITAL MANAGEMENT: A REVIEW. International Medical Science Research Journal, 4(2), 224–234. https://doi.org/10.51594/imsrj.v4i2.820
21. Pasquer, A., Ducarroz, S., Lifante, J. C., Skinner, S., Poncet, G., & Duclos, A. (2024). Operating room organization and surgical performance: a systematic review. Patient Safety in Surgery, 18(1), 5. https://doi.org/10.1186/s13037-023-00388-3
22. Rahimi, I., & Gandomi, A. H. (2021). A Comprehensive Review and Analysis of Operating Room and Surgery Scheduling. Archives of Computational Methods in Engineering, 28(3), 1667–1688. https://doi.org/10.1007/s11831-020-09432-2
23. Rais, A., & Vianaa, A. (2011). Operations research in healthcare: A survey. International Transactions in Operational Research, 18(1), 1–31. https://doi.org/10.1111/j.1475-3995.2010.00767.x
24. Riise, A., Mannino, C., & Burke, E. K. (2016). Modelling and solving generalised operational surgery scheduling problems. Computers & Operations Research, 66, 1–11. https://doi.org/10.1016/j.cor.2015.07.003
25. Rowse, E. L., Lewis, R., Harper, P. R., & Thompson, J. M. (2015). Applying set partitioning methods in the construction of operating theater schedules.
26. Samudra, M., Van Riet, C., Demeulemeester, E., Cardoen, B., Vansteenkiste, N., & Rademakers, F. E. (2016). Scheduling operating rooms: achievements, challenges and pitfalls. Journal of Scheduling, 19(5), 493–525. https://doi.org/10.1007/s10951-016-0489-6
27. Sandbaek, B. E., Helgheim, B. I., Larsen, O. I., & Fasting, S. (2014). Impact of changed management policies on operating room efficiency. BMC Health Services Research, 14(1), 224. https://doi.org/10.1186/1472-6963-14-224
28. Schouten, A. M., Flipse, S. M., van Nieuwenhuizen, K. E., Jansen, F. W., van der Eijk, A. C., & van den Dobbelsteen, J. J. (2023). Operating Room Performance Optimization Metrics: a Systematic Review. In Journal of Medical Systems (Vol. 47, Issue 1). Springer. https://doi.org/10.1007/s10916-023-01912-9
29. Shaikh, M., Vayani, A. H., Akram, S., & Qamar, N. (2022). Open-source electronic health record systems: A systematic review of most recent advances. Health Informatics Journal, 28(2). https://doi.org/10.1177/14604582221099828
30. Shehadeh, K. S., & Padman, R. (2022). Stochastic optimization approaches for elective surgery scheduling with downstream capacity constraints: Models, challenges, and opportunities. Computers & Operations Research, 137, 105523. https://doi.org/10.1016/j.cor.2021.105523
31. Tong, A., Sainsbury, P., & Craig, J. (2007). Consolidated criteria for reporting qualitative research (COREQ): a 32-item checklist for interviews and focus groups. Internation-

al Journal for Quality in Health Care, 19(6), 349–357. https://doi.org/10.1093/intqhc/mzm042
32. Toub, M., Souissi, O., & Achchab, S. (2022). Operating room scheduling 2019 survey. In Int. J. Medical Engineering and Informatics (Vol. 14, Issue 1).
33. van Veen-Berkx, E., Bitter, J., Kazemier, G., Scheffer, G. J., & Gooszen, H. G. (2015). Multidisciplinary Teamwork Improves Use of the Operating Room: A Multicenter Study. Journal of the American College of Surgeons, 220(6), 1070–1076. https://doi.org/10.1016/j.jamcollsurg.2015.02.012
34. Visintin, F., Cappanera, P., Banditori, C., & Danese, P. (2017). Development and implementation of an operating room scheduling tool: an action research study. Production Planning & Control, 28(9), 758–775. https://doi.org/10.1080/09537287.2017.1310328
35. Zenteno, A. C., Carnes, T., Levi, R., Daily, B. J., & Dunn, P. F. (2016). Systematic OR Block Allocation at a Large Academic Medical Center. Annals of Surgery, 264(6), 973–981. https://doi.org/10.1097/SLA.0000000000001560
36. Zenteno, A. C., Carnes, T., Levi, R., Daily, B. J., Price, D., Moss, S. C., & Dunn, P. F. (2015). Pooled Open Blocks Shorten Wait Times for Nonelective Surgical Cases. Annals of Surgery, 262(1), 60–67. https://doi.org/10.1097/SLA.0000000000001003
37. Zhu, S., Fan, W., Yang, S., Pei, J., & Pardalos, P. M. (2019a). Operating room planning and surgical case scheduling: a review of literature. Journal of Combinatorial Optimization, 37(3), 757–805. https://doi.org/10.1007/s10878-018-0322-6
38. Zhu, S., Fan, W., Yang, S., Pei, J., & Pardalos, P. M. (2019b). Operating room planning and surgical case scheduling: a review of literature. Journal of Combinatorial Optimization, 37(3), 757–805. https://doi.org/10.1007/s10878-018-0322-6



IV

OPUS II

Operating Room Planning and Utilization Strategies in a Top Clinical Center: A Comparative Case Study with University Medical Centers

To develop broadly applicable operating room (OR) planning strategies, a clear understanding of current practices is essential. Building on our previous OPUS I study, which mapped OR planning processes, bottlenecks, and best practices across all seven Dutch University Medical Centers (UMCs), this study examines OR planning in a Top Clinical Center (TCC) to explore how it is organized and how it compares to UMCs. We analyzed contextual data on the TCC and UMCs, created a generalized OR planning overview for UMCs from OPUS I interviews, and conducted seven stakeholder interviews at the TCC to map its planning process and gather improvement suggestions. The results show both similarities and differences between the TCC and UMCs, with the TCC following a more structured, recurring planning cycle. Stakeholders at the TCC prioritized improvements in communication, timely access to information, and data-driven feedback—mirroring preferences seen in UMCs. While planning strategies such as transparency, clarified responsibilities, and data use appear broadly relevant, successful implementation depends on alignment with local factors like organizational size, governance, and team structure.

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4.1 Introduction

Operating room (OR) planning strategies have been widely explored within the field of operations research, with a strong emphasis on the use of computational modeling (Cardoen et al., 2010; Schouten et al., 2023). Still, such research has had limited impact on improving OR scheduling in real-world hospital settings (Zhu et al., 2019): Harris & Claudio (2022) note an increasing trend of using real-life data to test OR planning models, but studies focusing on the actual application of these strategies in practice remain scarce. Additionally, Samudra et al. (2016) highlight that many OR planning models are tailored to specific cases, limiting their broader applicability. They argue that developing generalizable strategies could enhance the implementation of research findings in hospital practice. To support this, they recommend first gaining a comprehensive understanding of how OR planning is currently conducted in hospitals, as a foundation for creating models that are more widely applicable.

The Dutch healthcare system comprises three main types of hospitals: UMCs, general hospitals and specialized hospitals (Kroneman et al., 2016). UMCs are large, publicly funded institutions affiliated with universities, responsible for delivering highly specialized care alongside education and research. They function as tertiary referral centers and cover a wide range of medical disciplines. General hospitals provide a broad spectrum of secondary care and are typically structured around partnerships of self-employed physicians. A separate category within the general hospitals is the 'Samenwerkende Topklinische Ziekenhuizen (STZ)', which are top clinical centers (TCC) that provide both regular referral care and highly specialized care. Specialized hospitals —also known as focus clinics or categorical hospitals—concentrate on specific areas of care, such as oncology or orthopedics, and generally operate on a smaller scale. These hospital types differ in funding models, organizational structure, patient case-mix, and scale. As a result, planning strategies developed within UMCs may not be directly transferable to other hospital contexts.

Although previous research aimed at improving operating room processes in UMCs often acknowledges that interventions may not be generalizable to other hospital settings, it rarely examines the organizational factors that could influence this generalizability or hinder successful implementation—whether in other UMCs or different types of institutions (Chohan et al., 2022; Ellis et al., 2020;

Kubala et al., 2021; Schmitt et al., 2022; Singh et al., 2023). A systematic review by Pasquer et al. (2024) highlighted the limited research on how organizational determinants affect operative performance more broadly. As a result, there remains a gap in understanding which organizational factors should be considered when implementing OR planning strategies into everyday hospital practice. Contributing to this effort, our previous study (Schouten et al., 2025) provided an observational analysis of OR planning practices in the seven University Medical Centers (UMCs) in the Netherlands, which offered insights into planning in academic hospital settings. In this study we provided an overview of operating room planning practices within the UMCs in the Netherlands and offered recommendations to enhance their planning strategies. However, due to structural and organizational differences between UMCs and other types of hospitals, this perspective may present a one-sided view of OR planning within the broader Dutch healthcare system.

The current study aims to investigate the OR planning practices in a TCC hospital, to gain insight into how OR planning is organized in this organizational context and to explore how these practices compare to those observed in Dutch University Medical Centers. We replicate the study protocol from OPUS I in the current study: OPUS II. We first describe the organizational structures of both the UMCs and the selected case hospital. Next, we summarize OR planning strategies commonly observed in UMCs. We then conduct a case study in which key stakeholders involved in OR planning at the Top-clinical center are interviewed to construct a detailed overview of their planning processes. This overview, along with their planning priorities and optimization preferences, is subsequently compared to the findings from OPUS I to assess alignment and contextual differences.

4.2 Method

To develop an overview of the organizational structure surrounding surgery planning, we collected and analyzed data on financial resources, physical capacity, and patient case-mix characteristics of both the TCC and UMCs. Additionally, we conducted seven stakeholder interviews at the TCC to map the surgery planning process. This methodology was designed in line with the Consolidated Criteria for Reporting Qualitative Research (COREQ) checklist (Tong et al., 2007).

4.2.1 Study design

The study design for OPUS II consisted of three main components:

1. *Organizational context analysis:* We collected information on the organizational structure of both the UMCs and the selected Top-clinical center. This included financial and physical infrastructure aspects, as well as patient case-mix characteristics. Data for the UMCs were gathered in consultation with an OR manager representative, providing a high-level overview of typical structures and practices across the seven UMCs.
2. *Generalized OR planning process in UMCs:* We constructed a generalized overview of OR planning in Dutch UMCs by continuing the analysis from OPUS I. Planning process overviews developed for that study were compared, and recurring actions observed in three or more hospitals were included in a consolidated overview. Each action was assigned to the actor most commonly responsible for it, and the sequence of actions was determined accordingly. The result is a representative model of OR planning in UMCs, serving as a benchmark for comparison with the Top-clinical center.
3. *Case study in a TCC hospital:* A follow-up case study was conducted in a TCC hospital to map its OR planning processes. This involved interviews with eight key stakeholders involved in OR planning, aimed at gaining detailed insights into their organizational structure, planning approach, priorities, and preferences. The findings were then compared to the generalized UMC model to identify similarities and contextual differences.

The interview approach replicates the methodology used in a previous study (Schouten et al., 2025) using an adaption of the Functional Resonance Analysis Method (FRAM) model (Hollnagel, 2017) with the positioning framework of Hans et al., 2007. In this study, interviewees were selected from key stakeholder groups involved in OR planning within the TCC hospital. They were asked to describe their own actions, responsibilities, and interactions with colleagues throughout the OR planning process. To support this, participants were guided by a blank timeline-based template featuring stakeholder-specific swimming lanes, covering the planning period from one year before surgery up to the day of the procedure. In addition to mapping the planning process, participants were asked to reflect on current bottlenecks and suggest interventions they would prefer to see implemented to improve the OR planning workflow.

Case selection

The TCC hospital was selected based on the level of comparability with the UMCs in terms of surgical diversity—including both inpatient and outpatient care, as well as a mix of elective and emergency procedures—while operating under a different governance and funding structure. Unlike UMCs, it is not directly affiliated with a university, its physicians are largely self-employed, and it is not designated as a level-one trauma center. These characteristics allow for a meaningful comparison with UMCs while reflecting a distinct hospital type. Moreover, the hospital serves as a representative example of top-clinical centers in the Netherlands, many of which share similar features: a strong regional function, a focus on specific patient populations, and organizational models that emphasize operational efficiency over academic mandates. As such, this case provides valuable insight into whether and how OR planning strategies from academic contexts can be applied more broadly.

Participant selection

A total of eight stakeholders involved in the OR planning process were interviewed for this study. Participants were selected based on their direct involvement in shaping the OR planning outcomes or in coordinating the deployment of OR personnel, including surgeons, anesthetic nurses, and operating room assistants. Individuals responsible for planning related to intensive care unit (ICU) staff, inpatient wards, outpatient clinics, or medical materials were excluded, as their roles were considered peripheral to the core OR planning process under investigation. Participants were identified in collaboration with the hospital's OR management and were contacted individually via email with an invitation to participate in the study.

Interview protocol

The study was conducted at a TCC hospital in the Netherlands and included two rounds of semi-structured interviews with key stakeholders involved in OR planning. The first round took place on-site at the hospital, with both researchers and the interviewee present. During these sessions, participants engaged with a visual planning overview and provided insights into their roles and responsibilities. The second round of interviews was conducted remotely via Microsoft Teams to allow for follow-up questions and refinement of earlier input. All participants provided written informed consent. No audio recordings were made.

Consistent with the approach used in the previous OPUS I study, data collection in this follow-up study (OPUS II) consisted of three phases:

1. *Initial interviews with open structure:* in this phase, stakeholders were guided through an open discussion of their involvement in OR planning using a blank template featuring stakeholder-specific swimming lanes and a planning timeline. Unlike the previous study, where a hospital policy document was used to construct an initial draft, no such document was used here due to ongoing revisions that would have misrepresented actual practice.
2. *Draft overview development and feedback:* based on the first-round interviews, a draft planning overview was constructed. This draft was then discussed in the second round of interviews, during which participants reviewed the proposed representation and suggested changes. These suggestions were incorporated into the revised version.
3. *Final validation:* The updated overview was sent to participants via email for a final accuracy check.

Throughout the process, the first researcher documented participants' input directly on the overview template during the interviews, while the second researcher took complementary field notes. These field notes were used to verify the primary notes and to compile participant *"wish lists"* for improving OR planning.

4.2.2 Analysis and findings

To compare the number of actions by planning level and stakeholder, the overviews of both the UMCs and the TCC hospital were digitized using Microsoft Excel 2024 (Microsoft Corp.). A general overview of the most common actions across UMCs was then created. Actions from all UMCs were compiled into a single Excel sheet, and overlapping actions were identified based on content. Actions appearing in three or more UMCs were included in the general overview. Each action was placed on the timeline according to the product it contributed to (e.g., the annual blueprint) and its typical sequence. The stakeholder responsible for each action was determined by frequency; in cases of a tie, the stakeholder most commonly reported to by the others was assigned. The TCC hospital was excluded from the construction of this general UMC overview.

Stakeholder suggestions for improving the OR planning process – referred to as *"wishes"* – were gathered during the interviews and recorded in Microsoft Excel 2024. Each wish reflected a specific intervention or proposed change. Two researchers independently reviewed and categorized the wishes. Initially, these were matched to a predefined set of categories derived from themes emerging during data collection. If a wish did not align with an existing category, a new category was created through researcher consensus.

4.3 Results

This section presents the organizational context of the UMCs and the TCC hospital, an overview of the interviewed stakeholders, and a description of the OR planning processes.

4.3.1 Organizational Context: UMCs vs. the Top Clinical Center

UMCs differ from other hospital types, including TCC hospitals, in several key organizational aspects (Kroneman et al., 2016; RIVM, 2024). Table 1 compares these dimensions, highlighting financial structures, physical infrastructure, and patient case-mix characteristics.

Financially, the TCC hospital derives 93% of its revenue from healthcare services, compared to 68% in UMCs. UMCs receive a significantly larger portion of funding from government contributions—23% versus only 4% in the TCC hospital. This difference reflects the UMCs' dual role in both healthcare delivery and academic research and education. UMCs also access more diverse funding sources, with 8% coming from other programs, compared to 3% in the TCC hospital (Rathenau Institute, 2022).In terms of infrastructure, UMCs operate on a larger scale. The case hospital has 10 ORs, while UMCs range from 20 to 45 ORs per hospital. Bed capacity also differs substantially: the TCC hospital has 475 beds, while UMCs range from 532 to 1,125 beds. Notably, the TCC hospital does not have a dedicated emergency OR, whereas UMCs typically allocate specific ORs and time slots for emergency procedures (Interviews OPUS I).

The patient case-mix further illustrates these structural differences. UMCs provide a much higher proportion of highly specialized referral care—45.1% compared to 21.5% in the TCC hospital. Conversely, the TCC hospital handles a larger share of regular referral care (78.5%) than UMCs (54.9%). This aligns with the broad-

er role UMCs play in managing complex cases and operating as tertiary referral centers. Moreover, seven out of the ten level-one trauma centers in the Netherlands are located within UMCs, underlining their responsibility for high-acuity emergency care.

Table 1 Organizational context of the UMCs vs. the TCC.

Organizational aspect	TCC hospital	UMCs	Reference(s)
Financial aspects			
% Revenue from healthcare services	93%	68%	Annual account case hospital (2020); Rathenau Institute (2022
% Government contributions (R&E)	4%	23%	Annual account case hospital (2020); Rathenau Institute (2022
% Other funding programs	3%	8%	Annual account case hospital (2020); Rathenau Institute (2022
Physical infrastructure			
Number of ORs, incl. day treatment ORs	10	20 - 45	Rathenau Institute (2022)
Number of dedicated emergency ORs	0, With dedicated timeslots	0 - 2	Interviews OPUS I (Schouten et al., 2025) and current study
Number of Beds	475	532* - 1125	Rathenau Institute (2022)
Patient case-mix			
% Highly specialized referral care	21,5%	45,1%	NZA (2022), using ROBIJN method and DBC data
% Regular referral care	78,5%**	54,9%	NZA (2022), using ROBIJN method and DBC data

* Data from 2017 due to missing 2019 figures for some UMCs.
** For comparison: General hospitals typically treat 80.3% regular referral care and 19.7% highly specialized care, placing TCC hospitals closer to general hospitals than to UMCs. The ROBIJN method used to determine case-mix is not 100% accurate (NZA, 2022).

4.3.2 Overview of participants and their context in the hospital

Table 2 provides an overview of the stakeholders interviewed in this study, along with the specific roles they performed in the OR planning process.

Table 2 Organizational context of the UMCs vs. the TCC.

Role in hospital	Description	n UMCs	n TCC
Operating Room manager	Oversees the entire OR center.	7	1
Medical coordinator	Typically an anesthesiologist, responsible for coordinating surgeries on the scheduled day alongside the program coordinator. Together, they manage emergency surgeries, delays, and other issues. The medical coordinator is accountable for medical decisions.	8	0
Program coordinator	Usually an OR nurse who takes on this role a few days a week. Works with the medical coordinator to manage emergencies, delays, and schedule gaps caused by staffing shortages.	7	0
Operating Room team leader	Leads the team of OR nurses.	7	1
Planning office	Each medical specialty generally has its own office responsible for scheduling patients. In some cases, one office may handle scheduling for multiple specialties.	5	1
Medical specialist	Often, a lead medical specialist is responsible for overseeing the planning aspects for their specialty.	5	1
Capacity center	Develops an annual budget cycle that includes financial, production, and capacity planning. This cycle determines the patient care to be provided by the hospital and the required capacity.	7	1
Board of directors	Responsible for overseeing the organization's overall strategic direction, ensuring high standards of patient care, financial stability, and regulatory compliance.	1	0
Senior planner/ Project leader	Responsible for the distribution budgeted surgery hours across specific ORs and days.	3	1
Staff planner	Develops staff planning for OR nurses and anesthesia nurses.	4	1

In addition to differences in funding, infrastructure, and patient case-mix, the TCC hospital also differs from UMCs in its internal organizational structure. In the case hospital, the roles of program coordinator and OR staff planner are combined and performed by a single individual, whereas these functions are typically separated in UMCs. Moreover, the hospital does not employ a senior planner; instead, a project leader has been responsible for optimizing the OR planning process and has developed the baseline OR blueprint for the coming years. The organization of OR assistants also varies: in the TCC hospital, assistants are part of dedicated teams and commonly work with the same surgeons, fostering stable team dynamics. In contrast, UMCs organize their assistants into units based on expertise, allowing for more flexible deployment across surgical teams. Finally, while UMCs often assign an anesthesiologist to act as a medical coordinator within the OR planning team, this role is absent in the TCC hospital. Instead, an anesthesiologist is appointed to oversee the emergency OR schedule on a daily basis.

4.3.3 Overview of OR Planning in the TCC hospital

This section outlines the OR planning structure of the TCC hospital and highlights key similarities and differences compared to typical UMC practices. A general overview of the UMC strategies is provided in Appendix 4.1, with the TCC overview in Appendix 4.2.

Strategic level

In the TCC hospital, the OR planning process begins with the finance department—under the responsibility of the board of directors—negotiating with health insurers to establish treatment volumes per Diagnosis and Treatment Code (DTC). In parallel, medical departments define their own business strategies, which are then discussed during portfolio meetings. Each DTC is linked to a pre-determined surgical time. Based on these values, the capacity center calculates the total required OR hours per specialty. Unlike UMCs, where OR management typically leads the blueprint development, the TCC hospital creates the OR blueprint—organized as a recurring four-week cycle—in tandem with budget planning. The calculated hours and proposed blueprint are finalized in a budget approval meeting in September, involving medical department representatives, the finance department, and the board of directors.

Tactical level

The strategic planning outcomes are further reviewed in monthly Strategic Planning Meetings (SPMs), where stakeholders including the board of directors, OR management, the capacity center, care unit leaders, medical specialists, and finance managers discuss and align on capacity. Staffing availability is checked during a separate roster meeting attended by an anesthesiologist, an OR assistant, and an anesthetic nurse. This information feeds into the Tactical Planning Meeting (TPM), where participants evaluate and, if necessary, adjust the blueprint for the upcoming three months. Changes—such as reallocating flexible ORs—are implemented by a planner from the admissions office and shared with departments in Excel format. At the tactical level, strategies varied among the UMCs, with each institution adopting its own approach. The TCC hospital also employed a distinct strategy, characterized by a structured and recurring tactical planning cycle, which contrasts with the less standardized coordination typically seen at the tactical level in UMCs.

Offline operational level

Medical departments distribute their allocated hours from the blueprint among sub-specialties and coordinate internally with physicians and outpatient schedules. They return this information to the admissions office, where a planner finalizes and enters it into the Electronic Health Record (EHR). From there, patient scheduling proceeds based on waiting lists, typically involving collaboration between medical specialists and the OR day coordinator. In parallel, OR staff planners develop the duty roster for OR personnel. The day before surgery, the coordinator finalizes the surgery order and confirms that all preoperative screenings (POS) are completed.Weekly planning is evaluated during dedicated meetings led by the planning office. Unlike in UMCs, no formal multidisciplinary meetings were reported. However, bi-weekly planning meetings with the planning office play a role in coordination.

Online operational level

Daily coordination in the TCC hospital is highly pragmatic. Surgeons consult with each other and with the admissions office at fixed times during the day to schedule emergency cases. When an emergency arises, the medical specialist informs the anesthesiologist and OR day coordinator, who adjust the schedule accordingly. Additionally, the OR schedule is reviewed daily for accuracy.

The hospital proactively reserves designated emergency time slots. Some specialties maintain 'white spots'—unfilled blocks used for potential emergency cases. Once an elective patient is scheduled, it is uncommon for the case to be rescheduled, contrasting with more dynamic adjustments seen in UMC settings.

4.3.4 Differences in OR planning between UMCs and the TCC

Figure 1 presents the number of actions observed at each planning level across the participating hospitals. The TCC hospital ("Case") shows a distinct distribution of planning activities: 10 actions at the strategic level, 2 at the tactical level, 4 at the offline operational level, and 6 at the online operational level. While the number of strategic actions aligns closely with many UMCs (e.g., Hospitals 4 and 8 also score 10), the TCC hospital performs fewer tactical and offline operational actions than most. For example, Hospitals 2 and 4 each perform 7 actions at the tactical level, and Hospital 3 performs 9 at the offline operational level—substantially more than the 2 and 4 actions observed respectively in the TCC hospital.

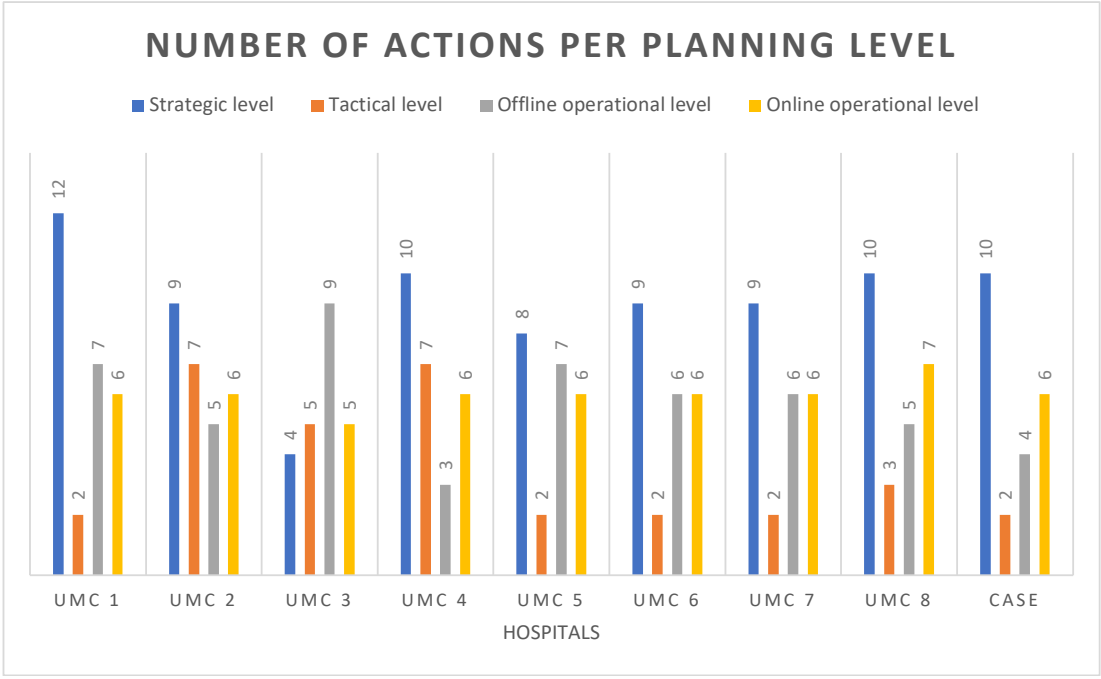


Figure 1 Distribution of OR planning actions across organizational levels in UMCs and the TCC hospital.

Unlike some UMCs, such as Hospital 4, which offsets fewer operational actions (3) with a high number of tactical actions (7), the TCC hospital does not show this type of balancing across planning levels. Instead, its activity is concentrated at the strategic and online operational levels, with limited involvement in the intermediate planning layers. This suggests a top-down, streamlined planning approach in the TCC hospital, possibly reflecting a more centralized structure with fewer layers of coordination. While this may support efficiency and rapid decision-making, it could also limit flexibility and adaptability in day-to-day scheduling compared to the more distributed processes seen in UMCs.

Figure 2 displays the number of actions performed per stakeholder across hospitals. In the TCC hospital (*"Case"*), the planning office (5 actions), medical specialists (5), and the capacity center (4) take on a prominent share of responsibilities in the OR planning process.

