Development of a Decision Support System for Operating Room Schedule Management

Master Thesis

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by

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Preface

You are about to read my master's thesis, which marks the conclusion of my studies in Delft. This project offered me a unique perspective on the operational side of an operating room complex. During my time at the hospital, I was fortunate to meet people who are not only highly passionate about their work but also dedicated to improving care delivery every day. This enthusiasm was truly inspiring, helping me stay positive even when I faced moments of doubt. Through this thesis, I hope to contribute to a better working environment in the operating room and assist LUMC in making a step in the right direction.

This project would not have been possible without the support and collaboration of many individuals. I want to express my gratitude to Anneke, who met with me bi-weekly, always willing to brainstorm and offer valuable feedback. I also want to thank John for his support and guidance throughout this project, giving me the freedom to approach it my way. A special thanks to Lieke for helping me make initial contact with the operating room manager, who was welcoming and did not hesitate one second to share valuable information. Finally, I would like to thank the interviewees for their openness in sharing their experiences about working in the operating room complex.

While I received valuable feedback and guidance from the professionals in the field, my family, roommate, and boyfriend provided crucial support in the background. Always reminding me not to worry about the outcome of the project, because they are proud of me anyway. Thank you all — it means the world to me.

Sanne Smid
Delft, May 2024

Summary

The operating complex is one of the most expensive units in the hospital, making its smooth operation crucial [Cardoen et al., 2010]. To achieve optimal patient scheduling, significant research has been done, mainly focusing on creating the best initial schedules [Zhu et al., 2019, Harris and Claudio, 2022]. However, the day of surgery often brings unexpected events that cause delays, cancellations, or emergency surgeries, introducing uncertainty into the schedule [Hicks et al., 2020, Van Riet and Demeulemeester, 2015]. Even though effective decision-making on the day of surgery greatly affects the operating complex's performance, research on the topic and implementation of solutions is lacking [Stepaniak et al., 2009, Dexter et al., 2004, 2016, Van Riet and Demeulemeester, 2015, Zhu et al., 2019]. Furthermore, scheduling decisions on the day of surgery have a huge impact staff satisfaction and retention, as well as patient outcomes [Fügener et al., 2017, Eijkemans et al., 2010, Viftrup et al., 2021, Al Talalwah and McIltrot, 2019]. This underscores the need to focus on scheduling decisions made on the day of surgery.

Currently, a coordinator or coordination team is responsible for overseeing the schedule's execution on the day of surgery. However, they must often rely on their own experience and judgment, which has been shown to not always yield optimal outcomes and can lead to workplace frustration [Stepaniak et al., 2010, Riley and Manias, 2006]. To address this issue, this thesis aims to equip the OR coordinator with a system that supports scheduling decisions on the day of surgery, which is universally applicable and uses readily available hospital data. By providing the OR coordinator with real-time insights into the schedule's progress, the goal is to reduce staff overtime while ensuring patients receive timely care.

To achieve this objective, the exploration begins with a detailed analysis of the operating room policy document to understand the nuances of operating room coordination. By distinguishing which elements are unique to the case study hospital and which are applicable more broadly, the goal is to identify the components of a decision support system that require a flexible design for universal applicability. This analysis reveals significant similarities across hospitals, suggesting the potential for a decision support system that could be universally used in Dutch University Medical Centers (UMCs).

Further insights are derived from the OR policy document and additional scientific sources to map out the processes leading to schedule changes on the day of surgery in a detailed process flowchart. This flowchart and the OR policy analysis serves as the basis for a proposed concept for a decision support system. Both the flowchart and the decision support system are designed with a focus on common policy statements to ensure they are transferable to other UMCs.

Interviews with operating room complex staff were performed to validate of the process flowchart and obtain their vision on the concept decision support system. Operating room complex staff suggest several minor adjustments to the process flowchart to ensure it aligns with their real-world experiences. Feedback on the proposed concept for a decision support system is positive, indicating that it addresses a significant information gap. Since both the flowchart and the concept are based on the OR policy document, this document seems to be a reliable source for mapping out schedule management processes, and guiding the design of support systems to fit them.

During validation interviews staff frequently elaborate on interactions they have with other stakeholders when making scheduling decisions on the day of surgery. This observation leads to the conclusion that a decision support system will always require human input and cannot be a fully automated standalone system. Additionally, the system must be accessible to other stakeholders to promote collaboration with the OR coordinator.

An important aspect of the proposed concept for the decision support system is its reliance on historical data for estimating the duration of surgical procedures. Through evaluation of hospital data it was discovered that the hospital's data, extracted from internal systems, is in poor condition — lacking standardization, and often incomplete. This hinders the ability to create databases with historical case durations at the procedure level.

To address this, a different approach is suggested. Rather than calculating historical durations per procedure, the average duration of cases categorized by surgical specialty and the registered planned duration, is calculated and used to construct schedules. Although this method isn't highly specific, it is expected to create schedules with a reduced likelihood of overtime, as procedure times tend to be overestimated. However, relying solely on historical data for scheduling will continue to lead to discrepancies between expected and actual durations. Various uncertainties during surgery contribute to these discrepancies, and while more detailed data could improve predictions, the current data limitations make this challenging.

As a solution, continuously tracking the OR schedule and updating it using intermediate time registrations of the surgical process is proposed to provide insights into real-time schedule development throughout the day. This approach aims to minimize the impact of uncertainties and improve the OR coordinator's ability to make more effective decisions on the day of surgery.

Analysis of the revised concept showed a significant capacity to predict overtime accurately. However, the optimal intervention window identified in this analysis did not always perform as expected when applied to control situations. This suggests that the current strength of the decision support system lies in real-time schedule tracking. The system's ability to estimate OR closing times varied depending on the accuracy of surgery estimations, update frequency and the setup of the initial schedules. Optimal conditions for precise OR closing time predictions were typically observed when surgeries had appropriately sized, often short, planned durations, along with enough data points for real-time updates. The system's capability to estimate OR closing times is expected to improve as the frequency of intermediate data points increases, especially for surgeries with longer planned durations.

To summarize, the OR policy document offers valuable guidance for defining the essential features of an effective decision support system for daily OR schedule management. By identifying the differences and similarities in operating room policies across various centers, it became possible to develop a flowchart that illustrates the workflow of an OR coordinator when faced with uncertainty on the day of surgery. Minor modifications may be needed to ensure the flowchart's applicability to other university medical centers.

This thesis also demonstrates that the structure and availability of data have a significant impact on a decision support system's input and output. The final decision support system presented in this thesis utilizes readily available hospital data to track and update the OR schedule throughout the day. Although its performance in predicting overtime shows promise, there's room for improvement. To enhance the effectiveness of such systems, future efforts should focus on standardizing input data, introducing intermediate data points, and adhering to established scheduling rules.

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Nomenclature

Abbreviations

Abbreviation	Definition
CHI	General Surgery
CTC	Cardiothoracic Surgery
DSS	Decision Support System
GYN	Gyneacology
KAA	Oral & Maxillofacial Surgery
KNO	Otorhinolaryngology
LUMC	Leiden University Medical Centre
NCH	Neurological Surgery
NFU	Nederlandse Federatie van Universitair Medische Centra
OOG	Ophthalmology
OR	Operating Room
ORT	Orthopaedics
PBH	Prolonged Business Hours
PD	Planned Duration
PM	ProMemorie
UMC	University Medical Center
URO	Urology
VRV	Obstetrics

1 Introduction

Healthcare professionals, especially those working in high-pressure environments like the operating room (OR), often experience significant workload and emotional stress [Wheelock et al., 2015, James-Scotter et al., 2019]. Additionally, within the dynamic OR setting, various sources of uncertainty lead to delays and variations on the day of surgery, resulting in extended work hours for staff [Hicks et al., 2020, Van Riet and Demeulemeester, 2015]. The combination of heavy workloads, mental stress, and long work hours makes it increasingly challenging to retain operating room staff [Wei et al., 2023, Phillips, 2020, James-Scotter et al., 2019, Fügener et al., 2017]. Though emotional burden is harder to tackle, effective scheduling and real-time evaluation of case duration can contribute to minimizing variability and addressing uncertainty, thereby reducing overtime hours and enhancing staff retention and satisfaction [Fügener et al., 2017, Eijkemans et al., 2010].