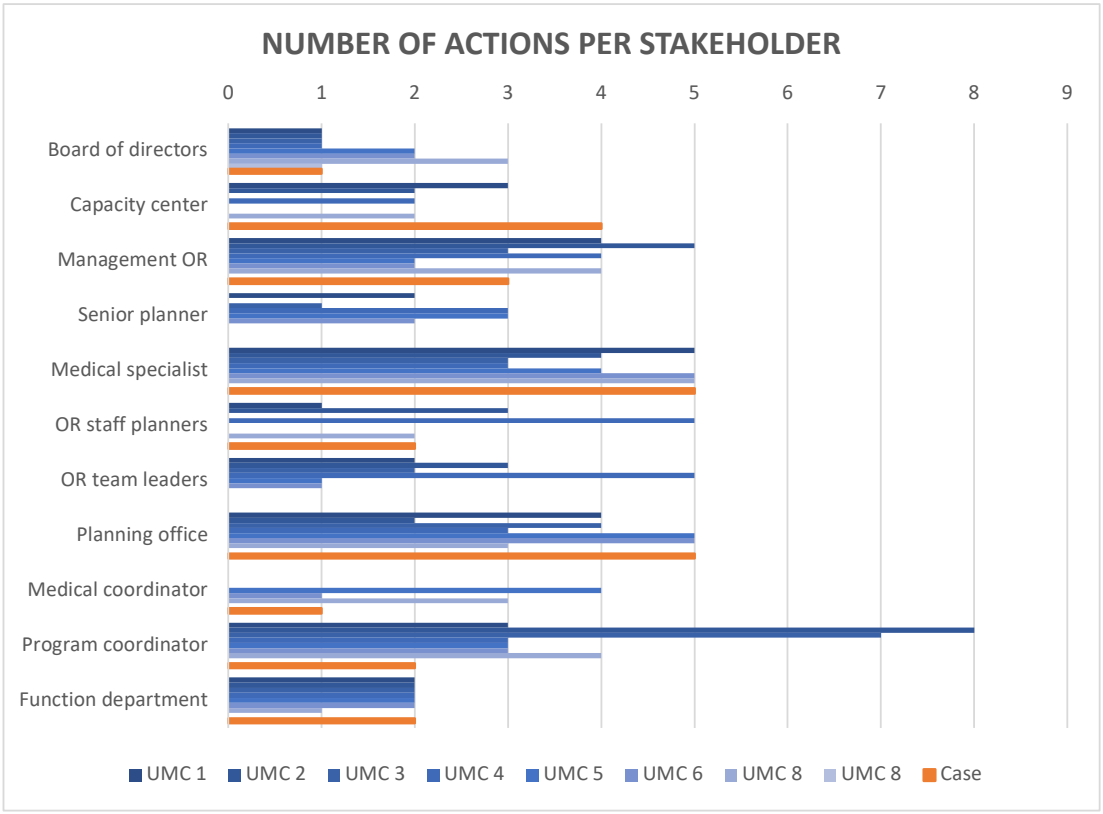


Figure 2 Number of Actions per stakeholder in UMCs and the TCC hospital.

The capacity center appears to assume tasks that in many UMCs would be performed by a senior planner—a role that is entirely absent in the TCC hospital (0 actions). In contrast to several UMCs where the program coordinator plays a substantial role—such as Hospital 2 (8 actions) and Hospital 3 (7 actions)—the TCC hospital's program coordinator is involved to a lesser extent (2 actions), and primarily in a consultative capacity. Similarly, the medical coordinator performs only 1 action in the TCC hospital, with limited involvement compared to, for example, Hospital 5 (4 actions) and Hospital 8 (3 actions).

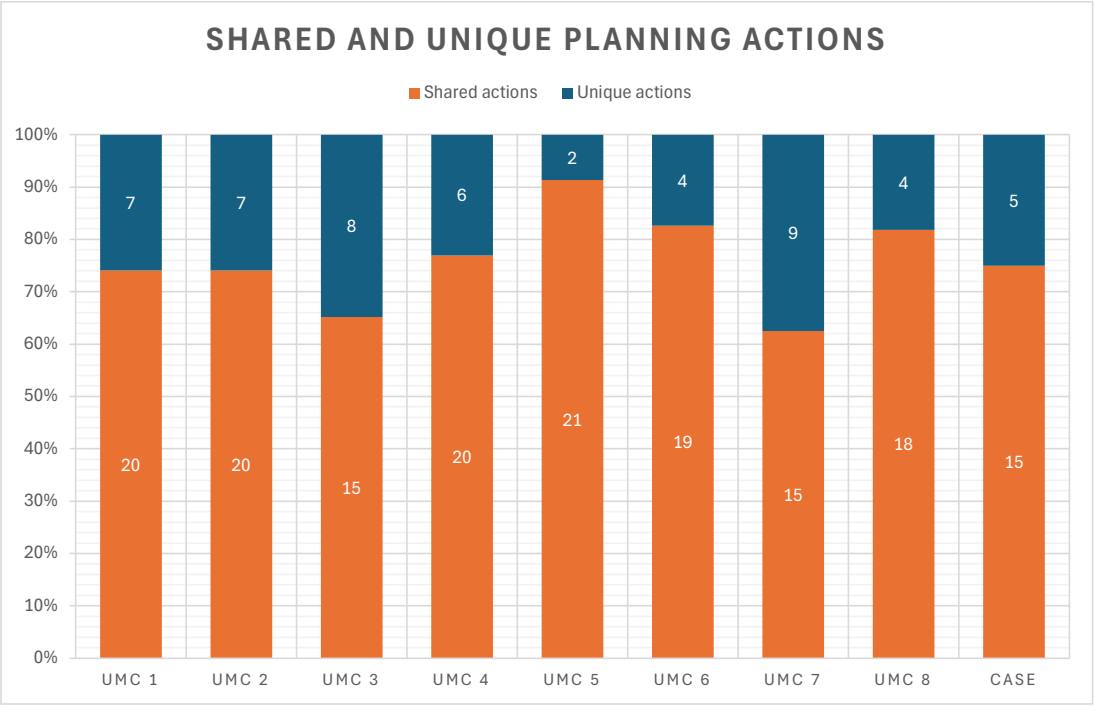


Figure 3 Proportion of shared (orange) and unique (blue) planning actions per hospital. Actions were defined as shared when they were reported by at least three UMCs. Bars are normalized to 100% to highlight differences in relative shares across the eight UMCs and the case hospital (TCC).

Most actions at the offline operational level are concentrated within the planning office in the TCC hospital. The OR staff planners contribute to 2 actions, whereas in many UMCs this role is minimal or absent altogether. Meanwhile, OR team leaders are not actively involved in the case hospital, although they perform up to 5 actions in other hospitals (e.g., Hospital 4). Overall, this distribution highlights a more centralized approach in the TCC hospital, with greater reliance on a few key roles—particularly the planning office and capacity center—and fewer distributed responsibilities across planning stakeholders compared to UMCs.

Figure 3 compares the proportion of shared versus unique planning actions across the eight UMCs and the TCC case hospital. Actions were defined as shared when they were reported by at least three UMCs. The stacked bars are normalized to 100%, allowing direct comparison of relative shares between hospitals. UMC 5 shows the highest proportion of shared actions—90.5% of its actions are shared (21 shared, 2 unique)—followed by UMC 6 (82.6%, 19 shared, 4 unique). UMC 7 has the lowest proportion of shared actions at 62.5% (15 shared, 9 unique). The case hospital reports a total of 20 actions, of which 75% (15 actions) are shared and 5 are unique. While the case hospital's total number of actions (20) is slightly lower than that of most UMCs (22–27 actions), its relative proportion of shared actions is comparable to the UMCs (75% vs 62,5–90,5%). No clear pattern emerges that links the proportion of shared actions to hospital size, region, or workflow style; the variation appears mainly related to differences in the total number of actions recorded in each hospital.

Out of the 27 unique planning actions identified across all hospitals, 11 are shared by six or more UMCs, indicating a high degree of consistency for these tasks. The TCC hospital performs all 11 of these most common actions, though with one structural difference: the action "Develop decentral weekly planning" is centralized in the TCC hospital rather than handled by individual departments. These frequently shared actions are most often situated at the strategic level (5 actions), followed by the online operational level (3), and the offline operational level (2). The tactical level contains no actions that are shared by three or more UMCs, reinforcing earlier findings that tactical-level planning is the least standardized and involves the fewest distinct actions across hospitals.

4.3.5 Stakeholder preferences for improving OR planning

During the interviews, stakeholders from the TCC hospital shared a range of preferences and ideas for improving the surgery planning process. These suggestions reflect both strategic and operational considerations and highlight opportunities to optimize coordination, timing, and the use of data within the hospital's current planning structure.

A recurring theme was the ongoing revision of the OR planning process, which was actively underway at the time of the interviews. The project leader had already implemented changes up to the integration of the OR blueprint, and stakeholders expressed the wish to further evolve this process. A key preference was to assign blueprint construction to the planning office, clarifying responsibilities and streamlining the process. The next intended phase of the revision will focus on optimizing planning activities at the operational level. Many stakeholders emphasized the importance of data-driven feedback loops. One interviewee proposed the development of a dashboard with key performance indicators (KPIs), such as metrics on the timeliness of surgeries. Another participant supported this idea and recommended integrating such feedback into the Tactical Planning Meetings to inform forward-looking decisions.

Improving communication and coordination protocols across departments also emerged as a priority. Stakeholders expressed a need for clear procedural rules outlining: (1) how and when patients should be entered into the Electronic Health Record, (2) how changes to the OR schedule should be communicated at the online operational level, and (3) how emergency cases should be managed. In particular, they suggested that surgeons coordinate among themselves regarding emergency surgeries to reduce the burden on OR staff and avoid last-minute disruptions. Another area of concern was the timing of information availability. Stakeholders identified three specific improvements: gaining earlier access to surgeon rosters, incorporating multi-year planning into strategic discussions, and increasing the number of designated emergency timeslots from four to five to reduce interference with elective scheduling.

Finally, interviewees expressed satisfaction with the hospital's decision to return to the practice of developing the OR blueprint before scheduling staff, a sequence that had been temporarily reversed during the COVID-19 pandemic.

This approach was perceived to enhance production efficiency and provide greater flexibility in workforce planning, by allowing staffing decisions to be based on a clear projection of surgical demand.

4.4 Discussion

This study aimed to assess the adaptability of OR planning strategies previously identified in Dutch UMCs by applying the same study framework to a hospital with a different organizational structure. Using the OPUS I protocol, we conducted a case study in a TCC hospital to examine how organizational context influences OR planning. The findings show that while many of the same planning steps and roles are present, differences in hospital scale, structure, and team configuration affect how these activities are organized and carried out.

Organizational structure

The TCC hospital operates with a centralized OR planning model, contrasting with the departmentally decentralized approach typically found in UMCs. This centralization is enabled by the hospital's smaller scale—10 operating rooms compared to 20–45 in UMCs—and more consistent team assignments for OR nurses. In this hospital, OR staff are scheduled in dedicated surgical teams associated with specific ORs, allowing staff rosters to be finalized earlier. Such a model is less feasible in UMCs due to their broader case-mix and the need for staff to rotate across specialties.

Comparison of OR planning processes

The overall structure of the OR planning process in the TCC hospital largely mirrors that of UMCs, but several differences were observed across planning levels. At the tactical level, the TCC hospital incorporates available staff capacity early when assessing the feasibility of the OR blueprint. The central planning office (admissions office) plays a key role in coordinating adjustments across departments—an approach not commonly seen in UMCs, where planning is typically managed within individual medical departments. At the offline operational level, the planning office assumes a prominent role and takes on responsibilities that would usually be handled by program coordinators in UMCs. This centralization reduces the need for weekly multidisciplinary meetings and is instead supported by bi-weekly planning discussions. At the online operational level, emergency

surgeries are scheduled using designated time slots rather than fully dedicated emergency ORs. Once elective surgeries are scheduled, it is uncommon for them to be rescheduled in response to emergencies, in contrast to the more flexible approach often seen in UMCs. In both hospital types, data is primarily used to estimate the duration of surgical procedures, typically by averaging recent cases performed by the same surgeon. However, broader integration of data-driven decision-making into planning processes remains in development in both settings.

Stakeholder preferences

Stakeholders in the TCC hospital shared improvement preferences that aligned with those found in UMCs in OPUS I. These included the desire for better data-driven feedback, clearer planning protocols, and improved timing of information availability. The fact that these themes arose in both decentralized and centralized settings highlights their relevance across a variety of hospital types.

However, one area of divergence emerged: stakeholders in the TCC hospital preferred to complete the blueprint before scheduling staff, citing stability in staffing levels as a supporting factor. In UMCs, where staff shortages are more prevalent, stakeholders preferred to prioritize staff availability earlier in the planning process.

Generalizability of findings

While the OR planning process in the TCC hospital differs from that of UMCs in terms of structure, scale, and role distribution, many of the underlying challenges and goals remain consistent. Themes such as improving transparency, optimizing timing, and strengthening interdisciplinary communication were raised by stakeholders in both contexts. This suggests that several of the strategic recommendations developed in OPUS I are not limited to academic settings but can be meaningfully applied in other hospital types—provided they are adapted to the local context.

In OPUS I, we emphasized the importance of enhancing process transparency through data use, establishing planning policies, and introducing automation only after workflows are clearly understood. In the TCC hospital, these strategies remain relevant but require a tailored approach.

For example, leveraging data for feedback loops—such as dashboards showing surgical timeliness—could be directly embedded into tactical planning meetings, supporting the hospital's already centralized coordination model. Similarly, while automation of planning tasks may offer long-term efficiencies, stakeholders in the TCC hospital stressed that such solutions should build on their current manual planning structure, and not replace the personal communication that facilitates quick coordination in a smaller-scale setting.

The call for clear, written planning policies also resonates strongly in this context. Despite having a centralized planning office, the TCC hospital still faces challenges in ensuring that all departments follow consistent rules for submitting surgical cases and responding to emergency changes. Documenting these processes could help align expectations across departments and reduce ad-hoc negotiation, especially as the hospital continues revising its planning system.

Limitations

This study shares several limitations with OPUS I. First, it is based on stakeholder-reported information, which may reflect individual perspectives and incomplete knowledge. Second, the study focuses on OR-related roles and excludes other departments such as material supply or ward staffing. Third, the planning process described represents a snapshot in time, during a period of ongoing process revision.

Furthermore, while OPUS I included all seven Dutch UMCs, this follow-up study focused on a single TCC hospital. As such, the findings cannot be assumed to represent all specialized or general hospitals in the Netherlands. Additional case studies are needed to build a broader understanding of OR planning across various hospital types.

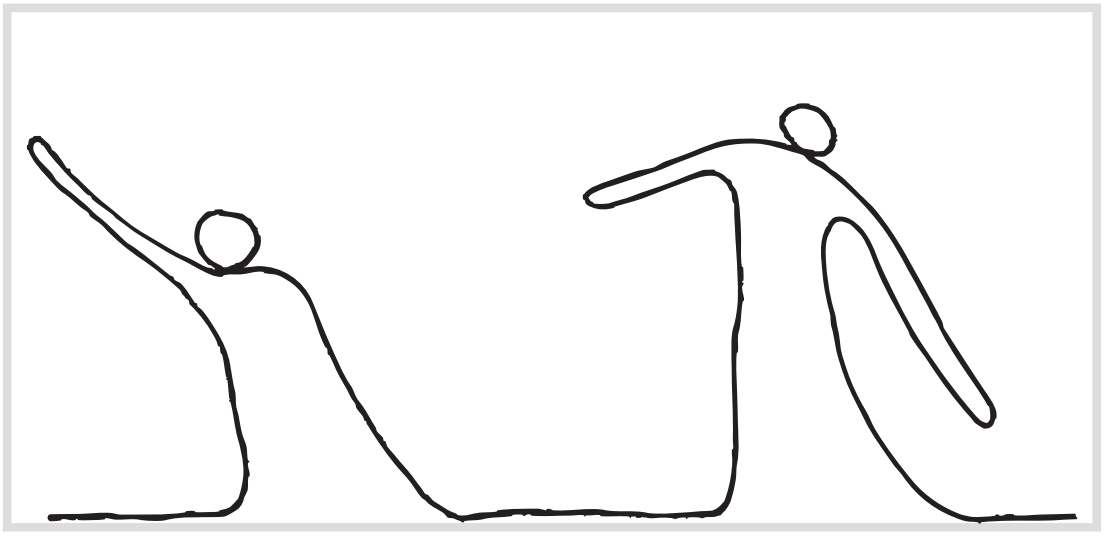
4.5 Conclusion

This study examined OR planning in a Top Clinical Center (TCC) to explore how planning is organized in this context and how it compares to UMCs. By applying the OPUS I framework to a TCC hospital, we found that while the overall structure of the OR planning process is comparable, there are important differences in how planning roles are distributed, how coordination is managed, and how flexibility is operationalized across planning levels. The TCC hospital's centralized plan-

ning model, smaller scale, and the usage of dedicated surgical teams allow for different planning choices—such as developing the OR blueprint before assigning staff and reserving fixed emergency time slots instead of maintaining fully dedicated emergency ORs.

Despite these contextual differences, the hospital shares many of the same core planning activities with UMCs. Stakeholders in both settings also emphasized similar priorities for improvement, including clearer communication, more timely availability of information, and stronger use of operational data. While the results stem from a single case, they suggest that some of the planning strategies explored in UMCs—such as improving transparency, clarifying planning responsibilities, and introducing data-driven feedback—may also hold value in other hospital contexts. However, successful implementation depends on careful alignment with local organizational characteristics, including size, governance model, and team structure.

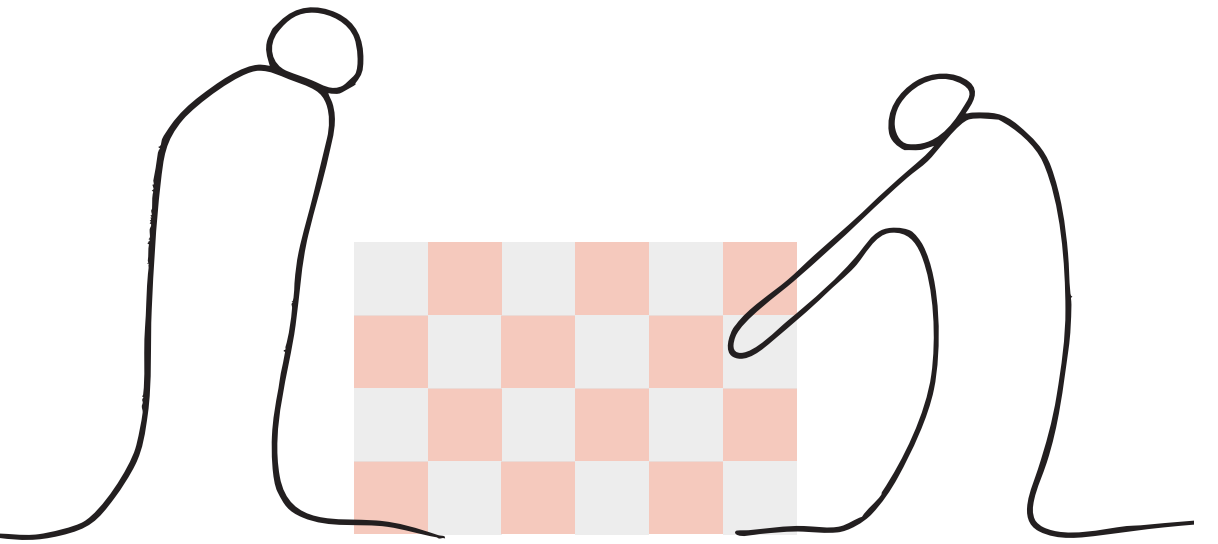
In conclusion, the strategic direction outlined in OPUS I appears relevant beyond the academic hospital context, but further research is needed to confirm its applicability more broadly. Future studies involving a more diverse range of specialized and general hospitals will help refine these insights and support the development of adaptable tools and policies for improving OR planning across the Dutch healthcare system.



References

1. 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
2. Chohan, M., Bihari, A., Tieszer, C., MacNevin, M., Churcher, C., Vandersluis, C., Cassar, F., Lin, C., Schemitsch, E., Sanders, D., & Lawendy, A.-R. (2022). Evaluation of a tiered operating room strategy at an academic centre: comparing high-efficiency and conventional operating rooms. Canadian Journal of Surgery, 65(6), E739–E748. https://doi.org/10.1503/cjs.004021
3. Ellis, D. B., Santoro, J., Spracklin, D., Kurzweil, V., Sylvia, S., Fagenholz, P., & Agarwala, A. (2020). Improving and Maintaining On-Time Start Times for Nonelective Cases in a Major Academic Medical Center. The Joint Commission Journal on Quality and Patient Safety, 46(2), 81–86. https://doi.org/10.1016/j.jcjq.2019.09.007
4. Hans, E. W., Herroelen, W., Leus, R., & Wullink, G. (2007). A hierarchical approach to multi-project planning under uncertainty. Omega, 35(5), 563–577. https://doi.org/10.1016/j.omega.2005.10.004
5. Harris, S., & Claudio, D. (2022). Current Trends in Operating Room Scheduling 2015 to 2020: a Literature Review. Operations Research Forum, 3(1), 21. https://doi.org/10.1007/s43069-022-00134-y
6. Hollnagel, E. (2017). FRAM: The Functional Resonance Analysis Method. CRC Press. https://doi.org/10.1201/9781315255071
7. Kroneman, M., Boerma, W., van den Berg, M., Groenewegen, P., de Jong, J., & van Ginneken, E. (2016). Netherlands: Health System Review. Health Systems in Transition, 18(2), 1–240.
8. Kubala, M., Gardner, J. R., Criddle, J., Nolder, A. R., & Richter, G. T. (2021). Process improvement strategy to implement an outpatient surgery center efficiency model in an academic inpatient setting. International Journal of Pediatric Otorhinolaryngology, 144, 110650. https://doi.org/10.1016/j.ijporl.2021.110650
9. NZA. (2022). Monitor umc's 2021, basiszorg in de umc's en inzet op de maatschappelijke opgaven.
10. Pasquer, A., Ducarroz, S., Lifante, J. C., Skinner, S., Poncet, G., & Duclos, A. (2024). Operating room organization and surgical performance: a systematic review. Patient Safety in Surgery, 18(1), 5. https://doi.org/10.1186/s13037-023-00388-3
11. Rathenau Instituut. (2022). Inkomsten, onderzoek en zorg van de universitair medische centra.
12. Samudra, M., Van Riet, C., Demeulemeester, E., Cardoen, B., Vansteenkiste, N., & Rademakers, F. E. (2016). Scheduling operating rooms: achievements, challenges and pitfalls. Journal of Scheduling, 19(5), 493–525. https://doi.org/10.1007/s10951-016-0489-6
13. Schmitt, N. C., Ryan, M., Halle, T., Sherrod, A., Wadsworth, J. T., Patel, M. R., & El-Deiry, M. W. (2022). Team-Based Surgical Scheduling for Improved Patient Access in a High-Volume, Tertiary Head and Neck Cancer Center. Annals of Surgical Oncology, 29(11), 7002–7006. https://doi.org/10.1245/s10434-022-12222-8
14. Schouten, A. M., Flipse, S. M., van Nieuwenhuizen, K. E., Jansen, F. W., van der Eijk, A. C., & van den Dobbelsteen, J. J. (2023). Operating Room Performance Optimization Metrics: a Systematic Review. In Journal of Medical Systems (Vol. 47, Issue 1). Springer. https://doi.org/10.1007/s10916-023-01912-9
15. Singh, D., Cai, L., Watt, D., Scoggins, E., Wald, S., & Nazerali, R. (2023). Improving Operating

Room Efficiency Through Reducing First Start Delays in an Academic Center. Journal for Healthcare Quality, 45(5), 308–313. https://doi.org/10.1097/JHQ.0000000000000398
16. Zhu, S., Fan, W., Yang, S., Pei, J., & Pardalos, P. M. (2019). Operating room planning and surgical case scheduling: a review of literature. Journal of Combinatorial Optimization, 37(3), 757–805. https://doi.org/10.1007/s10878-018-0322-6



V

Operation Hospital

A Serious Game to Raise Awareness among Future Patients about Day-of-Surgery Cancellations

Same-day surgery cancellations, often due to non-medical factors like scheduling conflicts and staff shortages, impact operating room efficiency, patient satisfaction, and staff morale. Traditional patient education rarely addresses these systemic issues, contributing to patient anxiety and misunderstanding. This study evaluated the effectiveness of a serious game in raising awareness about surgery cancellations and fostering empathy for healthcare providers, compared to a standard preoperative brochure. In a quasi-experimental design, an intervention group (n=9) played a board game simulating hospital resource management, while a control group (n=9) read the brochure. Pre- and post-intervention questionnaires assessed understanding, empathy, and anticipated anxiety. Post-intervention, 100% of the game group reported improved understanding versus 45% in the control group; empathy also increased more notably in the game group. Both groups reported moderate anxiety, though extreme anxiety was only seen in the control group. Most participants believed that knowing the reason for a cancellation would reduce anxiety, with this view more consistent in the intervention group. The game, while not a replacement for medical education, offers a valuable complement, helping patients better understand systemic healthcare challenges and manage expectations.

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5.1 Introduction

Surgery cancellations remain a persistent challenge in preoperative care, with rates varying widely across healthcare systems and regions. In developed countries, same-day elective surgery cancellation rates typically range from 0.37% to 28%, while in developing countries, these rates can be significantly higher—between 11% and 44% (Bharti et al., 2023). In the Netherlands, where this study was conducted, reported last-minute cancellation rates range from 14.3% to 20%. Notably, around 70% of these cancellations are attributed to scheduling conflicts rather than medical reasons (Scheenstra et al., 2021; Schretlen et al., 2021). Despite efforts to address this issue, cancellations on the day of surgery continue to be a significant concern in many medical centers. These cancellations negatively impact operating room (OR) efficiency, patient satisfaction, and the morale of medical teams (Armoeyan et al., 2021). Common reasons for surgery cancellations include a lack of available beds and insufficient OR time (Koh et al., 2021). Both the lack of beds and OR availability is often linked to staff shortages, which are closely associated with reduced patient satisfaction regarding physician and nursing care (Winter et al., 2020). Physicians have expressed the emotional difficulty of informing patients about surgery cancellations. Patients often react with anxiety, frustration, or anger, and explaining the reasons for the cancellation can be challenging for physicians (Viftrup et al., 2021).

To raise awareness among potential future patients about the likelihood and causes of day-of-surgery cancellations, we developed a serious game. In this board game, players step into the role of a physician tasked with guiding their patients through the nursing ward, operating room, and recovery ward. Along the way, players face challenges such as staff shortages, emergency cases, and competing demands from other players who also need beds for their patients. These challenges make it inevitable that players will occasionally need to cancel and reschedule a patient's surgery.

5.2 Background

Serious games have gained recognition as an effective educational tool across a range of disciplines (Zeng et al., 2020). Studies have highlighted healthcare as a key area for the application of educational serious games (Damaševičius et al., 2023). Unlike traditional teaching methods, serious games in healthcare stand

out because they offer a risk-free environment where individuals can practice high-stakes tasks and navigate unpredictable scenarios. These benefits have driven the rapid growth and innovation of health-focused educational games (Sharifzadeh et al., 2020).

In a systematic review, Sharifzadeh et al. (2020) found that most studies on serious healthcare games focused on improving knowledge, with a smaller portion aimed at skill development. The studies targeted various user groups, including healthcare providers, patients, public users, and mixed audiences. Among games designed for patients, only a small fraction addressed specific diseases, while the majority focused on broader topics like lifestyle behaviors, social interactions, cognition, and general health issues such as safety and nutrition.

5.2.1 Related work

An example of a serious healthcare game focused on patient expectation management was developed by Ingadottir et al. (2017). They developed a game focused on managing patient expectations about postoperative pain. The game simulates a real-life scenario where the player's avatar has returned home after surgery. By making decisions about daily activities, such as using pain medication, completing household tasks, or resting, players see how their choices impact the avatar's recovery. An example of a game focused on planning and the management of a medical department was developed by Zhang et al. (2020), who developed a serious game focused on logistics management in pediatric emergency medicine. The game used a multi-method simulation to model complex healthcare processes, incorporating game mechanics designed to enhance understanding of emergency department logistics.

5.2.2 Theories and game mechanics

Aster et al. (2024) conducted a systematic review on the theories and teaching effectiveness of serious games in healthcare. They highlighted examples in which Self-Determination Theory (Deci & Ryan, 1985) guided both game development and the selection of specific design elements. For example, competence was addressed by allowing participants to build on prior knowledge and access additional resources during gameplay. Minimal rules supported autonomy, while team-based collaboration fulfilled the need for relatedness.

The review also identified the use of Narrative Engagement (Miller-Day & Hecht, 2013) and Analogical Reasoning theories (Idson et al., 2004). Narrative engagement supported the integration of storylines to enhance decision-making skills, enabling medical students to transfer competencies to related scenarios. Analogical reasoning emphasized the effectiveness of structured case comparisons in teaching decision-making principles and inspired the puzzle-based design of some games.

5.2.3 Contribution of this study

Most serious healthcare games in the literature focus on training healthcare professionals or educating patients about their medical conditions or lifestyles. However, this study targets everyday individuals who may undergo surgery in the future. To promote expectation management and empathy for physicians, players assume a role that combines elements of a physician and an operating room manager. In this paper, we describe the development of the game, guided by Verschueren et al.'s (2019) framework for creating theory-driven, evidence-based serious games for health, and evaluate its efficacy through questionnaires.

5.3 Game design

This section will outline the scientific foundations, the design foundations, game design and the validation of the game design, following the framework proposed by Verschueren et al.

5.3.1 Scientific foundations

The target audience for this game consists of everyday individuals, including potential future patients, who may undergo surgery at some point in their lives. The game is designed to be accessible in non-clinical settings, such as homes, schools, or public awareness events. It aims to provide an engaging and educational experience in a casual format, making it suitable for players without prior medical knowledge. The gameplay mirrors real-world hospital challenges, offering players a chance to understand the logistical and ethical dilemmas faced by healthcare providers.

Outcome objectives

The primary objective of the game is to increase awareness among potential future patients about the causes and impacts of day-of-surgery cancellations. This includes helping players understand the logistical challenges, such as staff shortages and resource allocation, that influence surgical planning and decision-making in hospitals. The secondary objective is to foster empathy for healthcare providers by allowing players to experience the complex, high-pressure decision-making processes involved in balancing the needs of multiple patients. By stepping into the role of a physician and operating room manager, players gain insight into the ethical and emotional challenges healthcare professionals face. The tertiary objective is to reduce stress and anxiety for patients when their surgery is canceled or rescheduled. By providing a simulated experience of hospital decision-making, the game helps players better understand the systemic factors behind cancellations and delays, enabling them to approach such situations with greater patience and perspective.

Theoretical basis

The game is built on the hypothesis that interactive, role-playing experiences can improve awareness and empathy in players. By immersing players in the decision-making processes of surgical planning, the game aims to influence their understanding of hospital operations while reducing their stress and anxiety about surgery cancellations. The game draws on Self-Determination Theory (SDT) to address autonomy, competence, and relatedness in the player experience. By giving players control over decisions, the game fulfills their need for autonomy, while challenging tasks and learning opportunities enhance feelings of competence. Interactions with other players or simulated characters foster relatedness. The Experiential Learning Theory (Kolb et al., 2001) allows for learning through experience, reflection, and decision-making. Additionally, Cognitive Behavioral Theory (CBT) (Beck, 1963) underpins the game's goal of reducing anxiety by exposing players to challenging scenarios in a safe, controlled environment. To ensure the game's logistics were structured realistically, we applied the positioning framework of Hans et al. (2007). This framework outlines different planning levels in surgical scheduling: strategic planning (long-term decisions like capacity dimensioning and resource allocation), tactical planning (medium-term decisions such as scheduling and resource allocation), and operational planning, divided into offline (week-to-week) and online (day-to-day) decision-making.

Tool evaluation

The evaluation of the serious game involves a structured approach to assess its efficacy in achieving the outlined objectives. This includes pre- and post-game questionnaires to measure changes in awareness, empathy, and anxiety levels. The study employs a quasi-experimental design featuring two groups: an intervention group that plays the game and a comparison group that receives traditional educational material about surgery cancellations. For the comparison condition, an official brochure from a Dutch hospital – typically provided to patients as part of their pre-surgery briefing – was translated into English while preserving its original layout (Appendix 5.1). Both the intervention and comparison groups are assessed before and after the intervention to evaluate the game's impact in relation to conventional educational methods.

Protocol:

1. *Recruitment:* participants are recruited from the general population, focusing on adult individuals. Recruitment criteria include a minimal age of 18 years old.
2. *Pre-intervention assessment:* both groups complete a baseline questionnaire measuring their awareness of surgery cancellations, empathy for healthcare providers, and anxiety related to surgical uncertainty.
3. *Intervention:* the intervention group plays the serious game, while the comparison group reviews traditional educational materials. Each session is conducted in a controlled environment to minimize external influences.
4. *Post-intervention assessment:* both groups complete a post-game questionnaire to assess changes in awareness, empathy, and anxiety.
5. *Analysis:* data is analyzed to compare pre- and post-intervention scores within and between groups.

5.3.2 Design foundations

To outline the design foundations, theory-mechanics mapping and design requirements are discussed.

Theory-mechanics mapping

This section translates theoretical elements into game mechanics, aligning the game's design with its educational and emotional goals. Self-Determination Theory (SDT) is applied through autonomy, competence, and relatedness.
Players control decisions, such as patient movement, task prioritization, and resource allocation, within flexible rules that encourage strategy experimentation. Task-based mechanics challenge players to manage waiting times, operating times, and recovery, reinforcing skills and a sense of accomplishment. Collaboration on the hospital mission and competition for the surgeon mission balance teamwork and individual goals.

Cognitive Behavioral Theory (CBT) integrates unpredictable challenges through action and emergency cards, simulating issues like staff shortages and emergency patients in a controlled environment. These scenarios reduce stress, build confidence, and encourage players to reframe surgery cancellations and delays, fostering empathy for healthcare providers. Narrative Engagement Theory immerses players in the roles of surgeons managing patient care and hospital resources. Mission cards drive the narrative with realistic goals, such as completing surgeries or minimizing penalties.

The Positioning Framework of Hans et al. (2007) organizes mechanics into strategic, tactical, and operational levels. At the strategic level, hospital and surgeon missions reflect long-term goals like resource efficiency and individual performance. The tactical level involves patient prioritization and allocation, simulating scheduling and medium-term planning. Operationally, players guide patients through phases, managing immediate decisions like staff reassignment and resource shortages, reflecting day-to-day hospital problem-solving.

Design requirements

The serious game is designed to simulate the context of hospital operations, focusing on the nursing ward, operating room, and recovery. It incorporates real-world challenges such as staff shortages, patient prioritization, and emergency cases while simplifying processes to ensure accessibility for non-medical players. Realism is balanced with playability by including relatable scenarios and realistic patient descriptions, intuitive mechanics, and clear instructions. Players take on a hybrid role as surgeon and OR manager, making decisions at strategic,

tactical, and operational levels. The game targets everyday individuals, including potential future patients, with varying levels of familiarity with healthcare systems, ensuring inclusivity through straightforward rules, visual aids, and adjustable difficulty levels.

5.3.3 Game development

V

This game is designed for 2-4 players aged 12 and up. Players assume the role of surgeons from different specialties, including neurosurgery, orthopedics, general surgery, thoracic surgery, cardiac surgery, and gynecology. Each player manages their specialty's patient waiting list, aiming to complete surgeries while adhering to hospital-wide goals. The objective is to collaboratively fulfill the Hospital Mission while individually competing to earn the most points. Failure to meet the hospital mission (e.g., more than three patient deaths or hospital bankruptcy) results in all players losing.

Hospital mission and surgeon mission

At the start of the game, players collaboratively draw Hospital Mission Cards (Figure 1), which specify objectives such as completing a set number of transplants, robotic surgeries, or C-sections. Each player is also responsible for fulfilling their personal Surgeon Mission, earning points by successfully operating on and discharging patients from their waiting list. Points vary by patient complexity, with more difficult procedures (e.g., robotic surgeries, transplants) offering higher rewards.

Managing waiting lists

Players start with a deck of patient cards representing their specialty and draw five cards to form their passive waiting list. Each round, players can transfer patients to their active waiting list, where waiting times begin to accumulate. Passive lists must remain below 10 patients to avoid penalties. Patients must progress through the nursing ward, operating room (OR), and recovery to be discharged.

Figure 1 Example of two Hospital Mission cards. To achieve the left mission card, at least two robot surgeries must be completed. To achieve the right mission card, at least two transplants and/or C-sections must be completed. At the start of the game, players receive a total of six (two plus four) coins to complete this Hospital Mission.

Hospital layout

The game board represents a hospital with five nursing ward beds, five ORs, and five recovery beds:

Patients and staff are represented by tokens that players move between hospital sections. Each patient's progress is tracked using time bars (waiting time, operating time, recovery time) on their patient card (Figure 3).

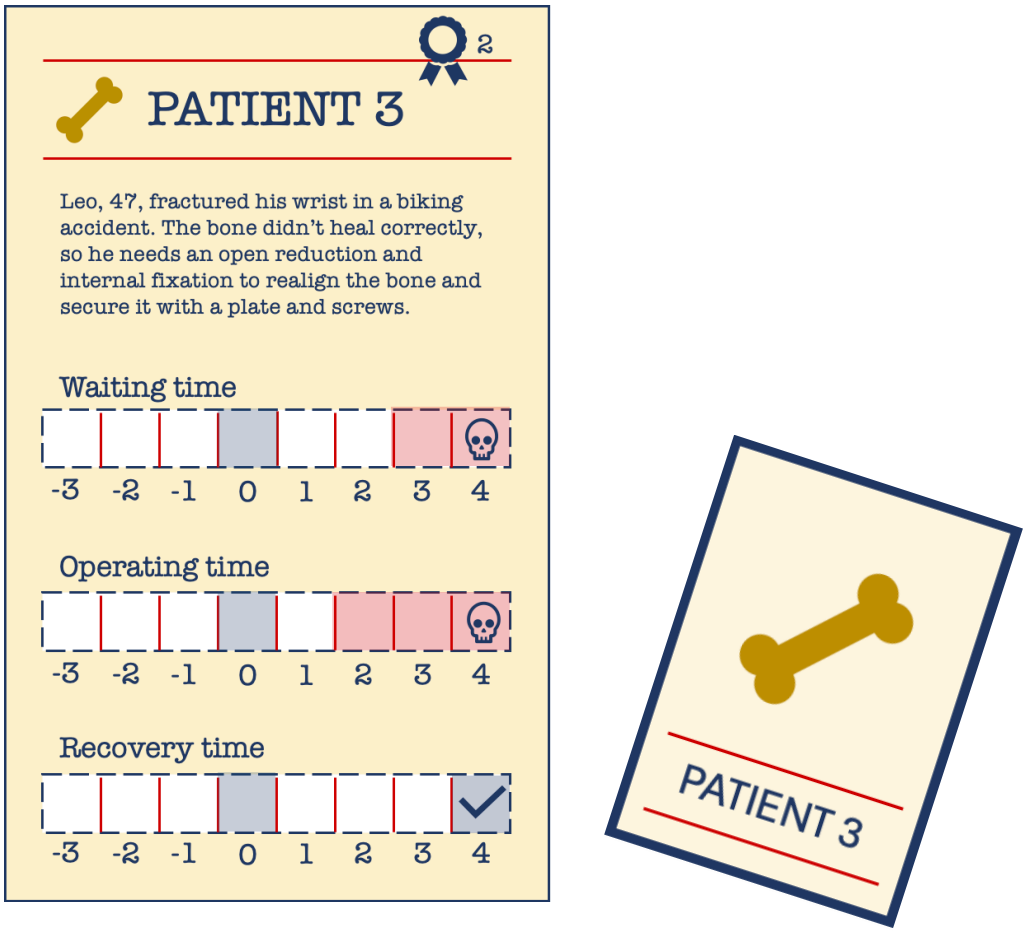


Figure 3 Patient card (left) of an orthopedic patient and its corresponding token (right). Patient cards lie in front of the player and are used to track waiting-, operating-, and recovery times. The tokens are moved from bed to bed to track the position of the patient in the hospital.

Daily operations

Each day consists of 10 rounds (8 regular hours and 2 overtime hours) (Figure 4).

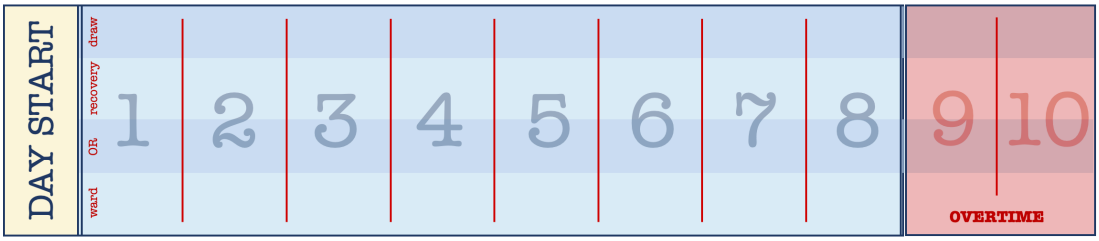


Figure 4 The clock, which marks a full working day with a day start and ten rounds. The rounds are tracked by moving a block a step to the right once a round was finished.

Overtime requires players to pay for extra staffing. Unfinished surgeries at the end of the day result in penalties. The day starts with:

1. *Team Day Start Card:* Determines the day's staffing levels (nurses, OR nurses, anesthesia nurses). Players collectively assign staff to available beds and ORs.
2. *Emergency Day Start Card:* Adds emergency patients to the nursing ward, requiring immediate admission. Players must move or hire staff to accommodate these patients.

During each round, players follow a structured sequence:

1. *Draw and execute* an Action Card (e.g., emergencies, resource challenges).
2. *Recovery Phase:* Discharge patients or progress recovery blocks.
3. *Operating Phase:* Transfer patients to recovery or progress operating blocks.
4. *Nursing Phase:* Transfer patients to the OR or progress waiting blocks.
5. *Active Waiting Lists:* Admit patients to the nursing ward or progress their waiting blocks.
6. *End-of-Round Decisions:* Players can hire staff or transfer patients from passive to active waiting lists.

Patient flow and time tracking

Patients move through the nursing ward, OR, and recovery phases based on resource availability and time requirements:

- *Waiting Time:* Increases each round a patient remains in the nursing ward or waiting list. Excessive waiting adds red blocks to the operating time bar, prolonging surgery.
- *Operating Time:* Progresses while patients are in the OR. Delays due to resource shortages (e.g., lack of OR nurses or anesthesia nurses) add red blocks.
- *Recovery Time:* Progresses in recovery beds. Patients who occupy beds too long do not die but block resources unnecessarily.

Special patient scenarios

- *Transplants:* Both the patient and donor require simultaneous OR availability, but only the patient needs nursing and recovery beds (Figure 5, left).
- *C-Sections:* The mother requires an OR, and after surgery, both mother and baby need recovery beds (Figure 5, middle).
- *Robotic Surgeries:* Can only be performed in OR5, which houses the robot, and typically require longer operating times (Figure 5, right).

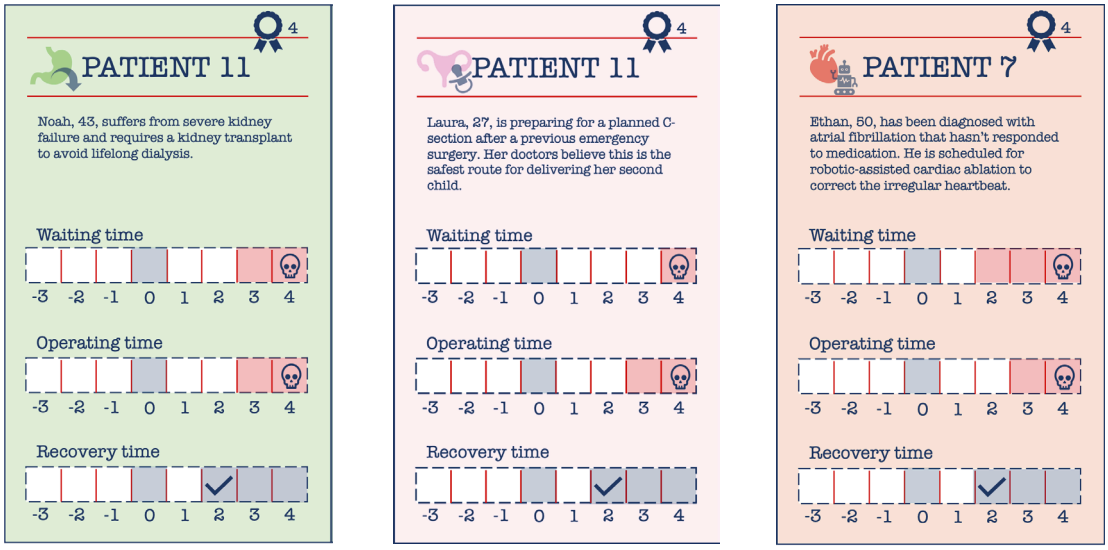


Figure 5 Transplant patient card (left), C-section patient card (middle) and Robotic surgery patient card (right).

Penalties

Players receive penalties for:

1. Sending patients home without surgery.
2. Returning patients from the OR to the nursing ward with unfinished surgery.
3. Allowing patients to die due to excessive waiting or operating time.

End of the day

At the end of each day, unfinished surgeries must stop, and affected patients are sent back to the nursing ward with their time bars reset. Players collaboratively plan staffing for the next day and draw new patients to their passive waiting lists. The game ends when all hospital mission objectives are fulfilled, and players calculate their final scores, subtracting penalties.

Winning Conditions

To win, players must collectively fulfill the Hospital Mission while competing for the highest individual score. Failure occurs if more than three patients die or if the hospital goes bankrupt. The player with the most points after subtracting penalties wins. Appendix 5.2 shows an overview of a game play scenario.

5.3.4 Validation

Awareness will be measured using pre- and post-game questionnaires with multiple-choice and Likert-scale items to assess participants' understanding of the causes and impacts of day-of-surgery cancellations, with a key question being, *"What are common reasons for day-of-surgery cancellations?"*

Empathy for healthcare providers will be evaluated through pre- and post-game questionnaires to measure changes in participants' understanding of the challenges faced by surgeons, with a central question, *"How difficult do you think it is for surgeons to manage surgery cancellations and resource shortages?"* Anxiety reduction will be assessed using pre- and post-game questionnaires, specifically the State-Trait Anxiety Inventory (STAI) (Spielberger, 1983), with a main question asking, *"How anxious would you feel if your surgery were canceled or postponed?"* If participants who played the game show higher scores in awareness and empathy, and lower scores in anxiety compared to the control group, this will be considered a positive validation of the game.

5.4 Results

The control group consisted of nine participants aged between 25 and 35. The intervention group also included nine participants, divided into three subgroups of three. Each group played the game for 30 minutes. Participants in the intervention group were likewise aged between 25 and 35. To ensure consistency, the action and patient cards were presented in the same order for each session. The study took place at the Technical University of Delft between March and April 2025.

5.4.1 The game sessions

In the first intervention session, no players received penalties, and the group encountered one emergency patient. They progressed through five rounds within the 30-minute timeframe, successfully completing one patient (fully recovered and discharged). They performed two robotic surgeries and one cesarean section. This group demonstrated strong collaboration and were willing to grant each other favors. The second group also received no penalties and completed five rounds. They operated on one emergency patient and successfully recovered and discharged both a robotic surgery and a cesarean section. This session was more

competitive than the first, and one participant did not operate on any patients. The third group also incurred no penalties. They performed two transplants and one cesarean section but did not fully complete any patients. This group was neither particularly competitive nor highly collaborative.

5.4.2 Questionnaire outcomes

In this section the results of the questionnaire on the topics awareness, empathy and anxiety are presented for both the control group and the intervention group. For the full questionnaire, see Appendix 5.3.

Awareness

Figure 6 presents the results of Question 1 from the questionnaire, in which participants were asked how likely they thought it was that a surgery would be cancelled. Most participants in the control group acknowledged the possibility of cancellations, although the brochure slightly shifted perceptions toward seeing them as less likely. Most participants in the intervention group saw cancellations as a realistic possibility, but the game shifted perceptions more strongly toward viewing cancellations as highly likely.

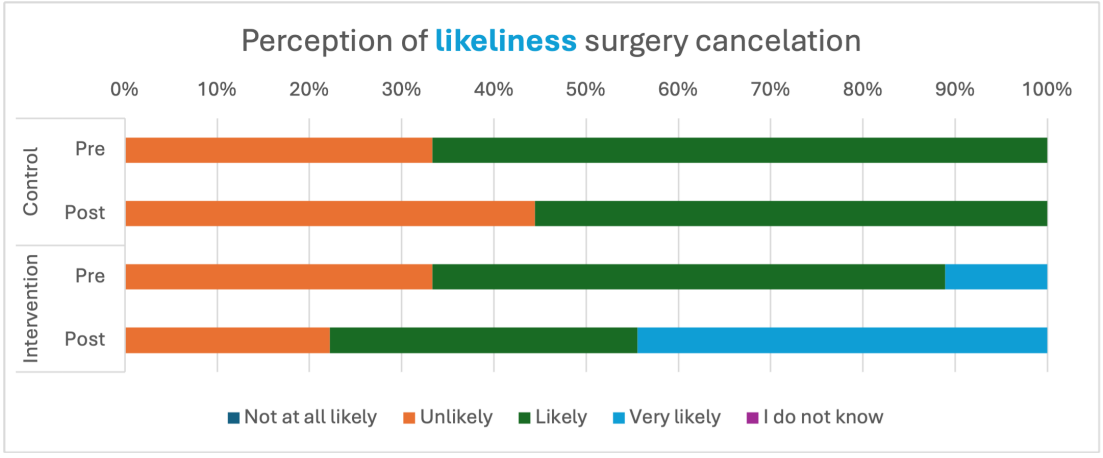


Figure 6 Perceived likelihood of surgery cancellation in the control and intervention groups. “Pre” refers to responses collected before the intervention (reading the brochure or playing the game), and “Post” refers to responses collected afterward.

Figure 7 presents the results of Question 2 from the questionnaire, which asked participants how likely they believed it was that a surgery could be cancelled while already in the hospital. Overall, the brochure led to a modest shift in perception, with more participants acknowledging the possibility of cancellations even after hospital admission. The intervention group showed a similar initial distribution, but the game led to a stronger shift in perception than the brochure, with more participants recognizing the likelihood of cancellations even once hospitalized.

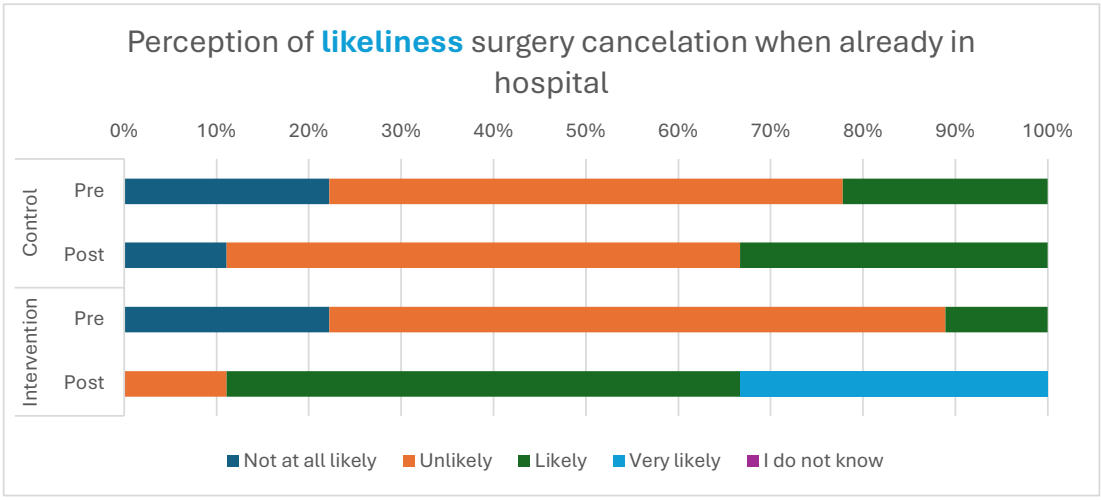


Figure 7 Perceived likelihood of surgery cancellation in the control and intervention groups. “Pre” refers to responses collected before the intervention (reading the brochure or playing the game), and “Post” refers to responses collected afterward.

Empathy

Figure 8 presents the results of Question 7 from the control group, which explored participants' agreement with statements related to empathy for healthcare workers. Overall, most participants acknowledged that healthcare professionals face difficult decisions when surgeries are cancelled, with this perception strengthening after reading the brochure. A similar trend was observed regarding the role of surgeons in balancing patient needs and hospital capacity. However, overall empathy toward the broader challenges faced by hospital staff slightly declined after the intervention.

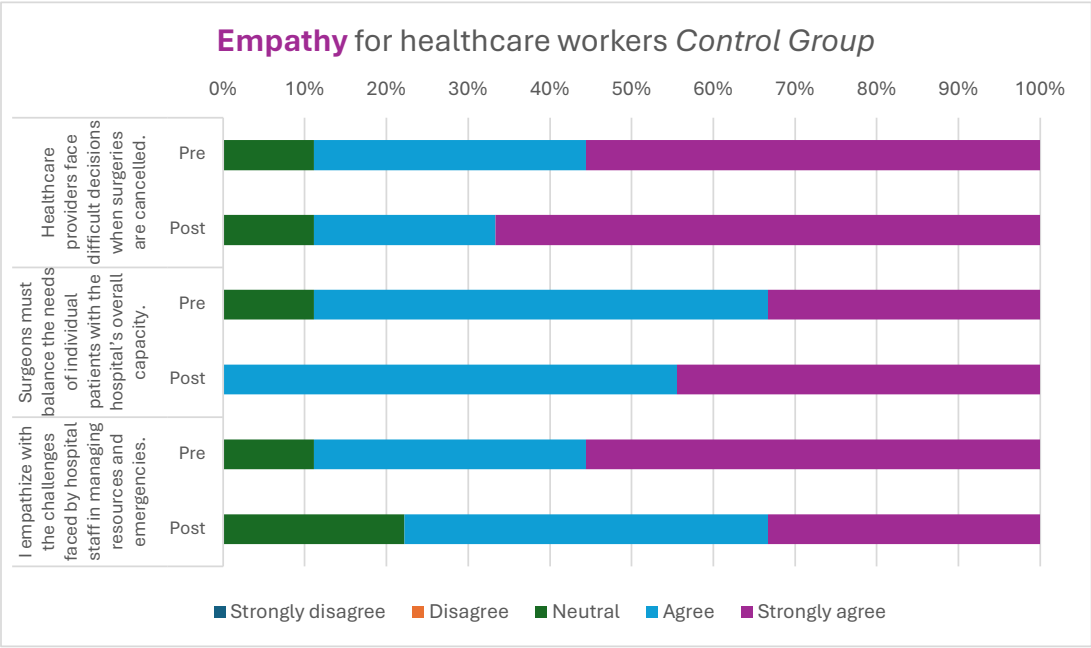


Figure 8 Control group responses to statements about empathy for healthcare workers, shown before ("Pre") and after ("Post") reading the brochure. Participants rated their agreement with statements on the challenges faced by healthcare providers during surgery cancellations, balancing patient needs with hospital capacity, and managing resources and emergencies.