Managing the daily OR schedule effectively not only impacts staff retention and satisfaction but it can also significantly affect patients. Research conducted by Samudra et al. [2017] highlights a notable peak in cancellations occurring between 14:00 and 15:00 on the day of surgery, often attributed to delays in preceding cases. This cancellation trend sheds light on the unfortunate reality that many patients, whose procedures are cancelled in this peak, have often spent the entire day waiting at the hospital [Radboud UMC, 2024, Prins I, 2019]. This prolonged wait not only adversely impacts patient satisfaction and leads to understandable frustration but also poses potential long-term health risks [Viftrup et al., 2021, Al Talalwah and McIltrot, 2019].

Currently, the OR leans on the expertise of the OR coordinator or a coordinating team to make decisions when uncertainty arises on the day of surgery. However, the presence of unconscious biases, personal preferences, and individual experiences may result in suboptimal decisions [Stepaniak et al., 2009]. Additionally, humans often struggle to consider multiple factors simultaneously when making decisions [Morelli et al., 2022, Brust-Renck et al., 2021]. This challenge is exacerbated in the context of operating room management, where the coordination of multiple variables simultaneously is inherently complex.

Decisions in the operating room are frequently grounded in the subjective expertise of the OR coordinator, lacking transparent justification beyond personal experience or intuition. This ambiguity in decision-making contributes to disagreements among staff members, negatively impacting teamwork and placing a significant burden of responsibility on the OR coordinator [Stepaniak et al., 2009, Riley and Manias, 2006].

Despite extensive research spanning two decades on operating room scheduling, there remains no universally accepted or widely applied system for OR scheduling. Most systems are designed to solve scheduling problems related to creating initial schedules, leaving a significant gap in applications for execution of the schedule on the day of surgery [Zhu et al., 2019, Harris and Claudio, 2022]. All while the day of surgery presents the greatest opportunities for reducing overtime, optimizing utilization rates, and enhancing efficiency, as uncertainty factors come into play and decisions can directly impact OR performance [Dexter et al., 2004, Stepaniak et al., 2009, Dexter et al., 2016].

Furthermore, there are several short comings of research on scheduling systems. Much of it is focused on scheduling systems in single hospitals, largely due to the significant variations in OR policies across different institutions, complicating the development of a generalizable system. While the local context is crucial for model development and success, it also limits the broader application of such systems [Ito et al., 2016, Harris and Claudio, 2022, Zhu et al., 2019, Samudra et al., 2016]. Furthermore, many scheduling systems lack real-world implementation, with much of the research on the topic being analytical in nature making it challenging for management to extract actionable insights [Harris and Claudio, 2022, Van Veen-Berkx et al., 2016]. Clear guidance from the research community on interpreting findings for practical applications is therefore essential. Lastly, research in which systems that have been implemented in hospital environments, pay little attention to real-world obstacles during implementation phase, leaving a gap in knowledge of causes of failure or reasons for success [Ito et al., 2016, Van Veen-Berkx et al., 2016, Harris and Claudio, 2022, Samudra et al., 2016].

This study seeks to develop a decision support system (DSS) for schedule management on the day of surgery, aligning with the workflow of OR coordinators to facilitate decision-making regarding schedule adjustments on the day of surgery. By utilizing data available within hospitals and from an ongoing bench-marking initiative among operating room complexes of eight Dutch university medical centers since 2004 [van Veen-Berkx et al., 2016], the goal is to design a system applicable across various university medical centers in the Netherlands. Through a thorough assessment of OR policy and the subsequent development of a system tailored to these policies, I hope to create a solution embraced by all staff and adaptable to the specific needs of individual hospitals through minor modifications.