Figure 9 presents the results of Question 7 from the intervention group, which assessed participants' agreement with statements related to empathy for healthcare workers. Overall, the game led to a marked increase in strong agreement with the challenges faced by healthcare workers, especially regarding the difficulty of surgery cancellations and the complexities of resource management. Although some divergence appeared in perceptions about surgeons balancing patient needs and capacity, most participants ultimately expressed heightened empathy post-intervention. Although some divergence appeared in perceptions about surgeons balancing patient needs and capacity, most participants ultimately expressed heightened empathy post-intervention.

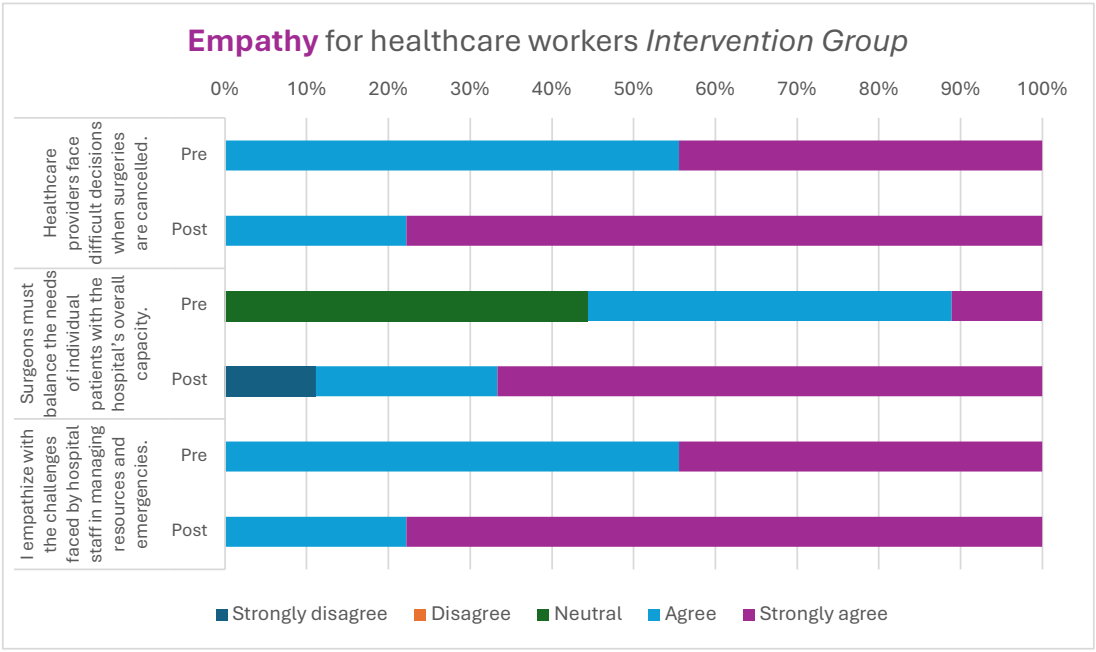


Figure 9 Intervention group responses to statements about empathy for healthcare workers, shown before ("Pre") and after ("Post") playing the game. Participants rated their agreement with statements on the challenges faced by healthcare providers during surgery cancellations, balancing patient needs with hospital capacity, and managing resources and emergencies.

Anxiety

Figure 10 presents the results of Question 8, which asked participants how anxious they would feel if their surgery were cancelled. Overall, the brochure led to a slight increase in the intensity of anticipated anxiety, with more participants expecting high or extreme anxiety following surgery cancellation. In the intervention group, the game maintained a focus on moderate levels of anxiety, with a slight increase in high anxiety, but a reduction in extreme anxiety. Figure 11 presents the results related to how participants believed their anxiety would be influenced if they understood the reason behind a surgery cancellation. Overall, the brochure led to a shift toward the belief that understanding the reason for cancellation could help reduce anxiety. In the intervention group, after playing the game, the distribution remained the same, with most participants still expecting reduced anxiety if the reason behind the cancellation was clear.

Understanding

After the intervention, both the control and intervention groups were asked whether the activity (brochure or game) had influenced their understanding of the factors contributing to surgery cancellations (Figure 12). In the control group, around 45% reported that reading the brochure helped them better understand

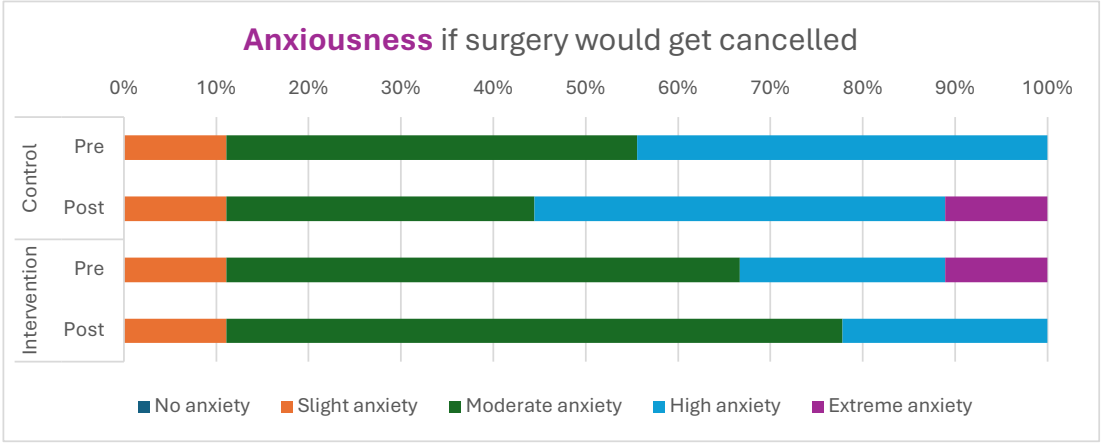


Figure 10 Reported levels of anticipated anxiety in response to surgery cancellation, as rated by control and intervention group participants before ("Pre") and after ("Post") the intervention. Participants indicated whether they would feel slight, moderate, high, or extreme anxiety if their surgery were cancelled.

these factors, while approximately 55% felt it did not change their understanding. In contrast, 100% of participants in the intervention group indicated that playing the game improved their understanding of why surgeries might be cancelled. This suggests that the game had a stronger impact on enhancing participants' awareness of the complexities involved in surgery scheduling and cancellations compared to the traditional brochure.

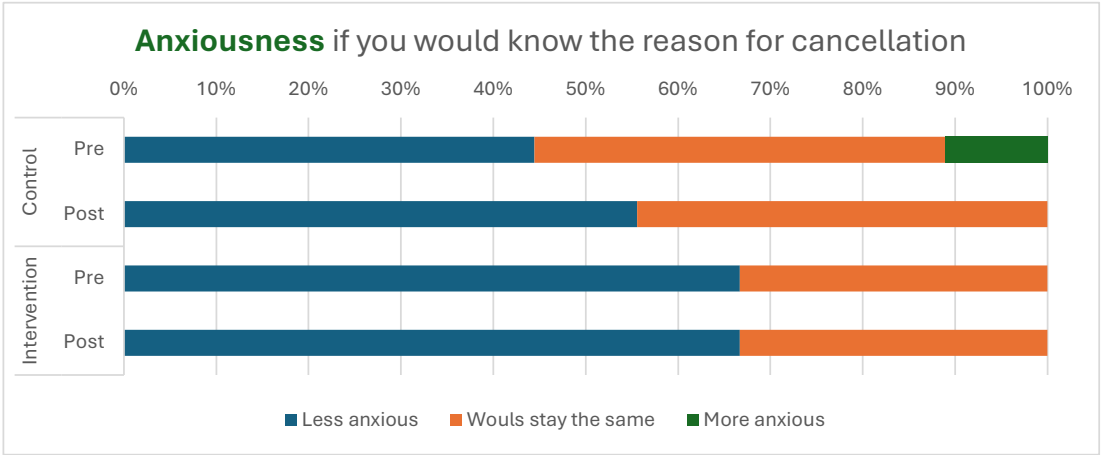


Figure 11 Anticipated levels of anxiety in response to surgery cancellation, depending on whether participants understood the reason for the cancellation. Responses from the control and intervention groups are shown before ("Pre") and after ("Post") the intervention. Participants indicated whether knowing the reason would result in slight, moderate, high, or extreme anxiety.

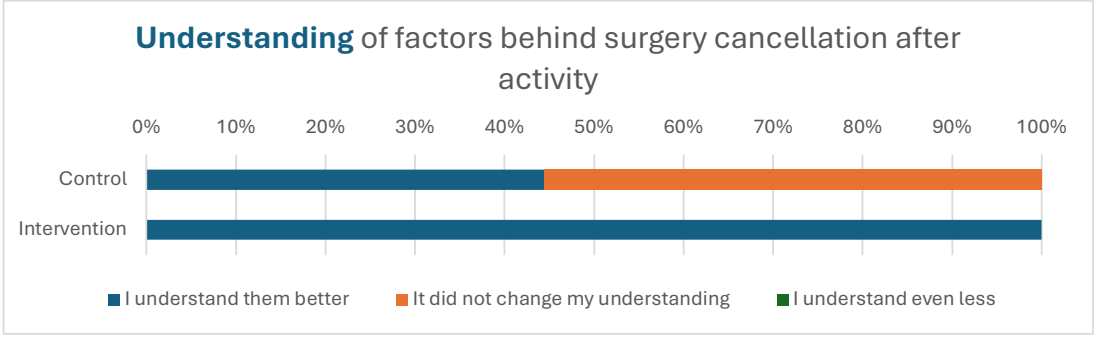


Figure 12 Participants' self-reported change in understanding of factors contributing to surgery cancellations after the intervention. The control group responded after reading the brochure, while the intervention group responded after playing the game.

5.5 Discussion

This study explored the effectiveness of a serious game in raising awareness about the causes and emotional impact of day-of-surgery cancellations, compared to traditional educational material. Our findings suggest that the game not only enhanced participants' understanding of the complexities behind surgery cancellations but also increased their empathy toward healthcare professionals facing these challenges.

The control group, which engaged with a hospital brochure, demonstrated a modest improvement in understanding. Post-intervention, around 45% felt they had a better grasp of the factors behind cancellations, while 55% reported no change. In contrast, 100% of participants in the intervention group, who played the serious game, reported an improved understanding. This highlights the greater educational impact of the interactive, scenario-based format of the game over passive reading material. The game's ability to simulate real-world challenges, such as staff shortages, emergency cases, and resource limitations, likely contributed to a more vivid and lasting learning experience, supporting findings from prior studies on serious games in healthcare (Aster et al., 2024; Sharifzadeh et al., 2020).

In terms of empathy for healthcare workers, both groups initially acknowledged the difficulties providers face when surgeries are cancelled. However, the game led to a stronger shift in perception. After playing, nearly 80% of the intervention group strongly agreed that healthcare providers face difficult decisions, compared to about 70% in the control group. Additionally, while empathy levels for resource and emergency management slightly declined in the control group, they remained high in the intervention group, suggesting that the game helped sustain or even deepen this understanding.

Regarding anxiety levels, participants across both groups anticipated moderate to high anxiety if their surgery were cancelled. Notably, after the intervention, a small number of control group participants indicated they would experience extreme anxiety. In contrast, no intervention group participants reported extreme anxiety post-gameplay. This could indicate that the game, by offering insight into the reasons behind cancellations, helped reduce the potential for extreme emotional reactions.

When considering whether knowing the reason for a cancellation would affect their anxiety, the majority of participants in both groups felt it would lessen their anxiety. However, this belief strengthened in the control group after reading the brochure, rising from 40% to nearly 60%. In the intervention group, a consistent 70% believed that understanding the reason would reduce their anxiety both before and after playing the game. This consistency suggests that the game effectively conveyed from the outset that behind-the-scenes challenges influence surgical scheduling.

Importantly, these findings should be interpreted in light of the different learning goals between the brochure and the game. The brochure is primarily focused on the medical aspects of surgery, including details on pain management, medication, and recovery. While the game includes some of this information through action and patient cards, its emphasis lies more on system-level challenges, such as resource allocation and staffing issues. Therefore, it is not intended, nor should it be seen, as a replacement for traditional educational materials like the brochure. Rather, the game could serve as a complementary tool, providing a broader understanding of the hospital environment and fostering empathy for the healthcare providers involved.

Moreover, it is important to recognize that the brochure used in this study represents just one part of the broader educational package that patients typically receive. In addition to written materials, patients are often given supplementary flyers with images of hospital areas to help them navigate and mentally prepare for their experience. They also have conversations with their physicians, which provide crucial, personalized information about their procedure and care. These multiple touchpoints contribute to a more comprehensive preparation for surgery, and any game-based intervention should be seen as an additional resource within this wider context.

Overall, the serious game proved to be a more impactful tool than the brochure in improving understanding and fostering empathy around the topic of surgery cancellations. These findings align with theoretical foundations highlighted by Aster et al. (2024), particularly Self-Determination Theory and Narrative Engagement, which emphasize the role of active participation, autonomy, and emotional involvement in learning.

The game's design, which allowed players to directly experience and respond to typical OR management constraints, likely increased engagement and facilitated a deeper cognitive and emotional connection to the topic.

5.5.1 Implications

This study contributes to the growing field of serious games in healthcare by demonstrating that such tools can be effectively used not only for professional training or patient self-care but also for managing expectations and emotions of potential future patients. By promoting a more nuanced understanding of systemic challenges, serious games could play a valuable role in preoperative education, ultimately supporting better communication between patients and healthcare providers. However, they should be integrated alongside traditional materials and physician guidance, not as standalone educational tools.

5.5.2 Limitations and Future Work

While the results are promising, the sample size was limited, and further studies with larger, more diverse populations are needed to confirm these findings. Additionally, long-term effects on participants' perceptions and behaviors were not assessed. Future research could explore whether this increased understanding persists over time and whether similar game-based interventions can reduce preoperative anxiety in actual clinical settings. Further, evaluating how such games could be effectively integrated into existing preoperative education programs would be valuable, ensuring they support rather than duplicate or replace essential medical information.

5.6 Conclusion

Surgery cancellations, particularly those occurring on the day of surgery, remain a significant challenge within healthcare systems, affecting both operational efficiency and patient experience. This study introduced a serious game aimed at raising awareness among potential future patients about the systemic factors contributing to surgery cancellations, while also fostering empathy for healthcare providers.

The findings indicate that the game was effective in enhancing participants' understanding of the logistical and staffing challenges faced by hospitals, and in

deepening their appreciation of the difficult decisions healthcare workers must make. Compared to a traditional educational brochure, the game led to greater improvements in perceived understanding and empathy, while also supporting moderate emotional responses to hypothetical surgery cancellations.

However, the game is not intended to replace conventional preoperative educational materials, which focus more heavily on medical information such as pain management and recovery expectations. Instead, it should be viewed as a complementary tool that can enrich patient education by addressing the broader context in which surgical care is delivered.

In conclusion, integrating serious games into preoperative education may offer a novel and engaging way to manage patient expectations, promote understanding of hospital dynamics, and support better communication between patients and healthcare professionals. Future research should explore the broader application of such tools in clinical settings and their potential to improve patient preparedness and satisfaction (Figure 13).

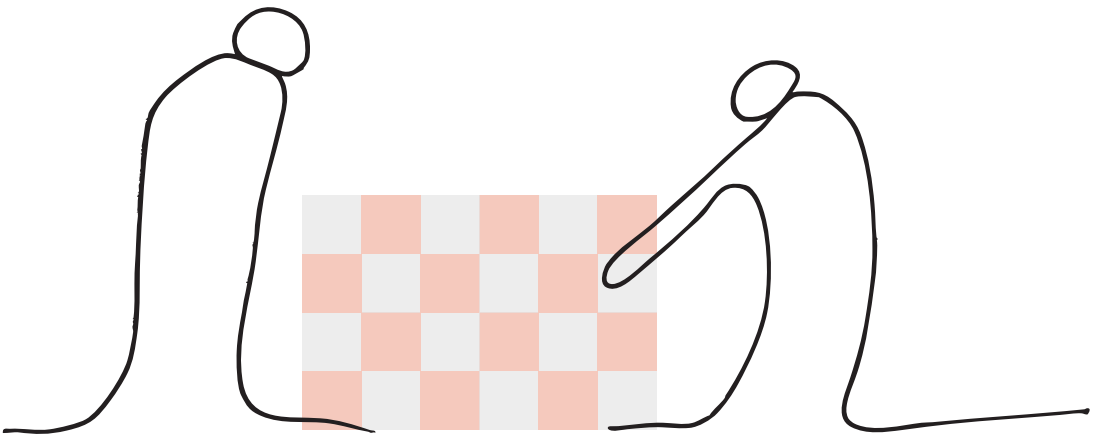
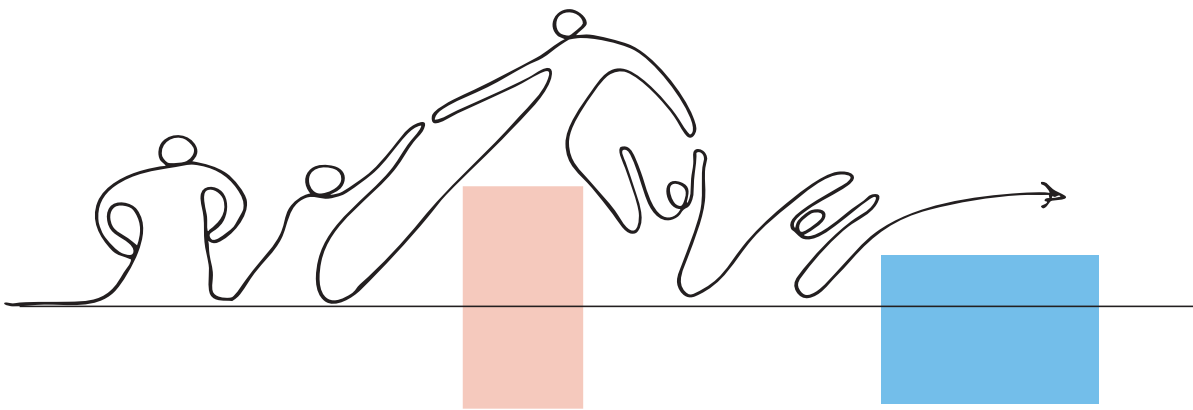


Figure 13 integrating serious games into preoperative education may offer a novel and engaging way to manage patient expectations, promote understanding of hospital dynamics, and support better communication between patients and healthcare professionals.

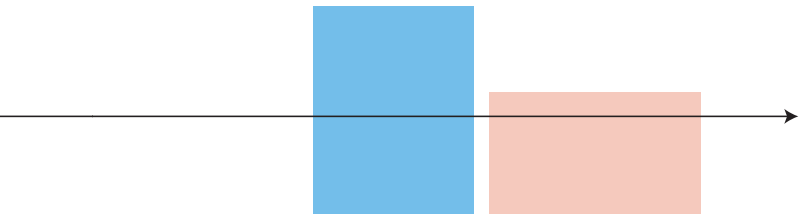
References

1. Armoeyan, M., Aarabi, A., & Akbari, L. (2021). The Effects of Surgery Cancellation on Patients, Families, and Staff: A Prospective Cross-Sectional Study. Journal of PeriAnesthesia Nursing, 36(6), 695-701.e2. https://doi.org/10.1016/j.jopan.2021.02.009
2. Aster, A., Laupichler, M. C., Zimmer, S., & Raupach, T. (2024). Game design elements of serious games in the education of medical and healthcare professions: a mixed-methods systematic review of underlying theories and teaching effectiveness. Advances in Health Sciences Education, 29(5), 1825–1848. https://doi.org/10.1007/s10459-024-10327-1
3. Beck, A. T. (1963). Thinking and Depression. Archives of General Psychiatry, 9(4), 324. https://doi.org/10.1001/archpsyc.1963.01720160014002
4. Bharti, A., Azmi, F., Chaudhary, N., & Pandey, C. (2023). Incidence and causes of cancellation of elective surgery on the scheduled day in a tertiary care hospital of India – A cross-sectional study. Journal of Indira Gandhi Institute Of Medical Science, 9(2), 165–169. https://doi.org/10.4103/jigims.jigims_25_23
5. Damaševičius, R., Maskeliūnas, R., & Blažauskas, T. (2023). Serious Games and Gamification in Healthcare: A Meta-Review. Information, 14(2), 105. https://doi.org/10.3390/info14020105
6. Deci, E. L., & Ryan, R. M. (1985). Intrinsic Motivation and Self-Determination in Human Behavior. Springer US. https://doi.org/10.1007/978-1-4899-2271-7
7. Hans, E. W., Herroelen, W., Leus, R., & Wullink, G. (2007). A hierarchical approach to multi-project planning under uncertainty. Omega, 35(5), 563–577. https://doi.org/10.1016/j.omega.2005.10.004
8. Idson, L. C., Chugh, D., Bereby&Meyer, Y., Moran, S., Grosskopf, B., & Bazerman, M. (2004). Overcoming focusing failures in competitive environments. Journal of Behavioral Decision Making, 17(3), 159–172. https://doi.org/10.1002/bdm.467
9. Ingadottir, B., Blondal, K., Thue, D., Zoega, S., Thylen, I., & Jaarsma, T. (2017). Development, Usability, and Efficacy of a Serious Game to Help Patients Learn About Pain Management After Surgery: An Evaluation Study. JMIR Serious Games, 5(2), e10. https://doi.org/10.2196/games.6894
10. Koh, W. X., Phelan, R., Hopman, W. M., & Engen, D. (2021). Cancellation of elective surgery: rates, reasons and effect on patient satisfaction. Canadian Journal of Surgery, 64(2), E155–E161. https://doi.org/10.1503/cjs.008119
11. Kolb, A. D., Boyatzis, E. R., & Mainemelis, C. (2001). Experiential Learning Theory: Previous Research and New Directions. In j. R. Sternberg & L.-F. Zhang (Eds.), Perspectives on thinking, learning and cognitive styles (1st ed., pp. 1–21). Taylor & Francis Group.
12. Miller-Day, M., & Hecht, M. L. (2013). Narrative Means to Preventative Ends: A Narrative Engagement Framework for Designing Prevention Interventions. Health Communication, 28(7), 657–670. https://doi.org/10.1080/10410236.2012.762861
13. Scheenstra, B., Princée, A. M. A., Imkamp, M. S. V, Kietselaer, B., Ganushchak, Y. M., van't Hof, A. W. J., & Maessen, J. G. (2021). Last-minute cancellation of adult patients scheduled for cardiothoracic surgery in a large Dutch tertiary care centre. Europe-

an Journal of Cardio-Thoracic Surgery, 61(1), 225–232. https://doi.org/10.1093/ejcts/ezab246
14. Schretlen, S., Hoefsmit, P., Kats, S., van Merode, G., Maessen, J., & Zandbergen, R. (2021). Reducing surgical cancellations: a successful application of Lean Six Sigma in healthcare. BMJ Open Quality, 10(3), e001342. https://doi.org/10.1136/bmjoq-2021-001342
15. Sharifzadeh, N., Kharrazi, H., Nazari, E., Tabesh, H., Edalati Khodabandeh, M., Heidari, S., & Tara, M. (2020). Health Education Serious Games Targeting Health Care Providers, Patients, and Public Health Users: Scoping Review. JMIR Serious Games, 8(1), e13459. https://doi.org/10.2196/13459
16. Spielberger, C. D. (1983). State-Trait Anxiety Inventory for Adults (STAI-AD). In APA PsycTests. https://doi.org/10.1037/t06496-000
17. Verschueren, S., Buffel, C., & Vander Stichele, G. (2019). Developing Theory-Driven, Evidence-Based Serious Games for Health: Framework Based on Research Community Insights. JMIR Serious Games, 7(2), e11565. https://doi.org/10.2196/11565
18. Viftrup, A., Dreyer, P., Nikolajsen, L., & Holm, A. (2021). Surgery cancellation: A scoping review of patients' experiences. Journal of Clinical Nursing, 30(3–4), 357–371. https://doi.org/10.1111/jocn.15582
19. Winter, V., Schreyögg, J., & Thiel, A. (2020). Hospital staff shortages: Environmental and organizational determinants and implications for patient satisfaction. Health Policy, 124(4), 380–388. https://doi.org/10.1016/j.healthpol.2020.01.001
20. Zeng, J., Parks, S., & Shang, J. (2020). To learn scientifically, effectively, and enjoyably: A review of educational games. Human Behavior and Emerging Technologies, 2(2), 186–195. https://doi.org/10.1002/hbe2.188
21. Zhang, C., Härenstam, K. P., Meijer, S., & Darwich, A. S. (2020). Serious Gaming of Logistics Management in Pediatric Emergency Medicine. International Journal of Serious Games, 7(1), 47–77. https://doi.org/10.17083/ijsg.v7i1.334



Discussion



This thesis set out to answer the overarching research question: ***How can we better understand and support the effective and sustainable implementation of medical technology in the operating room, considering both system-level processes and the experiences of healthcare professionals?*** To explore this question, we investigated how MedTech interacts with and influences clinical workflows in the operating room.

Findings

First, we found that optimization efforts in the OR often rely on narrow sets of metrics, with a strong emphasis on efficiency. Crucial aspects such as staff well-being are underrepresented, and insufficient attention is given to the interaction between quality and efficiency metrics. As a result, optimization strategies may inadvertently worsen other parts of the system. A broader, systems-based approach – one that aligns metrics across domains and integrates the perspectives of healthcare professionals – is essential for sustainable improvement.
Second, our investigation into the impact of OR technologies on intra-operative nurses showed that job satisfaction is shaped not only by workload, but also by the degree of engagement and perceived contribution to care. While minimally invasive and robotic-assisted procedures aim to improve outcomes, they can unintentionally reduce nurses' professional fulfillment. Addressing this requires both managerial and design strategies that promote involvement, reduce physical and mental strain, and ensure nurses' perspectives are heard when introducing new technologies.

Third, our study of OR planning strategies across Dutch hospitals highlighted structural bottlenecks, such as delayed long-term planning, unclear roles, and a lack of feedback mechanisms. Despite growing interest in automation and data-driven tools, our findings emphasize the need to first establish transparency and clarity in planning processes. Successful implementation of planning innovations requires a stepwise approach grounded in clear policies, stakeholder alignment, and system-wide accountability.
Fourth, our case study on the transferability of OR planning strategies showed that while core planning activities are consistent, successful implementation depends on alignment with local context. Applying the OPUS I framework to a specialized hospital revealed that factors like centralized planning, smaller scale, and stable staffing allow for different choices. Strategies from UMCs can be useful elsewhere, but must be adapted to local structures and governance.

Fifth, we examined how a serious game could educate future patients about the systemic causes of surgery cancellations and foster empathy for healthcare professionals. Participants who played the game showed greater understanding of OR planning challenges and higher empathy than those who read traditional materials. While not a replacement for medical preoperative education, the game can complement existing resources by highlighting system-level issues like staff shortages and bed constraints. This approach supports better communication and expectation management by bridging the gap between system dynamics and individual experiences.

Common threads

A common thread across all five studies in this thesis is the need to view MedTech not in isolation, but as part of a broader clinical ecosystem. Understanding how technology interacts with workflows requires looking beyond isolated metrics or outcomes and considering the full context in which care is delivered, including team dynamics, institutional structures, and long-term system goals. These findings are supported by others in the field. Jeilani and Hussein (2025) emphasize that organizational and environmental factors are critical to successful digital health implementation, while Buljac-Samardzic et al. (2020) highlight the importance of team dynamics in integrating new technologies into clinical practice.

Hierarchy is a key part of this context. In hospitals, hierarchical structures strongly influence how new technologies are received and used. Nurses and junior staff may hesitate to raise concerns or offer feedback, especially if their roles feel threatened or their input is not actively sought. Van Dongen et al. (2024) show how hierarchy can inhibit open communication, even when patient safety is at stake. Similarly, Lee & Lee (2024) and Lee et al. (2021) find that professional and age-based power dynamics can suppress the voices of frontline staff, leading to missed insights and disconnected innovation processes. These dynamics point to a broader lesson for engineers and innovators: reducing workload alone is not enough. While efficiency is often easy to measure, our findings show that removing tasks without considering engagement or job satisfaction can lower professional fulfillment. Alzoubi et al. (2024) similarly found that job satisfaction moderates the relationship between workload and care quality. To support sustainable innovation, transparency in workflows must come before automation.

All stakeholders need a shared understanding of how and why care processes function. Documenting and sharing workflows – whether for OR planning or daily routines – not only improves clarity and efficiency, but also empowers those with less formal authority. This helps build a more inclusive and adaptive culture around innovation. As Holden & Karsh (2010) argue through the Technology Acceptance Model, successful adoption depends on clear workflows and active user involvement from the outset.

Implications

This thesis has examined the effects of the rapidly growing presence of technology in and around the operating room. We have observed how workflows have already shifted in response to innovations such as robot-assisted surgery, while other processes, like OR planning, remain on the brink of change but often encounter resistance from those expected to engage with new systems. In several cases, technology has simplified tasks without necessarily improving the experience of work. More critically, we find a growing misalignment between the skillsets of medical professionals and the technological tools they are required to use.

This raises an essential question: is the technical workflow evolving faster than the human workflow? Surgical technologies have advanced significantly, yet the structure and composition of surgical teams have remained largely unchanged. Highly educated and clinically trained OR nurses – whose expertise is vital and whose numbers are already limited – are increasingly assigned to simpler, more technical roles during robotic procedures, leading to concerns about underutilization and diminished professional fulfillment. This tension is not unique to healthcare. Other fields have experienced similar challenges in adapting to technological change. In manufacturing and automation, for example, skilled machinists and assembly line workers once performed tasks manually or with basic mechanical tools. With the rise of automation, tasks became faster and more efficient but also more repetitive or obsolete. Some workers adapted by transitioning into higher-skilled roles such as robotics maintenance or systems engineering, while others faced displacement or were forced to retrain (Autor et al., 2003). A similar pattern emerged in banking and finance, where tellers and personal bankers once handled calculations and customer service directly. The introduction of ATMs, online banking, and financial algorithms automated much of this work, leaving behind a more specialized workforce focused on advisory roles and customer relations (Arner et al., 2015).

When comparing these developments to healthcare, several future scenarios emerge. One involves upskilling or reskilling, where nurses, planners, and other staff evolve into "health tech operators" or "data stewards," overseeing AI systems and translating their output into clinical practice (The NHS constitution, 2019). Another, perhaps more socially valued, scenario envisions overqualified staff focusing on human-centric tasks – communication, empathy, and ethical decision-making – while machines handle routine processes (Verghese et al., 2018). A more polarized scenario could also unfold, with high-skill roles (e.g., tech integration, clinical data science) and low-skill roles (e.g., basic support care) expanding, while middle-skill jobs shrink (Autor, 2015). However, given the deeply human nature of healthcare, it seems more likely that full automation will be resisted, leading instead to the adoption of hybrid systems – where technology supports but does not replace human judgment, and traditional roles are reshaped rather than removed (Greenhalgh et al., 2017).

A key factor in shaping these outcomes is the interplay between autonomy and complexity in healthcare jobs. Conventional healthcare practice is characterized by a relatively high level of autonomy, which enhances the capacity of professionals to manage complex tasks. Autonomy allows individuals to strategize, adapt, and regulate their work pace, as seen in current OR planning practices. Karasek's Demand-Control Model (1979) underscores this, suggesting that complex yet autonomous jobs are the most engaging, fostering growth, innovation, and job satisfaction. These are precisely the qualities that healthcare campaigns seek to promote in order to retain staff – by offering them perspectives and opportunities for professional development. Conversely, complex roles that lack autonomy often lead to stress, dissatisfaction, and burnout. Robotic surgery offers a cautionary example: by reducing both the complexity and autonomy of certain roles within the surgical team, it risks making work monotonous and demotivating. In other words, reducing complexity without restoring autonomy can erode job meaning and satisfaction.

It is undeniable that technology will reshape the healthcare workforce, regardless of which scenario ultimately unfolds. However, engineers and healthcare management bear a responsibility – and likely face a higher chance of success – when they develop and implement technology in ways that preserve or even enhance professional autonomy. Paradoxically, robotic surgery may offer part of the solution to staffing challenges, but only if we are willing to rethink how surgi-

cal teams are organized. By redistributing tasks to allow OR nurses to fully utilize their medical training during open surgeries, while creating space for more technically oriented staff to support robotic procedures, healthcare systems could optimize team capacity, alleviate workload pressures, and enhance professional satisfaction. In doing so, technology becomes an enabler of better care and more meaningful work, rather than a force of disruption.

Limitations

This study offers valuable insights into the interaction between MedTech and clinical workflows, but several limitations should be noted. First, despite advocating a systems approach, the study focused solely on the operating room, potentially overlooking effects on related departments like PACU or inpatient wards. Broader hospital interdependencies remain unexplored. In Chapter 2, findings are based on a single academic hospital (LUMC), where unique factors such as task-sharing among intra-operative nurses and medical trainees may have influenced results. The study did not differentiate between scrub and circulating nurses, despite known differences in their roles. A small sample size, subjective measures, and an adapted SURG-TLX tool limit generalizability and comparability. Efforts to use automated video analysis faced technical limitations in detecting fine motor tasks and handling poor lighting, further restricting objectivity. Chapters 3 and 4, focused on OR planning, relied on stakeholder interviews. These process maps may omit key elements and reflect only a moment in time. Chapter 4's conclusions are based on a single additional case, limiting transferability to other hospitals. Lastly, Chapter 5's serious game was tested with few participants. While initial feedback is positive, broader testing is needed to confirm its effectiveness.

Recommendations

Based on the findings presented in this thesis, several recommendations can be made to support more effective and sustainable implementation of medical technology in the operating room. These recommendations are aimed at different stakeholders involved in MedTech innovation, including developers, healthcare professionals, hospital administrators, researchers, and policymakers.

For MedTech innovators and developers (academia and industry):

- *Engage end users early and meaningfully, especially surgical nurses;* Their practical knowledge and lived experiences are essential for identifying usability issues, workload impact, and potential barriers to adoption.
- *Design for context, not just for function;* Innovations should be co-developed with an understanding of the specific workflows, team structures, and constraints of the hospital environment they aim to support.
- *Balance customization with adaptability;* While local tailoring increases relevance, build in mechanisms for flexibility and transferability across institutions to improve scalability and long-term impact.

For hospital leadership and OR management:

- *Clarify planning responsibilities and improve communication structures;* Lack of role clarity and poor information flow are persistent bottlenecks that hinder both daily operations and the implementation of innovations.
- *Invest in feedback loops and operational data use;* Make performance data visible and actionable at all planning levels to support continuous improvement and accountability.
- *Support staff well-being as a key condition for successful innovation;* Monitor how MedTech affects workload and morale, and ensure adequate training and support for staff adapting to new technologies.

For researchers and policy makers:

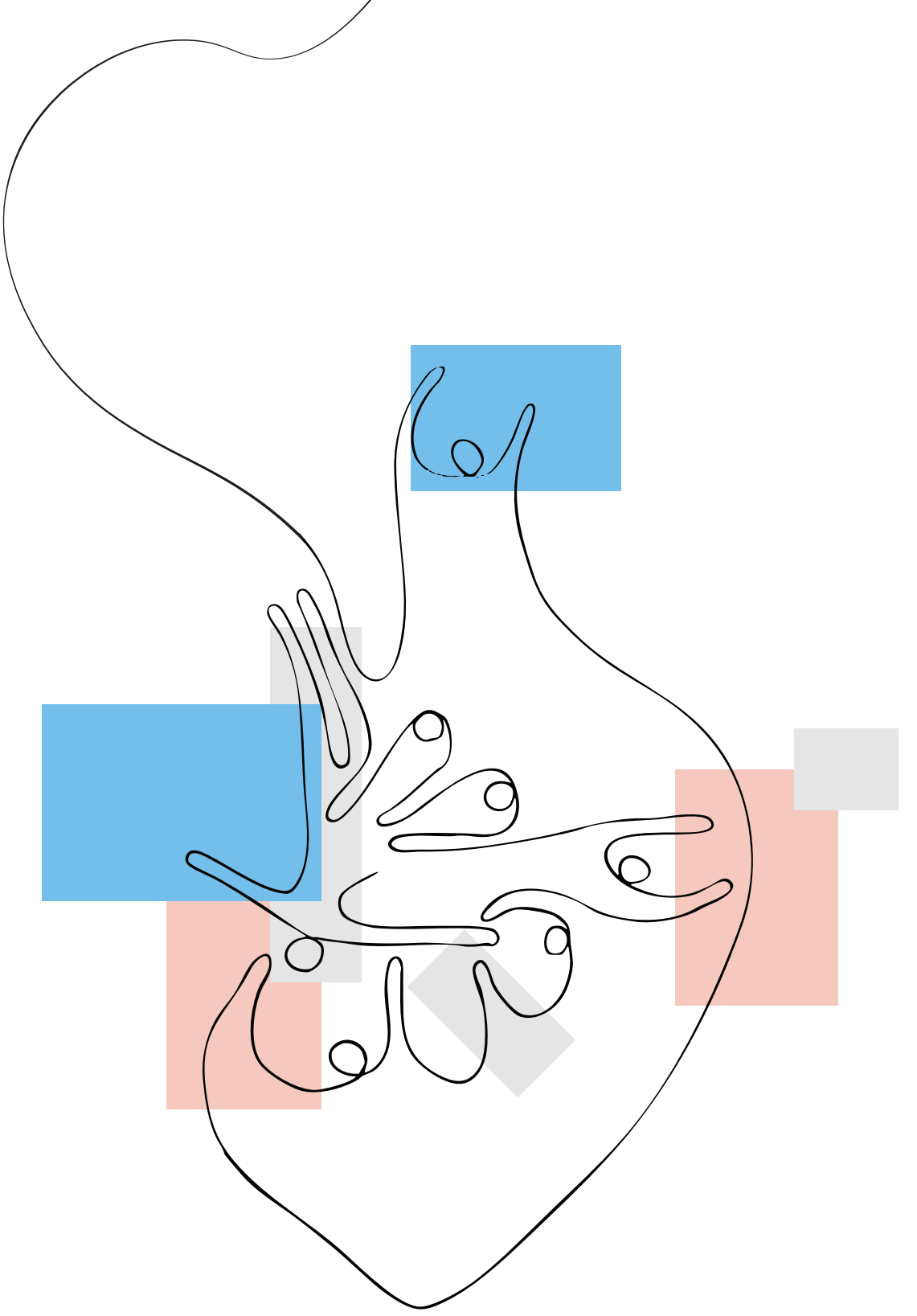
- *Include both technical and human metrics when evaluating MedTech;* Move beyond efficiency or accuracy alone – consider staff satisfaction, perceived value, and long-term organizational fit.
- *Develop frameworks that bridge academic insights and clinical practice;* Studies like OPUS and RESA can serve as templates for mapping workflows and identifying transferable strategies, but further work is needed to validate and implement them more broadly.
- *Use tools like serious games to support stakeholder understanding and dialogue;* Interactive formats can help future patients, staff, and decision-makers better grasp the complexity of OR planning and system-wide constraints.

References

1. Alzoubi, M. M., Al-Mugheed, K., Oweidat, I., Alrahbeni, T., Alnaeem, M. M., Alabdullah, A. A. S., Abdelaliem, S. M. F., & Hendy, A. (2024). Moderating role of relationships between workloads, job burnout, turnover intention, and healthcare quality among nurses. BMC Psychology, 12(1), 495. https://doi.org/10.1186/s40359-024-01891-7
2. Arner, D. W., Barberis, J. N., & Buckley, R. P. (2015). The Evolution of Fintech: A New Post-Crisis Paradigm? SSRN Electronic Journal. https://doi.org/10.2139/ssrn.2676553
3. Autor, D. H. (2015). Why Are There Still So Many Jobs? The History and Future of Workplace Automation. Journal of Economic Perspectives, 29(3), 3–30. https://doi.org/10.1257/jep.29.3.3
4. Autor, D. H., Levy, F., & Murnane, R. J. (2003). The Skill Content of Recent Technological Change: An Empirical Exploration. The Quarterly Journal of Economics, 118(4), 1279–1333. https://doi.org/10.1162/003355303322552801
5. Buljac-Samardzic, M., Doekhie, K. D., & van Wijngaarden, J. D. H. (2020). Interventions to improve team effectiveness within health care: a systematic review of the past decade. Human Resources for Health, 18(1), 2. https://doi.org/10.1186/s12960-019-0411-3
6. Greenhalgh, T., Wherton, J., Papoutsi, C., Lynch, J., Hughes, G., A'Court, C., Hinder, S., Fahy, N., Procter, R., & Shaw, S. (2017). Beyond Adoption: A New Framework for Theorizing and Evaluating Nonadoption, Abandonment, and Challenges to the Scale-Up, Spread, and Sustainability of Health and Care Technologies. Journal of Medical Internet Research, 19(11), e367. https://doi.org/10.2196/jmir.8775
7. Holden, R. J., & Karsh, B.-T. (2010). The Technology Acceptance Model: Its past and its future in health care. Journal of Biomedical Informatics, 43(1), 159–172. https://doi.org/10.1016/j.jbi.2009.07.002
8. Jeilani, A., & Hussein, A. (2025). Impact of digital health technologies adoption on healthcare workers' performance and workload: perspective with DOI and TOE models. BMC Health Services Research, 25(1), 271. https://doi.org/10.1186/s12913-025-12414-4
9. Karasek, R. A. (1979). Job Demands, Job Decision Latitude, and Mental Strain: Implications for Job Redesign. Administrative Science Quarterly, 24(2), 285. https://doi.org/10.2307/2392498
10. Lee, S. E., Choi, J., Lee, H., Sang, S., Lee, H., & Hong, H. C. (2021). Factors Influencing Nurses' Willingness to Speak Up Regarding Patient Safety in East Asia: A Systematic Review. Risk Management and Healthcare Policy, 14, 1053–1063. https://doi.org/10.2147/RMHP.S297349
11. Lee, S. E., & Lee, J. W. (2024). Effects of Hierarchical Unit Culture and Power Distance Orientation on Nurses' Silence Behavior: The Roles of Perceived Futility and Hospital Management Support for Patient Safety. Journal of Nursing Management, 2024(1). https://doi.org/10.1155/jonm/6564570
12. The NHS constitution. (2019). Preparing the healthcare workforce to deliver the digital future.
13. van Dongen, D., Guldenmund, F., Grossmann, I., & Groeneweg, J. (2024). Classification

of influencing factors of speaking-up behaviour in hospitals: a systematic review. BMC Health Services Research, 24(1), 1657. https://doi.org/10.1186/s12913-024-12138-x

14. Verghese, A., Shah, N. H., & Harrington, R. A. (2018). What This Computer Needs Is a Physician. JAMA, 319(1), 19. https://doi.org/10.1001/jama.2017.19198



Conclusion

Technology in the operating room is advancing rapidly, but the structures that surround it – team roles, workflows, and institutional processes – have remained largely unchanged. This thesis shows that while innovation is accelerating, the way we implement it is lagging behind. Medical technologies are often introduced into environments that are neither prepared nor designed to adapt, leading to friction, inefficiencies, and missed opportunities. The findings across five studies challenge the persistent assumption that better technology alone leads to better care. In reality, even the most advanced tools can fall flat if they fail to align with clinical workflows, institutional dynamics, or the professional identities of those expected to use them.

Too often, innovation is framed as a technical upgrade, rather than a socio-organizational shift. Our research reveals that intra-operative nurses – highly educated professionals – are increasingly sidelined during robotic procedures, while hospital planning systems chase automation without addressing basic process transparency or role clarity. These disconnects point to a fundamental misalignment: the technical workflow is evolving faster than the human one.

This thesis calls for a new approach to MedTech development – one that treats implementation not as a final step, but as a design challenge in its own right. Medical process engineering provides the tools to bridge the gap between abstract technical potential and concrete clinical reality. But bridging that gap also requires cultural change: accounting for hierarchies, and valuing well-being and meaning at work as much as productivity (Figure 1).

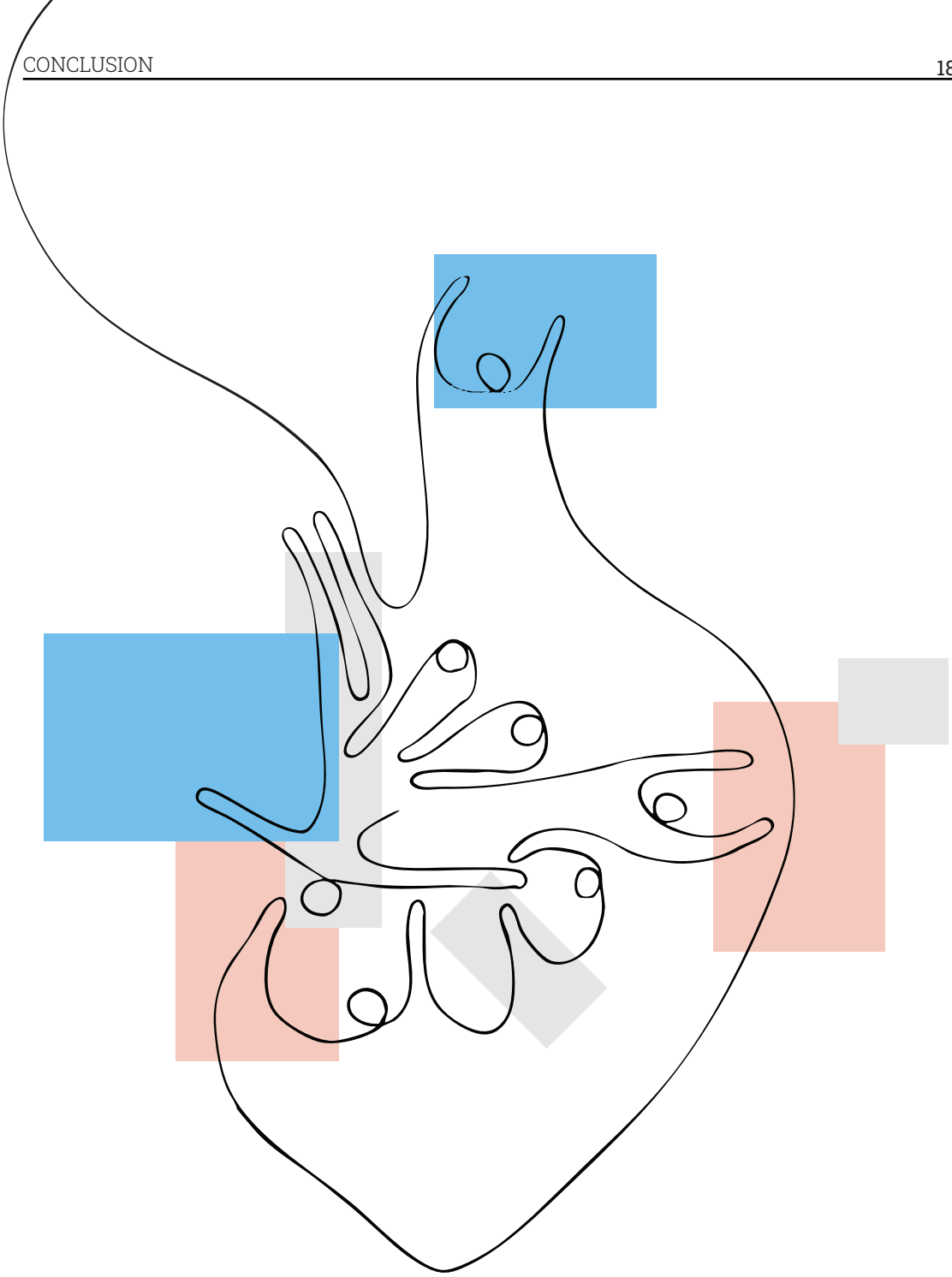


Figure 1 Top-down view of an operating room (OR), showing a patient and the OR team connected within a shared workflow. The skills and workflows of both people and technology are in sync, allowing for meaningful collaboration. By keeping people at the heart of the operation—and valuing well-being and purpose at work alongside productivity—we can bridge the gap between technical potential and clinical reality.

Dankwoord

For the English acknowledgements, see page 188

Men zegt vaak dat een PhD een eenzaam traject is. Voor mijn gevoel heb ik echter weinig alleen gedaan tijdens mijn PhD. Het boekje dat hier voor u ligt was er niet geweest zonder de bijzondere groep collega's, vrienden en familie om mij heen. Uit de grond van mijn hart wil ik hen hier bedanken.

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Secretariaat BME
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Committee members

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Communication Design for Innovation

Maarten, Caroline, Eva and **Michel**, I want to thank you for your role in my journey at TU Delft. When I was two years old, my mother sometimes took me to her work at your department. Back then I played with you in the hallway with a ball. When, in my second bachelor year in Industrial Design Engineering, I had not properly registered for the semester, I was allowed to do the Communication Design for Innovation (CDI) minor with you. Later I became a student assistant with you and I also followed the CDI master's. I grew up with you at TU Delft. You taught me to think independently and critically, and not to be afraid of complex or unclear problems. I am proud to be part of such an academic family.

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BME Secretariat

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Dad, from an early age you taught me to draw, tinker, and build. During my bachelor in Industrial Design we built wooden prototypes of bell pepper slicers together in the shed, and during my master in Biomedical Engineering we devised mechanisms for steerable needles. I think that if times in your youth had been different, you would have been a great engineer yourself. I am grateful that we were able to share so much on my path toward that. You were so proud when I started my PhD, and I would give anything in the world to be able to tell you that I finished it.

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Curriculum Vitae

Anneke Schouten - Leiden, 18 - 05 - 1994

EDUCATION

Master of Science in Biomechanical Engineering

TU Delft - Mechanical Engineering 09/2017 - 12/2020

Master of Science in Science Communication

TU Delft - Applied Sciences 09/2017 - 12/2020

Master graduation project

- Designed a communication tool to support Living Lab coordinators in successfully bringing healthcare innovations to market.
- Conducted seven interviews with engineers, doctors, and entrepreneurs involved in the ResearchOR Living Lab at Reinier de Graaf Hospital.
- Identified the importance of mapping and clearly communicating the evolving stakeholder composition in a Living Lab, enabling structure and flexibility without bureaucratic constraints.

Bachelor of Science in Industrial Design

With Honors Program

TU Delft - Industrial Design 09/2014 - 07/2017

Gymnasium, profile Nature and Technology

Bonaventura College, Leiden 09/2007 - 05/2014

EXPERIENCE

Program coordinator 4TU Health

4TU 12/2023 - 04/2025

- Coordinated brainstorms with representatives from the four Dutch technical universities (4TU).
- Developed and administered surveys to map the 4TU educational landscape.
- Assessed how well young professionals meet societal expectations.

Board member Young Medical Delta

Medical Delta 02/2021 - 02/2023

- Organized events, including an annual hackathon, symposia, and Thesis Awards.
- Facilitated collaboration across universities, industry, and healthcare, fostering multidisciplinary innovation in medical technology.

ACHIEVEMENTS

Paul Wetter Award
Award recipient for research on the impact of medical technology on intra-operative nurses' workload and job satisfaction
- SMIT 2024 conference, Taiwan.

Invited speaker Boston University
Michelle Teplensky lab, Biomechanical Engineering Department, October 2024.

University Teacher Qualification (UTQ)
Certified for the Develop, Supervise, Teach and Assess modules

Consortium member Convergence Grant
Project on Labour-Saving Technological Innovations to Enhance Job Satisfaction for Nurses. Awarded grant by the Erasmus Convergence of Health and Technology, October 2023.

CONFERENCES

iSMIT 2021 - International Society for Medical Innovation and Technology

Oslo, Norway 2022

- **Presentation** Operating Room Performance Optimization Metrics: a Systematic Review

BME 2023 - Dutch Bio-Mechanical Engineering Conference

Egmond aan zee, The Netherlands 2023

- **Poster** Care for Patients VS Care for Machines

iSMIT 2023 - International Society for Medical Innovation and Technology

Lukang, Taiwan 2023

- **Presentation** Anonymization of Surgery Videos with the Aim of Analyzing the Impact of Workload and Working Experience of Intra-operative Nurses

iSMIT 2024 - International Society for Medical Innovation and Technology

Caceres, Spain 2024

- **Presentation** Impact of Medical Technology on Intra-operative Nurses' Workload and Job satisfaction
- **Presentation** Operating Room Planning and Utilization Strategies within University Medical Centres

List of Publications

Operating Room Performance Optimization Metrics: a Systematic Review

A.M. Schouten, S.M. Flipse, K.E. van Nieuwehuizen, F.W.J. Jansen, A.C. van der Eijk, J.J. van den Dobbelsteen

2023 - Journal of Medical Systems

Impact of Operating Room Technology on Intra-operative Nurses' Workload and Job Satisfaction: an Observational Study

A.M. Schouten, R.M. Butler, C.E. Vrins, S.M. Flipse, F.W.J. Jansen, A.C. van der Eijk, J.J. van den Dobbelsteen

2025 - International Journal of Nursing Studies Advances

Towards Automatic Quantification of Operating Table Interaction in Operating Rooms

R.M. Butler, A.M. Schouten, A.C. van der Eijk, M. van der Elst, B.H.W. Hendriks, J.J. van den Dobbelsteen

2025 - International Journal of Computer Assisted Radiology and Surgery

OPUS I - Operating Room Planning and Utilization Strategies of University Medical Centers: an Observational Study

A.M. Schouten (1st), L. Horenberg (1st), S.M. Flipse, F.W.J. Jansen, A.C. van der Eijk, J.J. van den Dobbelsteen

Under review

A Serious Game to Raise Awareness among Future Patients about Day-of-Surgery Cancellations

A.M. Schouten, É. Kalmár, J.J. van den Dobbelsteen, A.C. van der Eijk, F.W. Jansen, S.M. Flipse

Under review

Appendices

I Appendix 1.1

- In Appendix 1.1, Supp. Tab. 1, the topic category and their corresponding sources are presented.

I Appendix 1.2

- Appendix 1.2, Supp. Fig. 1, shows a sunburst graph that illustrates the distribution of the labels per department (D_x).
- In Appendix 1.2, Supp. Fig. 2 zooms in on methods and corresponding topics of just the OR. This graph includes all OR data from both search criteria and shows the methods, topics and number of articles in each category.

II Appendix 2.1

- Appendix 2.1, Supp. Fig. 1, shows the SURG-TLX adaptation in which the participant scores open surgery, minimally invasive surgery and robotic-assisted surgery for each aspect of the standard SURG-TLX

II Appendix 2.2

- Appendix 2.2 contains the Data Management Plan.

II Appendix 2.3

- Appendix 2.3, Supp. Table 1, shows the annotation scheme used for the manual annotation of the videos.

II Appendix 2.4

- Appendix 2.4, Supp. Fig. 2, shows the frequency of factors impacting workload and job satisfaction as reported by nurses in the questionnaire, categorized into seven groups.