1.1. Problem Statement

The operating theater serves as both a significant cost and revenue center for hospitals, making its efficient management crucial for overall hospital performance [Cardoen et al., 2010]. However, managing the operating theater is challenging due to conflicting priorities, stakeholder preferences, resource scarcity, and uncertainty throughout the process [van Essen et al., 2012, Van Riet and Demeulemeester, 2015]. Additionally, with an aging population, there's an anticipated increase in demand for surgical services, further emphasizing the need for effective planning and scheduling procedures [Etzioni et al., 2003].

On the day of surgery, uncertainty starts to play out in real-time which necessitates changes made to the original schedule. Adequate decision-making with regard to scheduling decisions can significantly contribute to the performance of the OR, the well-being of staff and the satisfaction of a patient [James-Scotter et al., 2019, Al Talalwah and McIltrot, 2019]. Currently, the operating theater leans on the expertise of a schedule coordinator to make appropriate decisions. However, due to unconscious biases and personal preferences and risk-aversion level, they make subjective decisions which do not always have a positive effect on the schedule and performance of the OR [Stepaniak et al., 2009]. Moreover, different OR coordinators' subjective decisions may lead to variable OR performances, which hospitals seek to avoid [Stepaniak et al., 2009].

OR coordinators face the challenge of managing multiple ongoing ORs simultaneously, which can overwhelm cognitive capacity, hindering effective decision-making [Morelli et al., 2022, Brust-Renck et al., 2021]. Additionally, resistance from surgeons, stemming from perceived lack of transparency in decision-making processes, can lead to disputes and reduce job satisfaction for OR coordinators [Riley and Manias, 2006, James-Scotter et al., 2019]. Thus, providing data-driven support for decision-making is crucial to alleviate the burden of decision making for OR coordinators and improve decision quality.

1.2. Research Objective and Scope

The objective of this thesis is to design a decision support system (DSS) tailored to the needs of operating room coordinators, to assist planning decisions on the day of surgery. The primary focus lies on empowering OR coordinators to minimize overtime and optimize OR utilization efficiently. Furthermore, the system's design must be flexible enough to accommodate minor adaptations for seamless integration into other Dutch University Medical Centers (UMCs) utilizing similar electronic scheduling systems. To achieve this goal, several objectives are outlined;

- Evaluate differences and similarities in OR policies between hospitals
- Understand the workflow of OR coordinators in scheduling decision making
- Design Decision Support System
- Evaluate and analyse hospital data
- Analyse performance of Decision Support System

1.2.1. Scope

In developing the decision support system, the aim is to empower the OR coordinator to make informed decisions regarding the management of the daily schedule, with special attention to detecting and reducing overtime, supported by data. Currently, the focus is on incorporating basic information provided by the original schedule, such as patient details, specialties, surgeons, planned duration of cases, and operation names, along with timestamps generated throughout the progress of a surgical case and hospital data on case durations. The decision support system is being designed using data from Leiden University Medical Center (LUMC), with consideration given to structuring it in a way that facilitates its transfer to other UMCs in the Netherlands.

In the design approach, only available hospital data is taken into account, staff availability or material capacity is not considered. Staff availability is not included as rostering is typically done in advance based on the original schedule for the day. Therefore, any changes to the schedule are assumed to still have the necessary staff available. While this may be an overestimation, incorporating staff availability is currently not feasible. Moreover, the decision support system is intended to assist OR coordinators rather than replace them, allowing them to leverage their expertise and influence on the schedule.

Similarly, equipment capacity is not factored into the decision support system. Schedulers responsible for creating the schedule and ensuring that equipment is in order and available as needed. However, instances of equipment scarcity may arise during the day due to various reasons, requiring intervention from OR coordinators. Future iterations of the decision support system may explore incorporating considerations for material availability.

1.3. Research Questions

The main research question of this thesis is

What should the functionalities of a decision support system for daily schedule management be, such that OR coordinators can make optimal decisions in the face of occurring uncertainty using currently available hospital data, and it can be implemented in various University Medical Centers in the Netherlands?