II Appendix 2.5

- Appendix 2.5, Supp. Fig. 3, shows the percentage of Measured Movement by Procedure Type

II Appendix 2.6

- Appendix 2.6, Supp. Table 2, shows a summary of Hospital Data for Gynecological Procedures in 2023.

III Appendix 3

- Appendix 3, Supp. Fig. 1, shows the planning overview of Hospital 1.
- Appendix 3, Supp. Fig. 2, shows the planning overview of Hospital 2.
- Appendix 3, Supp. Fig. 3, shows the planning overview of Hospital 3.
- Appendix 3, Supp. Fig. 4, shows the planning overview of Hospital 4.
- Appendix 3, Supp. Fig. 5, shows the planning overview of Hospital 5.
- Appendix 3, Supp. Fig. 6, shows the planning overview of Hospital 6.
- Appendix 3, Supp. Fig. 7, shows the planning overview of Hospital 7.
- Appendix 3, Supp. Fig. 8, shows the planning overview of Hospital 8.

IV Appendix 4.1

- Appendix 4.1, Supp. Fig. 1, shows the general planning overview of the UMCs.

IV Appendix 4.2

- Appendix 4.2, Supp. Fig. 2, shows the planning overview of the TCC hospital.

V Appendix 5.1

- Appendix 5.1, Supp. Material 1, shows the hospital brochure for the control group.

V Appendix 5.2

- Appendix 5.2, Supp. Fig. 1, shows an overview of a game play scenario.

V Appendix 5.3

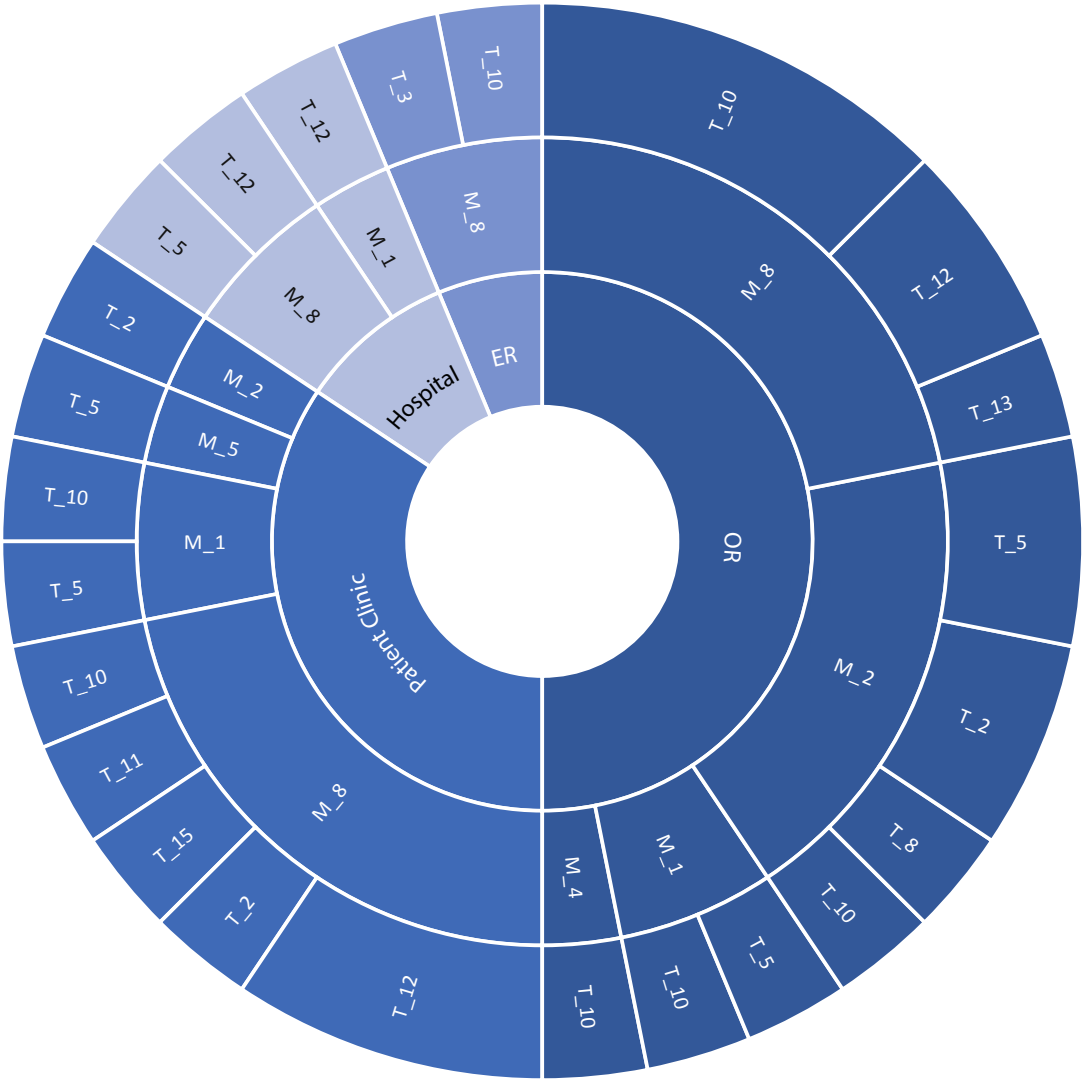
- Appendix 5.3, Supp. Material 2, shows the questionnaire for both the control and the intervention group.

I Appendix 1.1 Supplementary Table 1

Supplementary Table 1 The identified metrics and their corresponding sources.

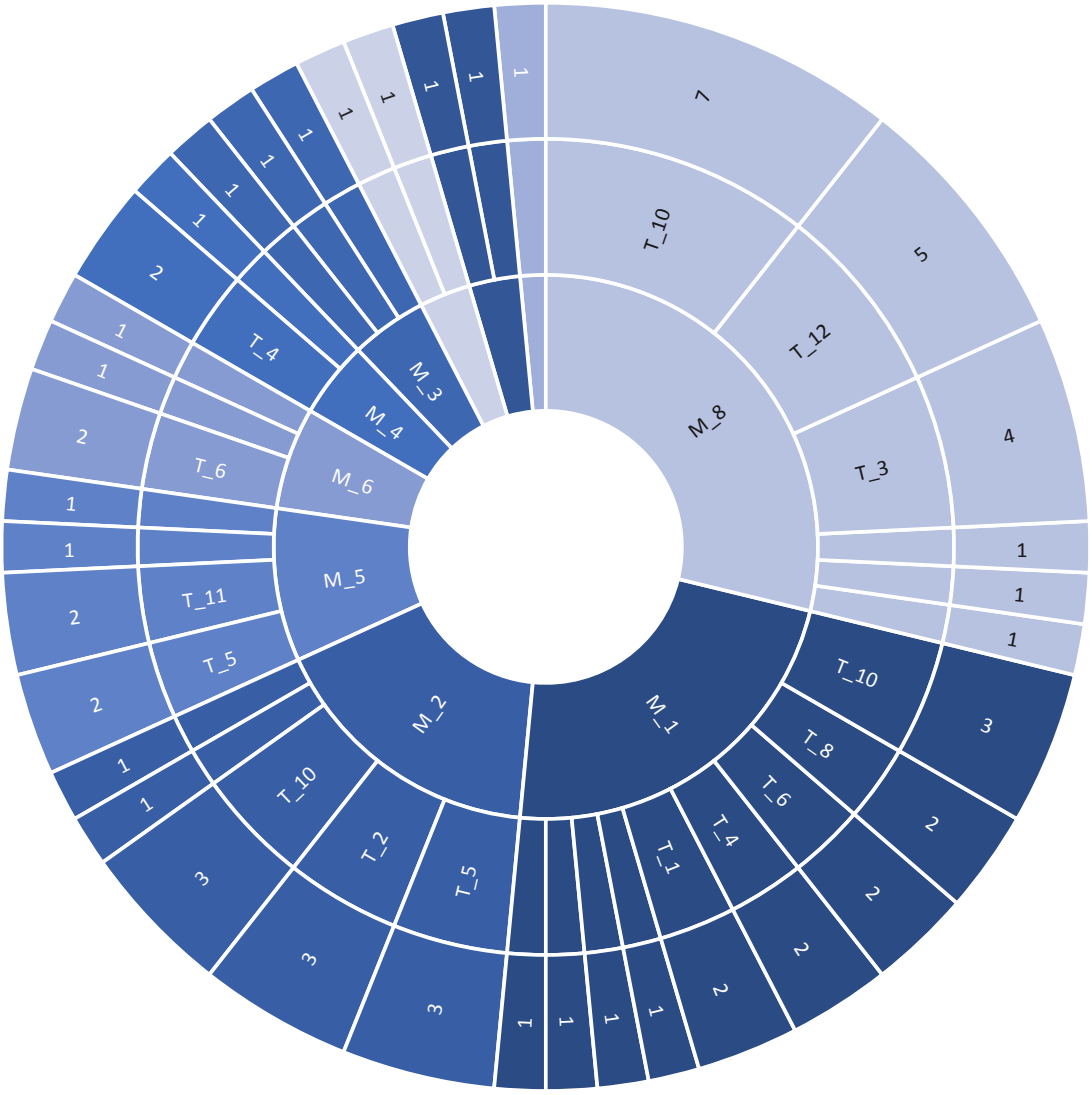
Label	Name	Source
T_1	Optimize role of surgeon	(14)
T_2	Reduce delays	(29)(30)(31)(32)(33)(34)(35)
T_3	Optimize patient flow	(18)(5)(20)(36)(37)(38)(39)(40)(41)(42)(43)(44)(44)(45)(46)(3)(47)(48)(49)
T_4	Reduce costs	(50)(8)(51)(52)(53)(54)(55)
T_5	Optimize management	(56)(57)(58)(59)(21)(10)(60)(61)(62)(22)(63)(64)(65)(66)(67)
T_6	Optimize teamwork	(68)(69)(70)(71)(72)(73)(74)
T_7	Reduce non operative time	(75)
T_8	Optimize anaesthesia procedure	(76)(77)(78)(79)(80)(81)(82)
T_9	Define OR efficiency	(17)
T_10	Optimize scheduling	(19)(83)(84)(85)(86)(87)(88)(89)(90)(91)(92)(93)(94)(95)(96)(97)(98)
T_11	Optimize overall equipment effectiveness	(99)(100)(101)(102)(103)
T_12	Optimize workflow tracking systems	(104)(105)(106)(107)(108)(109)(110)(111)(112)(113)(114)
T_13	Optimize overall productive capacity of a department	(115)(116)
T_14	Optimize department design	(117)(118)(119)(120)(121)
T_15	Reduce workload	(122)(123)

I Appendix 1.2 Supplementary Figure 1



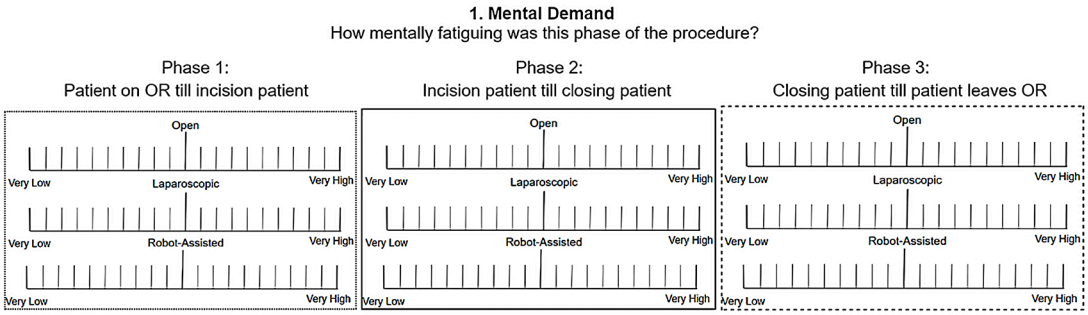
Supplementary Figure 1 Sunburst graph that illustrates the distribution of the articles per department. See Table 4 for the names and explanations of the labels in the figure.

I Appendix 1.2 Supplementary Figure 2



Supplementary Figure 2 Sunburst graph that illustrates the distribution of OR articles per method and topic. See Table 3 for the names and explanations of the labels in the figure.

II Appendix 2.1 Supplementary Figure 1



Supplementary Figure 1 SURG-TLX adaptation in which the participant scores open surgery, minimally invasive surgery and robotic-assisted surgery for each aspect of the standard SURG-TLX. Each aspect is scored this way for the three phases of the surgery: (1) entrance patient – first incision; (2) first incision – closing patient; (3) closing patient – exit patient.

II Appendix 2.2 Data Management Plan

Supplementary Table 1 The identified metrics and their corresponding sources.

Name and contact details	Ir. A.M. Schouten A.M.schouten@tudelft.nl
ORCID ID	-
Department	Gynaecology
Supervisor(s)	• Prof. Dr. F.W. Jansen, LUMC, Head of Department of Gynaecology • Dr. ir. J. Dijkstra, LUMC, Department of Radiology (Div. of Image Processing) • Dr. J.J. van den Dobbelsteen, TU Delft, BioMechanical Engineering
Project title	FLOW: Fresh Look at Operating room workFlow

Project background	Many studies have highlighted the importance of OR efficiency optimization. As a consequence, OR's have changed a lot in the last decades. Reassessing the workflow within the complex processes of the OR is therefore valuable. Obtaining reliable estimations of the duration of procedures and communicating the progress of interventions in real-time have been identified as crucial for the improvement of the efficiency of the OR. By doing so, the medical staff can anticipate and better manage the workflow. This improves the efficiency both during a procedure as well as the sequence between different procedures. Furthermore, automated recognition of OR procedures could lessen the administrative burden of the medical staff.
Description of your research	The objective of this study descriptive. It has the aim of providing insights in the daily workflow of an OR. Based on these insights, technical support with new methods for understanding, real-time monitoring and management of workflow can be generated. This way, efficiency and patient safety could be increased in the OR environment. A set of operations will be filmed on the OR of the gynaecology department. This study is non-comparative, non-interventional, single-site and observational. There is no formation of study groups who will be compared.
Project duration	Start: 01/05/2021 End: 01/05/2022
Name and contact details data management expert LUMC	Petra van Overveld P.G.M.van_Overveld@lumc.nl 071-526 3140
Funding body(ies)	Not applicable
Grant number	Not applicable
Partner organisations	Technical University Delft, Medical Delta

About this Data Management Plan

Date written	30/03/2021
Date last update	30/03/2021
Version	1.0

1. Data collection
Describing the data you will be creating/collecting

1.1 How will you collect, create and/or capture your data?

A set of GoPro video cameras will be mounted to the walls in OR9 with suction cups. The GoPro cameras will run on batteries. After each procedure, the battery will need to be swapped. At the same time, the memory cards can be taken out to transfer the data to a hard-drive using a computer. New batteries and memory cards will be placed in the cameras, to save time. During the next surgery the first set of batteries will be charged and the data from the memory cards will be transferred and deleted.

1.2 What is the format and estimated size of the data?

Data stage	Specification of dataset	Software choice	File format	Data size estimate
Raw data	Video recordings + audio	GoPro software installed on equipment	MP4	150GB
Processed data	Body part coordinates	Pose Estimation	JSON/XML	< 1GB
Results	Events or activities	x	JSON/XML	< 1GB

1.3 Will the project use existing data?

0 No
x Yes

If yes: what kind of data will you re-use?
0 Data collected by myself / my research group (previous research)
x Care data from electronic health records (EHR)
0 Data from academic collaborators (consortium partners usually with own PI)
0 Data from commercial collaborators (e.g. pharmaceutical company)
0 Data from an open access database / archive / repository
0 Data from a specialist commercial data provider
0 Data from an existing cohort, biobank or registry
0 Other data (please specify)

Is there an agreement for the use of existing data?
x No
0 Yes, I have a data transfer agreement (DTA)
0 Yes, this is written down in a consortium agreement
0 Yes, this is written down in a research agreement
0 Yes, other (please specify)

2. Data documentation
Documenting your data to help future users to understand and reuse it

2.1 How will files and folders be named and structured? How will versions and changes be handled?

	FLOW_videoRaw_BACKUP FLOW_audio FLOW_videoEdited FLOW_coordinates FLOW_results FLOW_software (version control LUMC Github with access rights) FLOW_documents
2.2	What metadata (standard) will be used to describe the dataset? (business metadata)
	x Generic metadata standard (e.g. Dublin Core) 0 Specialised metadata standard 0 Other metadata (standard) Please describe briefly: The Dublin Core metadata standard will be used to describe the total dataset, and the subsets containing clinical and questionnaire data. The metadata will be created using the Dublin Core generator.
2.3	What metadata (standard) will be used to describe and/or standardize data and variables? (technical metadata)
	x No metadata standard is used, but I will provide a detailed description of variables (dictionary) 0 Generic metadata standard (e.g. SNOMED, ICD10; see RDA Metadata Directory for examples) 0 Specialised metadata standard 0 Other metadata (standard)
	The recordings will be either in image format JPEG or PNG, or it will be video format MP4. Where possible SNOMED coding will be used for clinical variables. Data from HiX include diagnosis information using ICD10 coding. A dictionary for clinical data from HiX will be produced from variable descriptions from DIG.
2.4	What supporting information / documentation will you create to enhance understanding of the data?
	The research protocol will be stored with the data after approval by the METC. A data dictionary (code book) will be available for the clinical data. A readme.txt with a list of all available files and a description of their contents will be created at the end of the project, before archiving the data. Lab journal entries will be exported as pdf. After the project has been completed, metadata documentation will be created, specifying all relevant information needed to replicate our studies. We will also include the necessary software and tools needed for reuse and state whether embargoes, licences, commercial objectives or other conditions (like stated in informed consent agreements) have been imposed on the reuse of data. Readme.txt: README.md file - Will describe folder structure, containing files, file names and their format yyyymmdd_[type]_[name]_[version] - Camera setup and recording conditions - Type of proceduresComments in code

2.5	Indicate which laws or permits apply to your study
	Indicate which laws or permits apply to your study **x Algemene verordening Gegevensbescherming (AVG) / General Data Protection Regulation (GDPR)** **x Code of conduct for medical research (e.g. GCP)** **x Kwaliteitsborging mensgebonden onderzoek (Quality Assurance for Research involving Human Subjects)** 0 Wet Medisch Wetenschappelijk onderzoek met mensen (WMO) (Medical Research Involving Human Subjects Act) 0 Approval by ethical committee for human research (METC/CCMO) **0 Verklaring geen bezwaar from METC (letter of non-objection)** 0 Wet op geneeskundige behandelingsovereenkomst (Medical Treatment Contracts Act) 0 Gedragscode goed gebruik van lichaamsmateriaal (Code of conduct responsible use of human tissue) **x Report the collection of (in)directly identifiable (research) data to the Data Protection Officer** 0 Permission for animal experiments Centrale Commissie Dierproeven (CCD) 0 Permission for working with genetically modified organisms (GGO) 0 Other (please specify) Please add additional information if needed:

3. Data storage and security
Ensuring that all research data are stored securely and backed up or copied regularly during your research

3.1	Where will you store the different parts of your data?
	0 On departmental network storage drive (e.g. I:-drive) 0 On personal network storage drive (e.g. H:-drive) **x On a protected network storage drive (e.g. DataSafe)** 0 In a safe shared Virtual Research Environment (e.g. SharePoint Office 365) 0 In a safe personal Virtual Research Environment (e.g. OneDrive Office 365) 0 Physical storage (e.g. USB, external hard drive) 0 Cloud service (e.g. SURFdrive, Mendeley data) 0 Data management system (please specify) **x LUMC long-term storage** 0 Other (please specify)
	All data will be stored on DataSafe. Jouke Dijkstra, the project supervisor, will be in charge of the data and access to the data.
3.2	Are there any commercialisation, ethical or confidentiality restrictions about handling your data during your research?
	Yes
	Informed Consent needs to be signed by both personnel and patients.
3.3	Will you be doing research involving human subjects and/or human material?

	Will you be doing research involving human subjects and/or human material? 0 No, I will not be doing research involving human subjects and/or material 0 Yes, anonymized human material 0 Yes, pseudonimized human material **x Yes, pseudonimized human data** 0 Yes, pseudonimized human data and material
	The entire OR will be filmed, this includes patients and employees. However, in this research the video data will be translated to spatial data to detect activities and the face of patients will be blurred.
3.4	How will privacy be managed during the project? (if applicable)
	The combination of the distance of the video cameras, installed high up the walls to the employees and the employees wearing face and hear masks, make that all persons present in the OR are hard to recognize in the first place. In addition, the face of the patient will be blurred to ensure privacy. After recording, an algorithm will distract the spatial data of humans from these recordings and these will be used to extract the events. This further diminishes privacy issues.
	The data will be stored in the DataSafe and the supervisor of the project will be in control of the data. When publishing about this research, the faces of personnel will always be blurred.
3.5	How will access to the data be managed during the project?
	The data will be stored on the DataSafe with access rights for only a select group of people that are involved in the research project.
3.6	Is there any non-digital data or outputs that the project will generate? How will the non-digital data be handled and stored?
	Yes, the Informed Consents of patients and employees, which are used to get permission to film, are non-digital. These will be stored in a locked closet on the department of Radiology. They will also be scanned and stored in the DataSafe folder with the key file, since they contain personal information about the patients (name).
3.7	What costs do you expect for storage and data management during the project? How will these costs be covered?
	The expected size of the data will is estimated to be 150GB. 1TB will cost 100 euros for 1 year LTS. Hosting this data for 15 years will cost 225 euros.
	4. Data access, sharing and reuse **Managing access and security, sharing your data**
4.1	Are there any restrictions placed on sharing / reuse of some / all of your data? Will you share your data open access or with restricted access? Is there an embargo period before sharing your data?
	Because of ethical reasons and restrictions by the law, the raw video data of this project will never be shared without restrictions. Data will only be shared with people within the LUMC working on projects that follow up on this line of research.
4.2	If data is shared with restricted access: do you have a Data Transfer Agreement (DTA) available for reuse of your data?
	No, data is only used within the LUMC.

4.3	If intending to share any part of the data, do your consent forms and/or consortium agreement include information about intentions for sharing, retention of data and steps taken to protect participants privacy and confidentiality?
	Not applicable
4.4	Who is responsible for your data and has authority to grant (additional) access to your data?
	0 You 0 A colleague from the project **x Supervisor** 0 Data Access Committee 0 Funder 0 Collaborator / research partner organisation 0 Other Please describe briefly how this is arranged during your study and for the long term. Specify a person or (preferably) a role:
	This study is only just being set up. The project is financed by Medical Delta within a collaboration between TU Delft and LUMC. Jouke Dijkstra, who acts as LUMC supervisor will be in charge of granting access to the data.
	5. Data preservation and archiving **Preserving your data**
5.1	Please describe which parts of your data you will select for archiving and motivate why you would not archive (parts of) your data.
	All data needs to be archived. Unedited but compressed video data needs to be used to train algorithms in future research. The PIFs are necessary to be archived by law. The research results are necessary for the understanding and as a source for future research.
5.2	How long must your data be preserved?
	Minimal preservation time for different types of research: Pre-clinical research: 10 years Clinical research: 15 years Pharmaceutical clinical research: 20 years
5.3	Are there any requirements regarding the disposal of data?
	yes; The head of department is responsible for approval of data disposal. Paper informed consent forms will be disposed of in special locked confidential paper containers and will be destroyed as confidential material according to DIN66399-2 guidelines.
5.4	How will you ensure data findability and availability for the long term?
	I will not archive my data outside LUMC, but will ensure long term findability and availability (specify)
	Data will be stored on a drive that is accessible to the LKEB department. Jouke Dijkstra, the project supervisor, will be in charge of the data when this research part is finished. No plans are set for the deposit of metadata in a repository as of yet. Scripts might be published on GitLab.

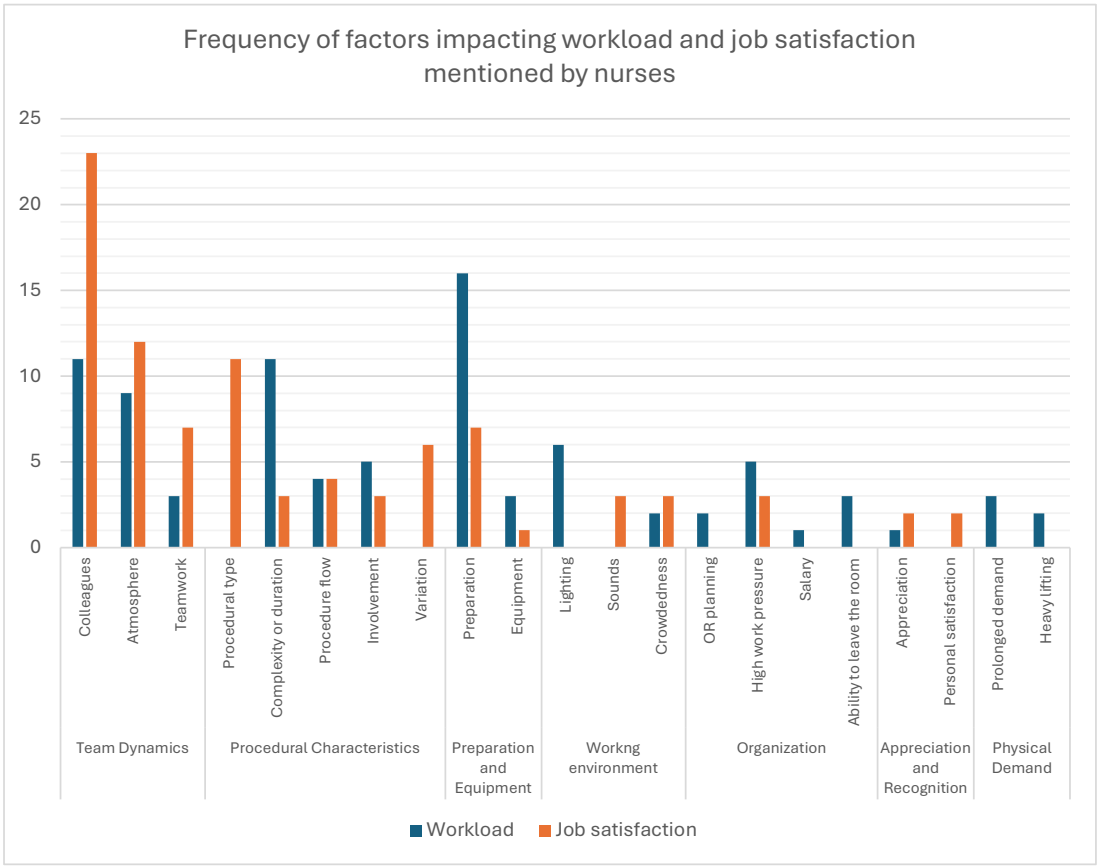
5.5	If archiving in a database / archive / repository, does it provide:
	A CoreTrustSeal ? No A Persistent Identifier (PID)? No
	Scripts might be published on GitLab. If so, we will make the work on GitLab citable by archiving the GitLab repository and assigning a DOI with a data archiving tool.
5.7	What costs (if any) will be associated with long-term storage of your data? How will these costs be covered?
	The costs for storage of about 150GB for 15 years will be 225 euros and will be covered by the Impact Project.
	5. Data preservation and archiving **Preserving your data**
6.1	Here you can put any additional information that you were not able to list in the boxes above

II Appendix 2.3 Supplementary Table 1

Supplementary Table 1 Annotation scheme used for the manual annotation of the videos. The results of these annotations were used to validate the outcomes retrieved from the automated analysis with AlphaPhose.

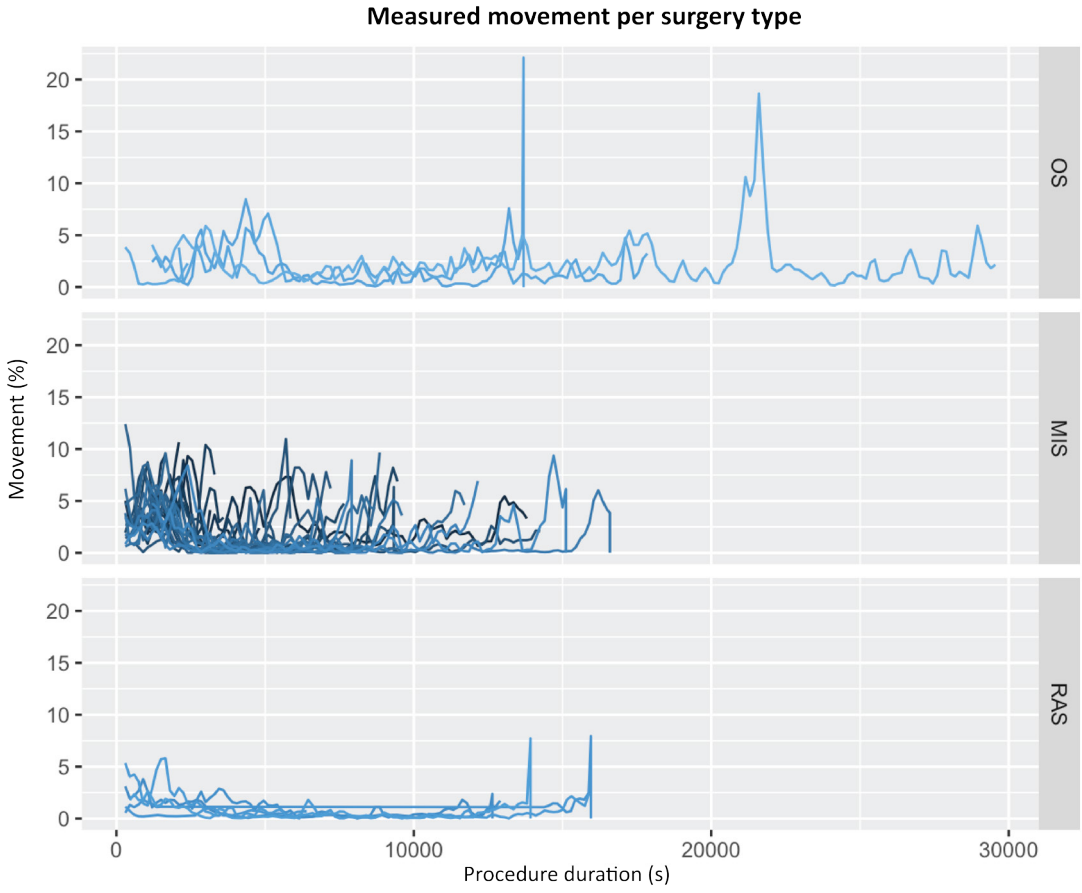
Surgical phase	Room characteristics	Operating Room team actions	Scrub nurse actions	View blockers
Patient in operating room	Light turned off	Number of staff members present over time	Not active	Patient covered with sterile sheets
Start anesthesia	Light turned on	Number of staff interacting with operating table	Handing instruments	Patient not covered with sterile sheets
End of induction	Door movements	Number of active staff members	Wrapping robot in plastic	Robot positioned at patient
Start surgical preparation		Number of non-active staff members	Moving instrument table/wagon	Robot in corner of the room
Start surgery			Unpacking instruments	
End surgery			Holding items at the operating table	
End anesthesia			Retrieving items from the operating table	
Patient leaves operating room				

Appendix 2.4 Supplementary Figure 2



Supplementary Figure 2 Frequency of factors impacting workload and job satisfaction as reported by nurses in the questionnaire, categorized into seven groups.

II Appendix 2.5 Supplementary Figure 3



Supplementary Figure 3 Percentage of Measured Movement by Procedure Type: Illustrating the percentage of total duration attributed to measured movement for open surgery (n = 4), MIS (n = 24), and RAS (n = 6). All 24 procedures have been individually plotted for each surgery type.

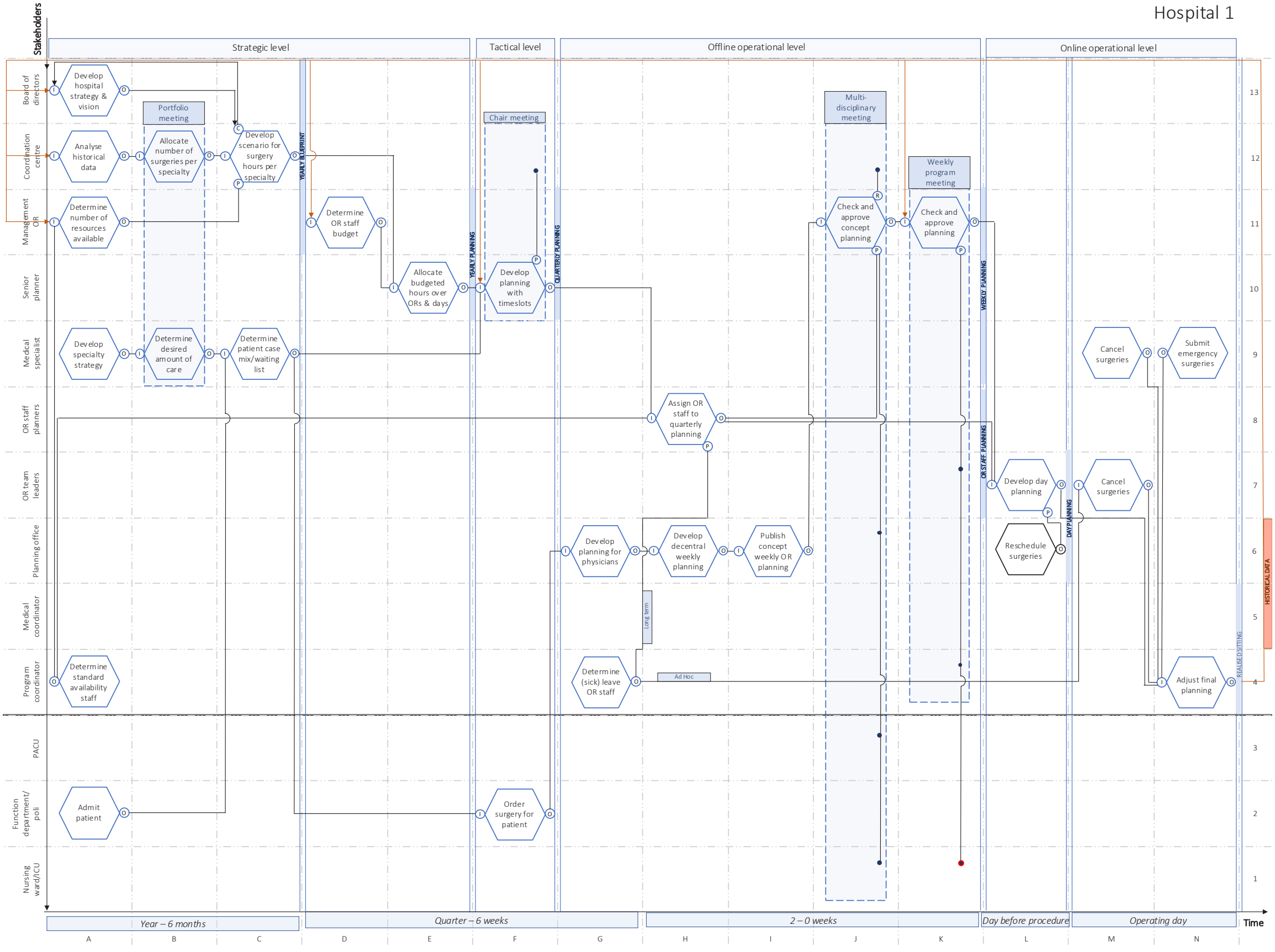
II Appendix 2.6 Supplementary Table 2

Supplementary Table 2 Summary of Hospital Data for Gynecological Procedures in 2023: Key metrics for open surgery (OS), minimally invasive surgery (MIS), and robotic-assisted surgery (RAS), including total procedure duration, difference from planned duration, ASA scores, and time spent in the dark during the cutting phase.

Procedure type	Total duration (min)	Difference from planned duration (min)	ASA score	Time in the dark (min)	Number of people in operating room (mean)
OS (N=148)	249.32 ± 107.24	−13.32 ± 59.09	2.05 ± 0.68	-	11.43
MIS (N = 236)	120.26 ± 65.52	−1.66 ± 29.26	1.78 ± 0.61	71.56 ± 55.60	9.82
RAS (N = 27)	249.41 ± 74.61	6.26 ± 66.75	1.39 ± 0.50	188.58 ± 70.65	10.42

III Appendix 3.1

Hospital 1


Stakeholders
Strategic level
Tactical level
Offline operational level
Online operational level
Board of directors
Coordination centre
Management OR
Senior planner
Medical specialist
OR staff planners
OR team leaders
Planning office
Medical coordinator
Program coordinator
PACU
Function department/ poli
Nursing ward/ICU
Develop hospital strategy & vision
Portfolio meeting
Analyse historical data
Allocate number of surgeries per specialty
Develop scenario for surgery hours per specialty
Determine number of resources available
Develop specialty strategy
Determine desired amount of care
Determine patient case mix/waiting list
YEARLY BLUEPRINT
Determine OR staff budget
Allocate budgeted hours over ORs & days
YEARLY PLANNING
Chair meeting
Develop planning with timeslots
QUARTERLY PLANNING
Assign OR staff to quarterly planning
Multi-disciplinary meeting
Check and approve concept planning
Weekly program meeting
Check and approve planning
WEEKLY PLANNING
OR STAFF PLANNING
Develop day planning
DAYPLANNING
Reschedule surgeries
Cancel surgeries
Submit emergency surgeries
Develop planning for physicians
Develop decentral weekly planning
Publish concept weekly OR planning
Long term
Ad Hoc
Determine (sick) leave OR staff
Adjust final planning
REALISED SITTING
HISTORICAL DATA
Determine standard availability staff
Admit patient
Order surgery for patient
1
2
3
4
5
6
7
8
9
10
11
12
13
Year – 6 months
Quarter – 6 weeks
2 – 0 weeks
Day before procedure
Operating day
Time
A
B
C
D
E
F
G
H
I
J
K
L
M
N

Hospital 2

Stakeholders

Strategic level | Tactical level | Offline operational level | Online operational level

Board of directors
Integral capacity centre
Management OR
Senior planner
Medical specialist
OR staff planners
OR team leaders
Planning office
Medical coordinator
Program coordinator
PACU/ recovery
Function department/ poli
Nursing ward/ICU

Develop tactical framework
Develop scenario for surgery hours per specialty
Determine OR capacity in hours per year
Check and approve scenario
Allocate surgery hours per specialty
Divide surgery hours over ORs
Allocate flexible ORs over specialties
Develop specialty strategy
Determine standard availability OR staff
Determine (sick) leave OR staff
Evaluate decentral weekly planning
Multi-disciplinary meeting
Assign staff to weekly planning
Weekly program meeting
Submit semi emergency surgeries
Cancel surgeries
Submit emergency surgeries
Manage patient waiting list
Develop decentral weekly planning
Develop ground planning
Develop quarterly planning
Publish concept quarterly OR planning
Check and approve concept planning
Check and approve planning
Fill white spots
Reschedule surgeries
Adjust final planning
Admit patient
Order surgery for patient

TACTICAL FRAMEWORK
YEARLY PLANNING
QUARTERLY PLANNING
OR STAFF PLANNING
WEEKLY PLANNING
DAY PLANNING
REALISED SITTING
HISTORICAL DATA

Year – 6 months | Quarter – 6 weeks | 2 – 0 weeks | Day before procedure | Operating day

Time

A B C D E F G H I J K L M N

1 2 3 4 5 6 7 8 9 10 11 12 13

Hospital 3

Stakeholders

Strategic level | Tactical level | Offline operational level | Online operational level

Board of directors
Capacity centre
Management OR
Senior planner
Medical specialist
OR staff planners
OR team leaders
Planning office
Medical coordinator
Program coordinator
Recovery
Function department/ poli
Nursing ward/CU

Allocate surgery hours for OR blueprint
Develop OR blueprint with surgery hours per specialty
Develop specialty strategy
Tactical planning meeting
Evaluate concept yearly planning
YEARLY BLUEPRINT
OR staff planning meeting
Adjust blueprint to staff shortage
YEARLY PLANNING
Develop and publish yearly planning
QUATERLY PLANNING
Weekly evaluation
Operational planning meeting
Submit emergency surgeries
Cancel surgeries
Develop staff planning
Manage patient waiting list
Publish complete OR planning specialty
Evaluate weekly planning
Check and approve weekly planning
Open and close ORs where necessary
Develop day planning
Make final changes planning and call patients
OR STAFF PLANNING
Assign semi emergencies to weekly planning
Manage changes elective planning
WEEKLY PLANNING
Manage sick leave
DAILY PLANNING
Verify, approve and document changes
Adjust final planning
REALISED SITTINGS
Admit patient
Order surgery
HISTORICAL DATA

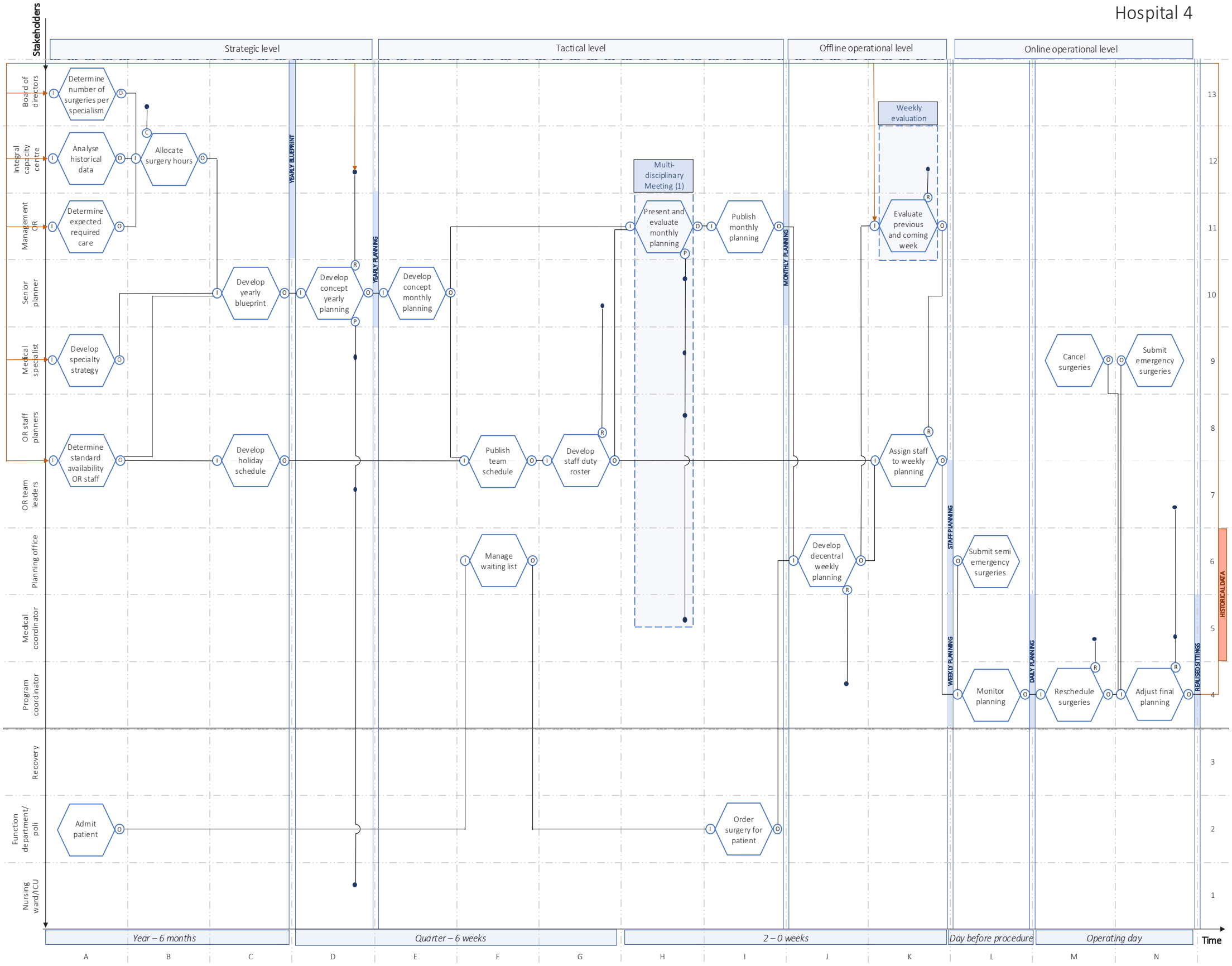
Year – 6 months | Quarter – 6 weeks | 2 – 0 weeks | Day before procedure | Operating day

Time

A B C D E F G H I J K L M N

13 12 11 10 9 8 7 6 5 4 3 2 1

Hospital 4


Stakeholders
Strategic level
Tactical level
Offline operational level
Online operational level
Board of directors
Integral capacity centre
Management OR
Senior planner
Medical specialist
OR staff planners
OR team leaders
Planning office
Medical coordinator
Program coordinator
Recovery
Function department/ poli
Nursing ward/CU
Determine number of surgeries per specialism
Analyse historical data
Allocate surgery hours
Determine expected required care
Develop specialty strategy
Develop yearly blueprint
Develop concept yearly planning
Develop concept monthly planning
Determine standard availability OR staff
Develop holiday schedule
Publish team schedule
Develop staff duty roster
Manage waiting list
Admit patient
Order surgery for patient
Multi-disciplinary Meeting (1)
Present and evaluate monthly planning
Publish monthly planning
Develop decentral weekly planning
Weekly evaluation
Evaluate previous and coming week
Assign staff to weekly planning
Submit semi emergency surgeries
Monitor planning
Reschedule surgeries
Adjust final planning
Cancel surgeries
Submit emergency surgeries
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YEARLY PLANNING
MONTHLY PLANNING
STAFF PLANNING
WEEKLY PLANNING
DAILY PLANNING
REALISED/SITTINGS
HISTORICAL DATA
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Quarter – 6 weeks
2 – 0 weeks
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Operating day
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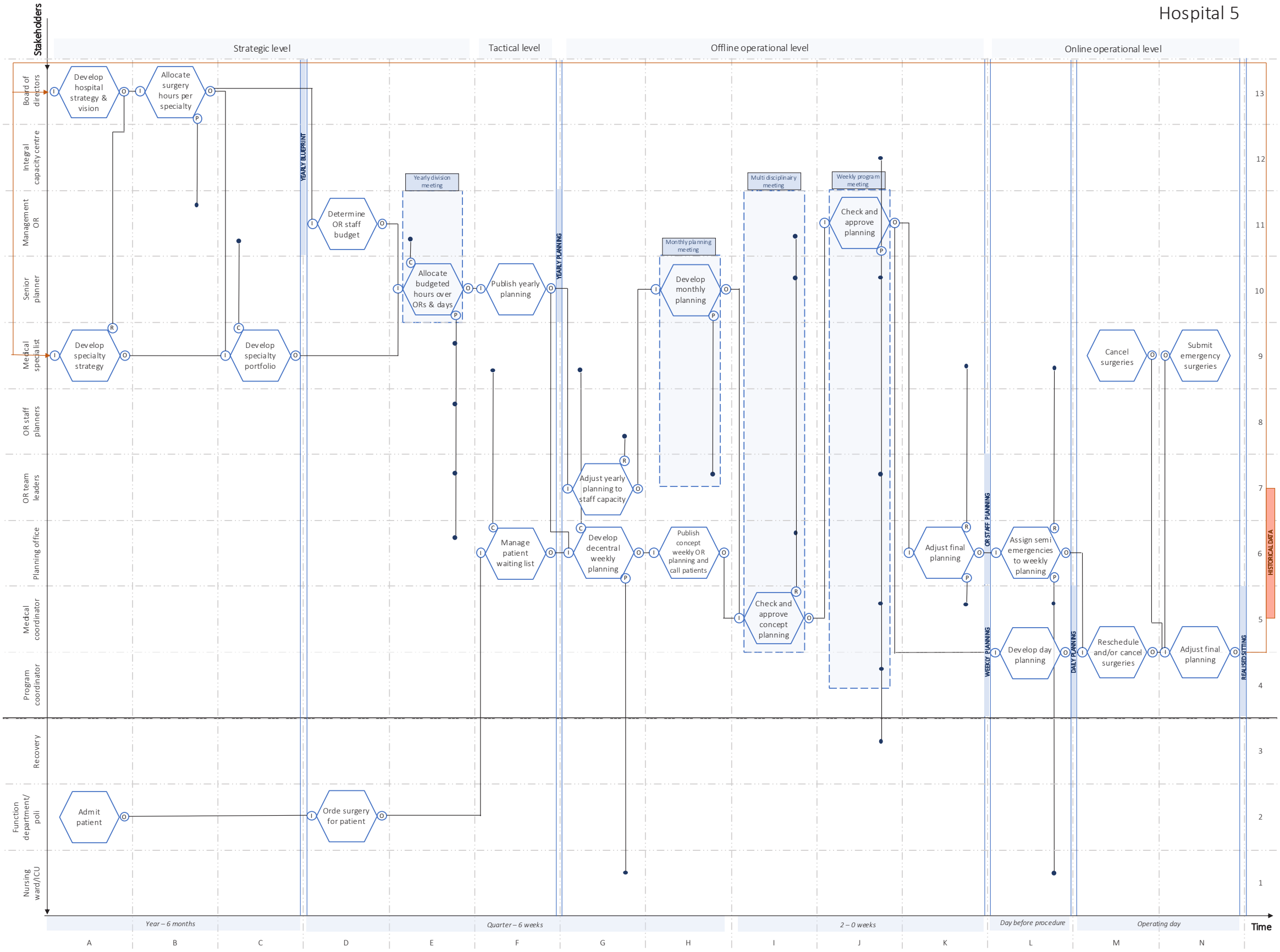
Hospital 5


Stakeholders
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Tactical level
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Online operational level
Board of directors
Integral capacity centre
Management OR
Senior planner
Medical specialist
OR staff planners
OR team leaders
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Medcal coordinator
Program coordinator
Recovery
Function department/ poli
Nursing ward/ICU
Develop hospital strategy & vision
Allocate surgery hours per specialty
Develop specialty strategy
Develop specialty portfolio
YEARLY BLUEPRINT
Determine OR staff budget
Yearly division meeting
Allocate budgeted hours over ORs & days
Publish yearly planning
YEARLY PLANNING
Monthly planning meeting
Develop monthly planning
Adjust yearly planning to staff capacity
Manage patient waiting list
Develop decentral weekly planning
Publish concept weekly OR planning and call patients
Multi disciplinary meeting
Check and approve concept planning
Weekly program meeting
Check and approve planning
Adjust final planning
ORSTAFF PLANNING
Assign semi emergencies to weekly planning
WEEKLY PLANNING
Develop day planning
DAILY PLANNING
Reschedule and/or cancel surgeries
REALISED SITTING
Adjust final planning
Cancel surgeries
Submit emergency surgeries
Admit patient
Orde surgery for patient
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Quarter – 6 weeks
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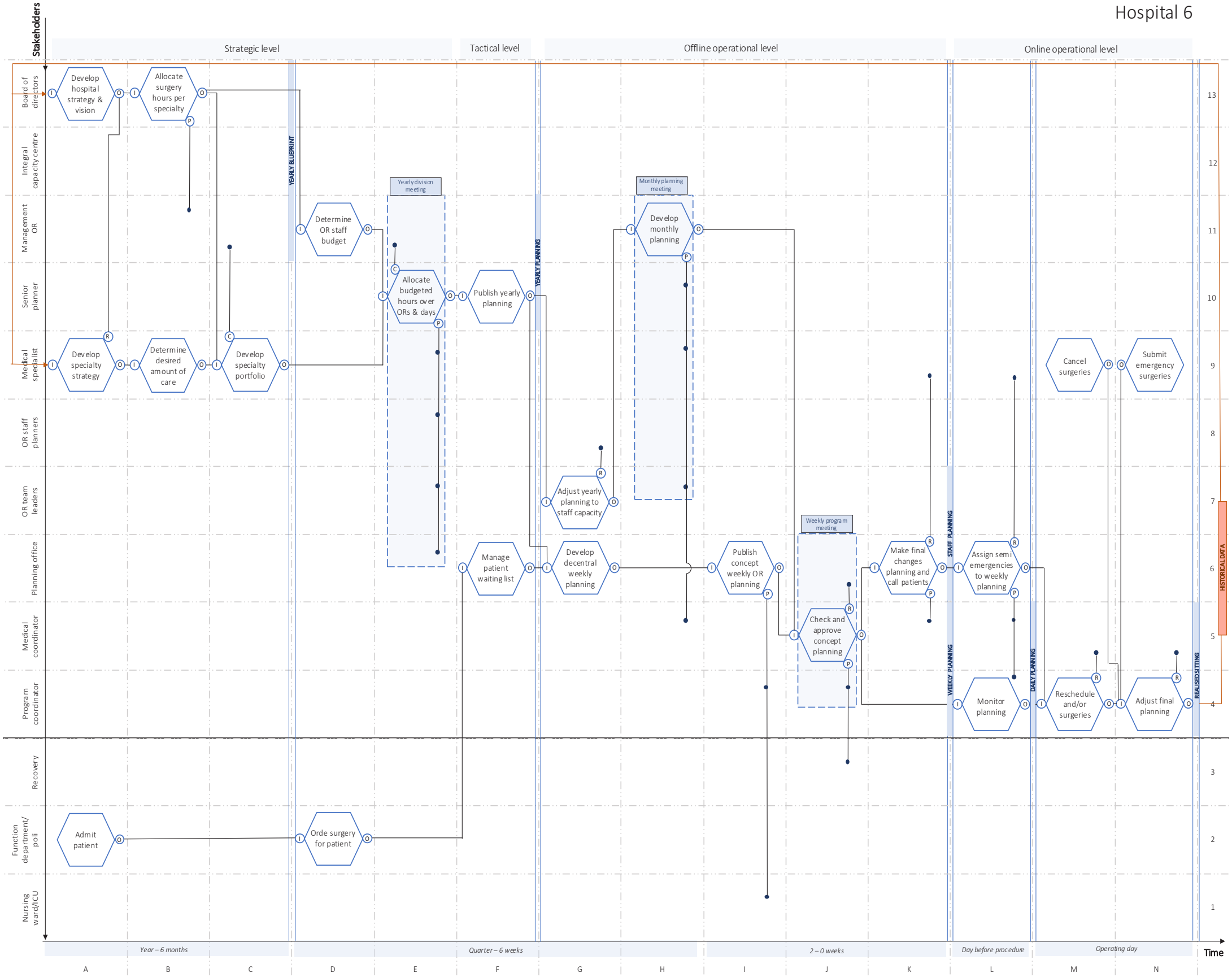
Hospital 6