Several subquestions have been constructed to help answer the main research question and support the previously posed objectives;

- What are the implications of differences and similarities in OR policies for the development of a universally applicable decision support system?
- What are the steps involved in the OR coordinator's workflow when making scheduling decisions on the day of surgery?
- How does the concept decision support system fulfill the needs of an OR Coordinator for decision making on the day of surgery?
- To what extent can current hospital data be used to create reliable schedules?
- How does hospital data shape the decision support system?
- To what extent does the decision support system offer insights that can guide scheduling decisions to prevent overtime?

2
Background Information

This chapter serves as the groundwork for this thesis as it highlights key elements relevant for development of a decision support system. It is divided into three parts, each addressing crucial aspects of the system's design. The first part delves into the sources of uncertainty during surgical procedures, pivotal for staff decision-making regarding schedule management. Additionally, scheduling decisions on the day of surgery can impact various operating room performance metrics, which will be evaluated and used to assess which performance metrics need to be incorportated in decision support system to asses the ORs performance in real-time. Lastly, information about the benchmarking OR project initiated in 2004 is provided, outlining its role in creating a standardized data registration structure utilized in developing the decision support system.

2.1. Uncertainty factors

The day of surgery is filled with uncertainties and lots of variability, as documented in various studies [Van Riet and Demeulemeester, 2015, Litvak and Long, 2000]. To effectively develop a decision support system targeting these uncertainties, it's advantageous to categorize them into broad factors that capture their impact on the schedule in a comprehensive way, without the need for too much detail. In this context, three primary factors of uncertainty - cancellation, delay, and emergency - serve as fundamental terms. Table 2.1 outlines the sources of uncertainty identified in the study by [Van Riet and Demeulemeester, 2015], associating each source with its corresponding generalized uncertainty factor. This classification facilitates a clearer understanding of the challenges faced in surgical scheduling and a better overview, allowing development of a decision support system that is not hampered by too much detail.

Table 2.1: Sources of uncertainty on the day of surgery and related uncertainty factors.

Uncertainty source	Uncertainty factor
Late arrivals of patients or no-shows	Delay or Cancellation
Late arrival of medical staff	Delay
Delay in support services	Delay
Inaccurate reservation of resources	Cancellation or Delay
Setup, clean up or change over time variability	Delay
Illness of patient or medical staff	Cancellation
Acute onset of abnormal medical conditions (e.g., infections)	Cancellation or Delay
Surgery duration variability	Delay
Duration variability of all upstream and downstream activities (length of stay)	Cancellation or Delay
Arrival of emergency patients	Emergency

This thesis primarily focuses on ensuring that the surgical schedule concludes on time at the end of the day with minimal cancellations. While variations in surgical duration, setup, clean up, turnover time, and other activities could result in early finishes, they are not considered problematic as they contribute to schedules finishing on time. Therefore, this thesis does not delve further into early finishes, as they are not part of the issue being addressed.

Some reasons for cancellation listed in Table 2.1 are not rooted in scheduling decisions. Illness of a patient is a common issue that will continue to exists no matter how well the scheduling decisions are made [Scheenstra et al., 2022]. Consequently, cases will continue to be cancelled on the day of surgery, which leave space for rescheduling of pending cases in other ORs [Dexter et al., 2016]. When faced with such decisions, schedulers must make informed choices to create alternative schedules, with a preference for minimizing overtime across all ORs and avoidable cancellations due to inaccurate reservation of resources.

2.2. Scheduling Performance Metrics

In healthcare, a multitude of performance metrics are utilized to assess the efficiency of operating rooms (ORs) [Schouten et al., 2023]. When evaluating operating room scheduling efficiency, a similar pattern emerges, with metrics such as utilization, overtime, and waiting time often employed [Rahimi and Gandomi, 2021, Harris and Claudio, 2022]. Utilization primarily concerns the utilization of ORs, typically of interest to management personnel [Marjamaa et al., 2008]. Reducing overtime as been linked to staff well-being, yet it may also be influenced by financial considerations [Fügener et al., 2017, Hicks et al., 2020]. Lastly, waiting time, particularly surgeon waiting time or idle time, is frequently examined, focusing on staff satisfaction [Rahimi and Gandomi, 2021]. Not much attention is payed to the patient in performance of scheduling solutions applicable to the day of surgery.