Stakeholders
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Online operational level
Board of directors
Integral capacity centre
Management OR
Senior planner
Medical specialist
OR staff planners
OR team leaders
Planning office
Medical coordinator
Program coordinator
Recovery
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Nursing ward/ICU
Develop hospital strategy & vision
Allocate surgery hours per specialty
Develop specialty strategy
Determine desired amount of care
Develop specialty portfolio
YEARLY BLUEPRINT
Determine OR staff budget
Yearly division meeting
Allocate budgeted hours over ORs & days
Publish yearly planning
YEARLY PLANNING
Adjust yearly planning to staff capacity
Manage patient waiting list
Develop decentral weekly planning
Publish concept weekly OR planning
Monthly planning meeting
Develop monthly planning
Weekly program meeting
Check and approve concept planning
Make final changes planning and call patients
STAFF PLANNING
Assign semi emergencies to weekly planning
WEEKLY PLANNING
Monitor planning
DAILY PLANNING
Cancel surgeries
Submit emergency surgeries
Reschedule and/or surgeries
REALISDSITTING
Adjust final planning
HISTORICAL DATA
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Quarter – 6 weeks
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Day before procedure
Operating day
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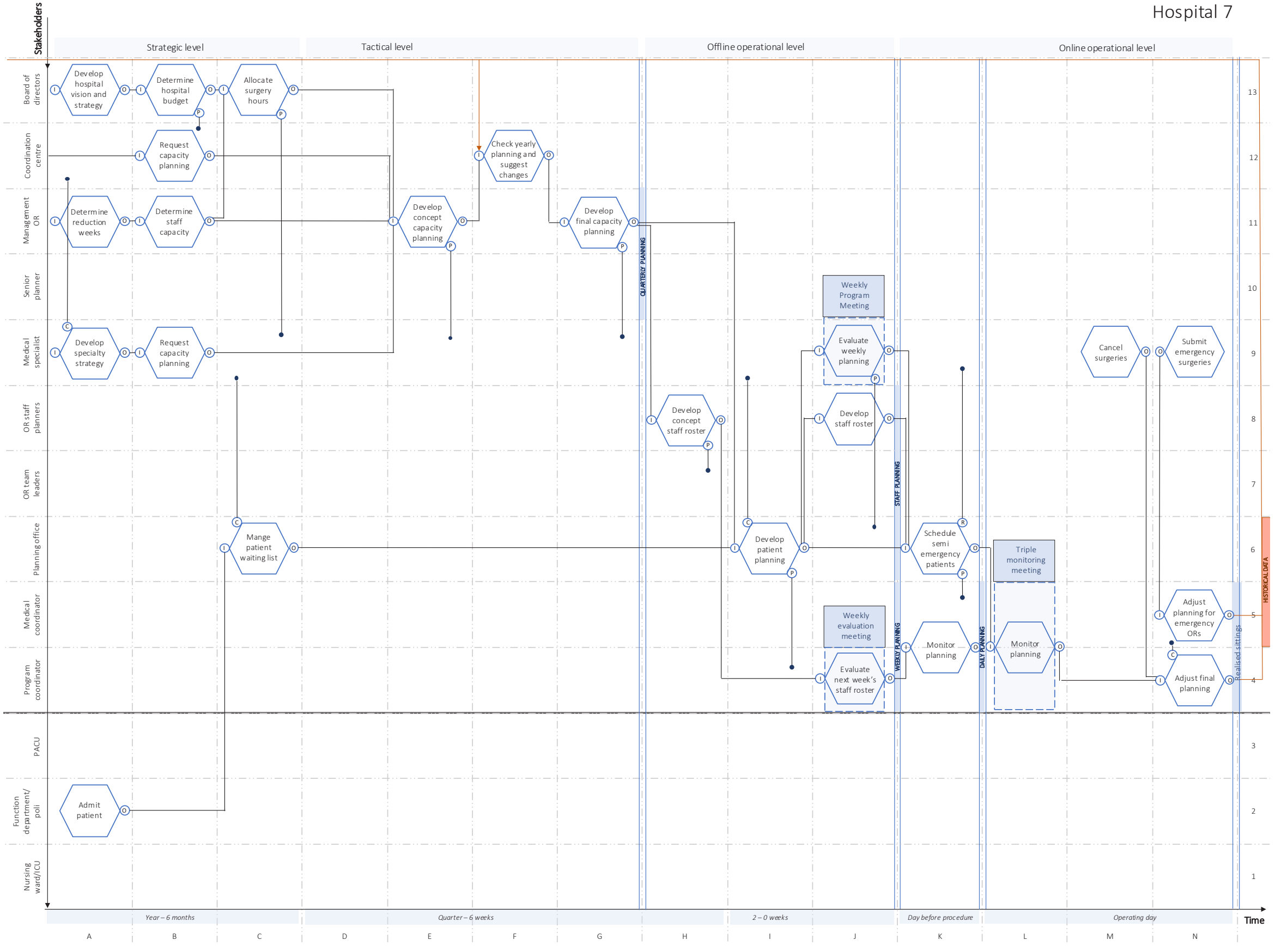
Hospital 7


Stakeholders
Strategic level
Tactical level
Offline operational level
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Board of directors
Coordination centre
Management OR
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Medical specialist
OR staff planners
OR team leaders
Planning office
Medical coordinator
Program coordinator
PACU
Function department/ poli
Nursing ward/ICU
Develop hospital vision and strategy
Determine hospital budget
Allocate surgery hours
Request capacity planning
Determine reduction weeks
Determine staff capacity
Develop concept capacity planning
Check yearly planning and suggest changes
Develop final capacity planning
Develop specialty strategy
Request capacity planning
Develop concept staff roster
Weekly Program Meeting
Evaluate weekly planning
Develop staff roster
Cancel surgeries
Submit emergency surgeries
Mange patient waiting list
Develop patient planning
Schedule semi emergency patients
Triple monitoring meeting
Weekly evaluation meeting
Evaluate next week's staff roster
Monitor planning
Monitor planning
Adjust planning for emergency ORs
Adjust final planning
Admit patient
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STAFF PLANNING
WEEKLY PLANNING
DAILY PLANNING
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Quarter – 6 weeks
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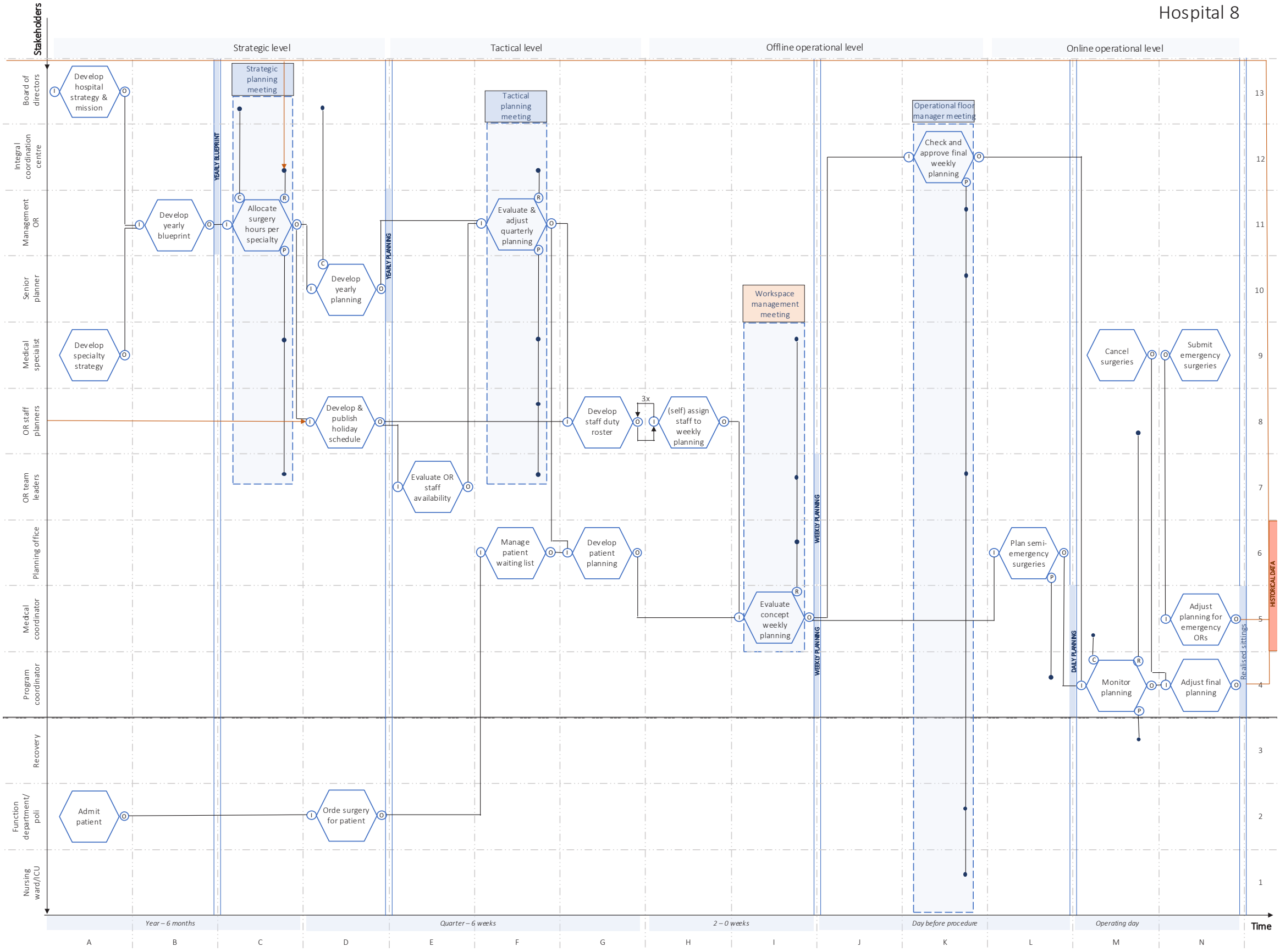
Hospital 8


Stakeholders
Strategic level
Tactical level
Offline operational level
Online operational level
Board of directors
Integral coordination centre
Management OR
Senior planner
Medical specialist
OR staff planners
OR team leaders
Planning office
Medical coordinator
Program coordinator
Recovery
Function department/ poli
Nursing ward/ICU
Develop hospital strategy & mission
Strategic planning meeting
Tactical planning meeting
Operational floor manager meeting
YEARLY BLUEPRINT
Develop yearly blueprint
Allocate surgery hours per specialty
Check and approve final weekly planning
Develop yearly planning
YEARLY PLANNING
Evaluate & adjust quarterly planning
Workspace management meeting
Develop specialty strategy
Cancel surgeries
Submit emergency surgeries
Develop & publish holiday schedule
Develop staff duty roster
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Evaluate OR staff availability
Manage patient waiting list
Develop patient planning
Plan semi-emergency surgeries
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Evaluate concept weekly planning
Adjust planning for emergency ORs
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Monitor planning
Adjust final planning
Realised sittings
HISTORICAL DATA
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V Appendix 5.1 Supplementary Material 1

Everything You Need to Know About Your Surgery

You are receiving this information because you will soon undergo a surgical procedure. Depending on the procedure, you may stay in our hospital for one or more days. Your doctor has informed you at the outpatient clinic about the expected duration of your stay.

Anesthesia

Anesthesia means numbness. You will receive anesthesia to protect your body from pain and the harmful effects of stress that surgery inevitably brings. We tailor the anesthesia to your age, weight, and health condition. Your body's reactions to the medications and procedure are carefully monitored during the operation. If necessary, bodily functions may be supported, for example, with a ventilator.

In the following sections, you will learn about the different types of anesthesia and important guidelines for the day of surgery, such as fasting instructions.

General Anesthesia

General anesthesia, also called narcosis, means your entire body is numbed, and you are unconscious. You will not notice the surgery and will not remember it afterward. Before the anesthesia, we insert an IV and connect you to a monitor to track your heart rate, blood pressure, and oxygen levels. You will receive oxygen through a mask over your nose and mouth. The anesthesia medication is administered through an IV. Once under anesthesia, the anesthesiologist places a breathing tube in your throat or windpipe. Additionally, an extra IV line or urinary catheter may be inserted if necessary.

Complications and Side Effects

- You may feel nauseous or vomit. The anesthesiologist can provide medication via IV to reduce these symptoms.
- Tooth damage may occur if inserting the breathing tube is difficult.
- You may experience hoarseness or a sore throat due to the breathing tube. This usually resolves within a few days.
- Incorrect positioning during surgery may cause nerve damage to an arm or leg, leading to tingling or weakness. This can last for weeks. If symptoms persist, please contact us.

Serious complications are very rare. The anesthesiologist will discuss any additional risks with you.

Spinal Anesthesia (Epidural)

This technique is used for surgeries on the lower body. An anesthetic fluid is injected into the lower back, temporarily disabling the nerves in your lower body, including movement in your legs. You remain conscious but can receive sedation if desired. Some people do not remember the procedure due to sedation. Spinal anesthesia reduces the risk of nausea compared to general anesthesia.

Complications and Side Effects

- A rare side effect is a headache, which worsens when sitting upright and improves when lying down. These symptoms usually disappear within a few days. If they persist, contact the Anesthesiology department.
- You may have mild back pain, which typically resolves within a few days. If it worsens or does not improve, consult the Anesthesiology department.

Regional Anesthesia (Nerve Block)

Regional anesthesia numbs only the area where the procedure is performed. This is often used for shoulder, arm, hand, leg, or foot surgeries. Using ultrasound and a small needle, anesthesia is applied around a nerve, temporarily disabling sensation (and sometimes strength) in that area. This method reduces nausea and provides better pain relief. It can be used alone or combined with general anesthesia or sedation, depending on the procedure and patient preference.

Complications and Side Effects

- Side effects and complications are rare. This method is internationally recognized as very safe.
- Possible side effects include inflammation or bruising at the injection site, or very rarely, nerve damage.

If the nerve block does not provide adequate pain relief, general anesthesia may be required.

Which Type of Anesthesia?

The anesthesiologist determines the most suitable anesthesia based on your preoperative assessment and discusses it with you. In some cases, only general anesthesia is an option. If you have a preference, discuss it with the anesthesiologist.

Breastfeeding and Anesthesia

If you are breastfeeding, please inform the anesthesiologist. In most cases, you can continue breastfeeding after surgery, regardless of the type of anesthesia.

Anesthesia for Children

Children almost always undergo surgery under general anesthesia. Depending on the procedure and the child's health, anesthesia may be administered via a mask or an IV. The anesthesiologist will inform you about this. If anesthesia is given via an IV, numbing patches will be applied to make the injection more comfortable.

Children should not undergo surgery immediately after vaccination. Follow these guidelines:

- At least 2 days must pass between a DTP or Hib vaccine and surgery.
- At least 2 weeks must pass between an MMR vaccine and surgery.

Preparing at Home

You will be informed of your surgery date by the hospital's scheduling department. This information can also be found in your patient portal. The admission time will be communicated by phone two days before your surgery.

Clothing and Aids

- For knee or foot surgery, wear loose-fitting pants or a skirt.
- If you have leg surgery and cannot walk afterward, bring crutches (available for rent at home care stores).
- For arm or hand surgery, wear a loose sweater or T-shirt. You may receive a sling, thick bandage, or cast after surgery.

Medication Use

Your medication use was discussed during the preoperative screening. The anesthesiologist will upload a letter in your patient portal with instructions regarding your medications on the day of surgery. If you must stop taking any medications, the nurse will advise you when to resume them after surgery.

Avoid aspirin-containing pain relievers (acetylsalicylic acid) in the week before surgery. If unsure, contact the preoperative screening.

Fasting Instructions

Following fasting guidelines is crucial to ensure your surgery proceeds as planned.

Laxation

For some procedures, it is necessary for you to undergo bowel cleansing. Your treating physician will inform you about this.

On the Day of Admission

Upon arrival, check in at the nursing department's reception desk. A nurse will welcome you, guide you through the process, and ask about medication use, dietary restrictions, and your emergency contact.

Attention
The exact time of the procedure is not guaranteed. A procedure may take longer than expected, or an emergency case may arise. As a result, you may have to wait for some time. We appreciate your understanding.

Preparation in the Department

For some procedures, the surgical area needs to be shaved. The nurse will do this before the operation using clippers. If prescribed, you will receive medication beforehand. For certain procedures, we may also provide a painkiller in advance to allow it time to take effect. The nurse will ask you to change into a hospital gown.

To the Operating Room

A nurse will take you to the operating complex, where an anesthesia assistant will receive you and guide you to the preparation area. An IV will be inserted, usually in your hand. Electrodes will be placed on your chest for an ECG (heart monitoring), and you will also receive a blood pressure cuff and a finger clip to measure your oxygen levels. Local anesthesia is usually administered in the recovery room.

Time-Out: An Extra Safety Check

The hospital aims to provide you with the best possible care. We work together with you to ensure a safe procedure and carefully check everything to prevent errors. That is why we will ask you several questions multiple times during your stay. This also applies when you undergo surgery.

When you enter the operating room, the entire surgical team will be present. Before you are placed under anesthesia, the so-called 'time-out procedure' takes place. The surgical team (specialist, anesthesiologist, surgical assistants, and anesthesia assistant) will verify several important details with you.

Final Check Before Starting...

Just before your surgery, we will ask you a few final questions in the operating room for verification. We will once again confirm your name, date of birth, and the procedure you are undergoing.
We will verbally check:

- Your identity
- Your date of birth
- Any allergies you may have
- The specific surgery you are having and, if applicable, the side of the body
- Any other important details for the procedure

These details are already recorded in your medical file, but this final check is essential to eliminate any last possible errors or uncertainties. If you have any questions, feel free to ask the doctor or nurse.

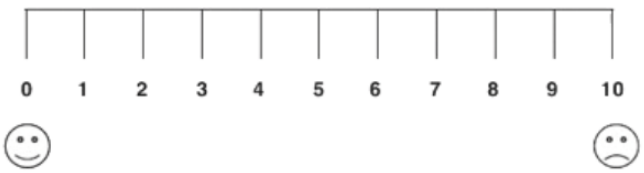
After the Surgery

You will be taken to the recovery room. Once you are sufficiently awake, have good pain control, and no complications, a nurse will transfer you back to your hospital room.

Pain Monitoring

At the hospital, we record pain levels in the nursing departments. This helps us gain better insight into the intensity of pain you experience, allowing us to respond appropriately and in a timely manner to manage it.

This means that we ask all patients on the ward daily to rate their pain on a scale. This is done alongside other routine checks, such as measuring blood pressure, pulse, and temperature. Patients who have recently undergone surgery are monitored more frequently.



Side Effects of Pain Medication

Unfortunately, painkillers can also have side effects such as nausea, vomiting, drowsiness, constipation, and dizziness. Additionally, some people may experience sweating, dry mouth, blurred or double vision, a full bladder, or itching. Always report any side effects to the nurse. They can provide further explanation or consult your treating physician if necessary. If you feel nauseous or think you are about to become nauseous, try to stay calm and avoid sudden movements. Inform the nurse as soon as possible. They can assist you and may provide medication to relieve the nausea.

Visitors

You may receive visitors shortly after surgery, depending on your condition. Check our website for visitation guidelines.

Going Home

If you are admitted for day surgery, you must always be picked up; you are not allowed to go home alone. Make sure you have someone to rely on during the first night in case you need assistance. It is recommended that you do not spend the first night alone. Sometimes, the doctor may decide that you need to stay in the hospital for an extra night. This does not necessarily mean something is wrong — people react differently to anesthesia and/or surgery. We strongly advise against working or making important decisions on the day of your surgery. All information about your stay in our hospital can be found in the patient brochure *"Your Admission to the hospital"*.

Public transport, taxis, and private transportation are generally no longer reimbursed by health insurers. However, some exceptions may apply. Please check with your health insurance provider.

V Appendix 5.2


ENTRANCE
EXIT
NURSING WARD BED 1
NURSING WARD BED 2
NURSING WARD BED 3
NURSING WARD BED 4
NURSING WARD BED 5
RECOVERY BED 1
RECOVERY BED 2
RECOVERY BED 3
RECOVERY BED 4
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NURSE
PATIENT 1
PATIENT 2
PATIENT 3
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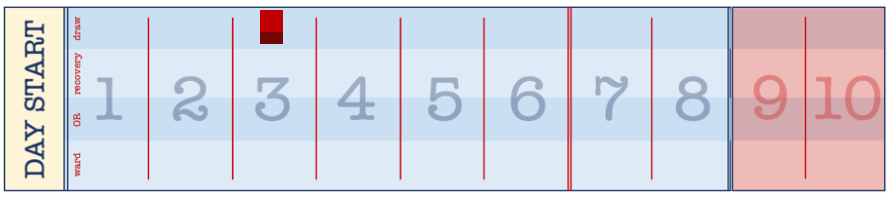
DAY START
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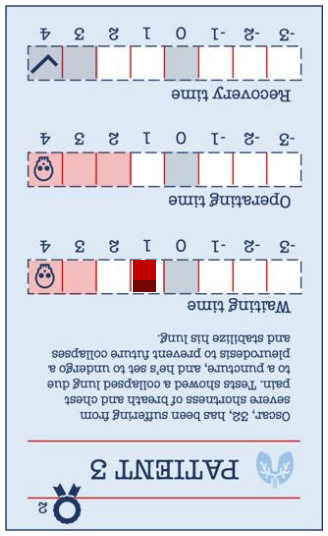
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PATIENT 3
Oscar, 52, has been suffering from severe shortness of breath and chest pain. Tests showed a collapsed lung due to a puncture, and he's set to undergo a pleurodesis to prevent future collapses and stabilize his lung.
Waiting time
Operating time
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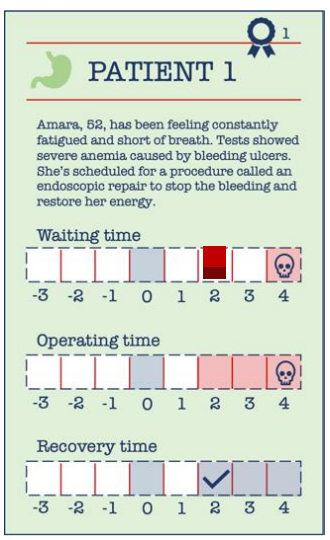
1
PATIENT 1
Amara, 52, has been feeling constantly fatigued and short of breath. Tests showed severe anemia caused by bleeding ulcers. She's scheduled for a procedure called an endoscopic repair to stop the bleeding and restore her energy.
Waiting time
Operating time
Recovery time
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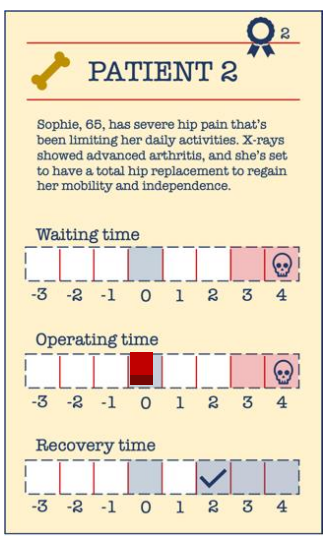
2
PATIENT 2
Sophie, 65, has severe hip pain that's been limiting her daily activities. X-rays showed advanced arthritis, and she's set to have a total hip replacement to regain her mobility and independence.
Waiting time
Operating time
Recovery time
-3 -2 -1 0 1 2 3 4

V Appendix 5.3 Supplementary material 2: questionnaire

Questionnaire for Evaluating Awareness, Empathy, and Anxiety About Surgery Planning

Dear participant,

Thank you for taking the time to complete this questionnaire. My name is Anneke Schouten, and I am conducting a study on awareness about surgery planning as part of my PhD project at TU Delft. This study aims to explore how individuals who may require surgery in the future perceive and understand the factors around surgery planning. By gaining insights into public awareness, we hope to improve communication and expectations around surgical scheduling and potential delays.

Your participation in this questionnaire is completely voluntary. The survey should take approximately 5 minutes to complete. Your responses will remain anonymous and will be used solely for research purposes. All data will be handled in accordance with data protection regulations and stored securely at TU Delft. No personally identifiable information will be collected, and you may withdraw from the study at any time without providing a reason.

Before starting the questionnaire, please confirm your consent to participate by checking the box below. Only participants who actively agree to the terms described above will be able to proceed.

☐ I have read and understood the information provided and voluntarily agree to participate in this study.

If you have any questions or concerns, please feel free to contact me at a.m.schouten@tudelft.nl.

Thank you for your valuable input!

Best regards,
Anneke Schouten

Introduction questions

1. *Have you ever had surgery?*

    - Yes
    - No

2. *Have you ever been involved in someone else's surgery process (e.g., providing support to a relative or assisting in decision-making)?*

    - Yes
    - No

Section 1

1. *How likely do you think it is that your surgery could be cancelled?*

    - 1 = Not at all likely
    - 2 = Unlikely
    - 3 = Likely
    - 4 = Very likely
    - I do not know

2. *How likely do you think it is that your surgery could be cancelled, if you are already in the hospital preparing for it?*

    - 1 = Not at all likely
    - 2 = Unlikely
    - 3 = Likely
    - 4 = Very likely
    - I do not know

3. *What factors do you think could lead to your surgery being cancelled at the last minute, even after you've arrived at the hospital?*

4. *Would you be more, or less prepared if you knew the reasons why your surgery would be cancelled?*

    - Less prepared
    - Would stay the same
    - More prepared

Section 2

5. *Imagine you are a surgeon who has to cancel a surgery due to unforeseen staff shortages. How would you explain this to the patient?*

6. *How would receiving this explanation make you feel as a patient?*

7. *To what extend do you agree with the following statements*
   (Please respond using a scale from 1 to 5, where each number represents your level of agreement.)

   1 means "Strongly disagree" – You completely disagree with the statement.
   2 means "Disagree" – You mostly disagree, though not entirely.
   3 means "Neutral" – You neither agree nor disagree, or you are unsure.
   4 means "Agree" – You mostly agree with the statement.
   5 means "Strongly agree" – You completely agree with the statement.

A) Healthcare providers face difficult decisions when surgeries are cancelled.

1 2 3 4 5

B) Surgeons must balance the needs of individual patients with the hospital's overall capacity.

1 2 3 4 5

C) I empathize with the challenges faced by hospital staff in managing resources and emergencies.

1 2 3 4 5

Section 3

8. *How anxious would you feel if your surgery were cancelled?*

   (Please respond using a scale from 1 to 5, where each number represents your level of anxiety.)

   1 means "No anxiety" – You would not feel anxious at all.
   2 means "Slight anxiety" – You would feel a little anxious, but not much.
   3 means "Moderate anxiety" – You would feel somewhat anxious, but it would be manageable.
   4 means "High anxiety" – You would feel quite anxious and uncomfortable.
   5 means "Extreme anxiety" – You would feel very anxious or distressed.

1 2 3 4 5

9. *Would you be less or more anxious if you knew the reasons why your surgery would be cancelled?*

   - Less anxious
   - Would stay the same
   - More anxious

10. *What would help reduce your anxiety about surgery cancellations?*

Section 4: Post questionnaire

11. *Name one thing you learned about surgery cancellations that you didn't know before.*

12. *How did this activity change your understanding of the factors behind surgery cancellation?*

- I understand them better
- It did not change my understanding
- I understand even less.

If you have any other comments or thoughts, please leave them below:

Post-Only Question for Intervention Group:

13. *Was there an aspect of the game that helped you understand surgery cancellations better? If yes, what was it, and why did it help?*

Technological innovation is advancing rapidly in healthcare, yet many promising solutions fail to move beyond pilots. Nowhere is this challenge more evident than in the operating room, where complex workflows, hierarchies, and human expertise shape what works in practice.
This dissertation investigates how medical technology interacts with surgical care, drawing on five studies of planning processes, workflow dynamics, and the experiences of surgical nurses. A central finding is that technology only succeeds when embedded in clinical ecosystems, rather than added as isolated upgrades.

The research shows that focusing solely on efficiency or workload reduction risks disengagement if autonomy and job satisfaction are overlooked. Instead, innovation should support – not replace – human judgment.

The thesis concludes that technological progress outpaces organizational change. Bridging this gap requires treating implementation as a design challenge, where transparency, professional involvement, and staff well-being are central to sustainable innovation.