In developing the decision support system, the objective is not only to empower OR coordinators to make decisions aligning with management objectives and staff well-being, but also to incorporate a component for patient satisfaction. As a result, fitting performance metrics for real-time schedule evaluation are selected, ensuring relevance to each stakeholder group. The next sections delve into the definition and elaboration of these performance metrics.

2.2.1. Utilization

Utilization serves as a crucial metric for assessing the effective use of time in the operating room (OR), commonly employed by management to identify the efficiency of the OR complex [Marjamaa et al., 2008]. Various methods exist to measure utilization, with some incorporating turnover times into the calculation, while others exclude them. Additionally, debates arise regarding whether OR usage outside of designated business hours should be factored into utilization calculations [Marjamaa et al., 2008, Arcidiacono et al., 2015].

In defining the expected performance of the schedule presented by the decision support system to be developed in Part 1 of this thesis, utilization is defined as the time used to perform surgical procedures within regular allocated operating hours, often referred to as 'raw' utilization [Arcidiacono et al., 2015]. This definition excludes turnover time and procedure time occurring beyond standard operating hours from the utilization calculation.

2.2.2. Overtime

Overtime in operating room performance metrics is commonly defined as the duration an OR operates beyond its allocated hours [Van Veen-Berkx et al., 2016, Rahimi and Gandomi, 2021]. However, there exist numerous variations in definitions across research papers [Schouten et al., 2023]. For instance, some define and restrict overtime to instances where staff receive financial compensation for additional work hours [Hicks et al., 2020, Zhu et al., 2020]. In the context of utilizing overtime as a performance metric in the decision support system, it is defined as the period during which an OR remains engaged in surgical procedures after surpassing the maximum scheduled hours for the day. Therefore, the allocated hours of an OR are utilized to determine when it enters overtime.

2.2.3. Patient Waiting Time

Patient waiting time is a frequently employed performance metric in creation of schedules before execution. Typically, it is computed as the duration between the agreement for surgery and the scheduled surgery date [Zhu et al., 2020, Addis et al., 2016]. Notably, there is a lack of research which incorporate patient waiting time metrics specifically tailored for the day of surgery.

To incorporate the patient waiting time metric into the decision support system, a minor modification is made to its calculation method. Instead of measuring patient waiting time in days from scheduling to surgery execution, which pertains to a more long-term perspective, the DSS will measure patient waiting time in minutes from the initially scheduled start time to the moment the patient enters the OR. This adjustment aims to alleviate the inconvenience and distress experienced by patients while waiting in the hospital, as this waiting time significantly influences their overall experience and satisfaction [Viftrup et al., 2021].

2.3. OR Benchmarking Project

In 2004, all eight UMCs in the Netherlands collaborated to establish a nationwide benchmarking initiative within their OR departments. The primary aim of this benchmark is to assess and enhance the utilization of operating room resources and economic efficiency across the UMCs. Each UMC contributes its surgical case records to a centralized OR benchmark database, which currently holds over 1 million surgical case records. Utilizing this extensive database, key performance indicators concerning OR capacity utilization are calculated. However, access to benchmarking results, identified by UMC, is restricted to participants [van Veen-Berkx et al., 2016].

As part of this benchmarking effort, standardized time registrations for the operative process were introduced [van Houdenhoven, 2006] (see Figure 2.1). These time registrations, aimed at evaluating OR efficiency, and have been integrated into the electronic patient record systems of all UMCs. Given their uniform adoption across UMCs, these time registrations serve as an ideal dataset for assessing and potentially enhancing OR performance proactively on the day of surgery.

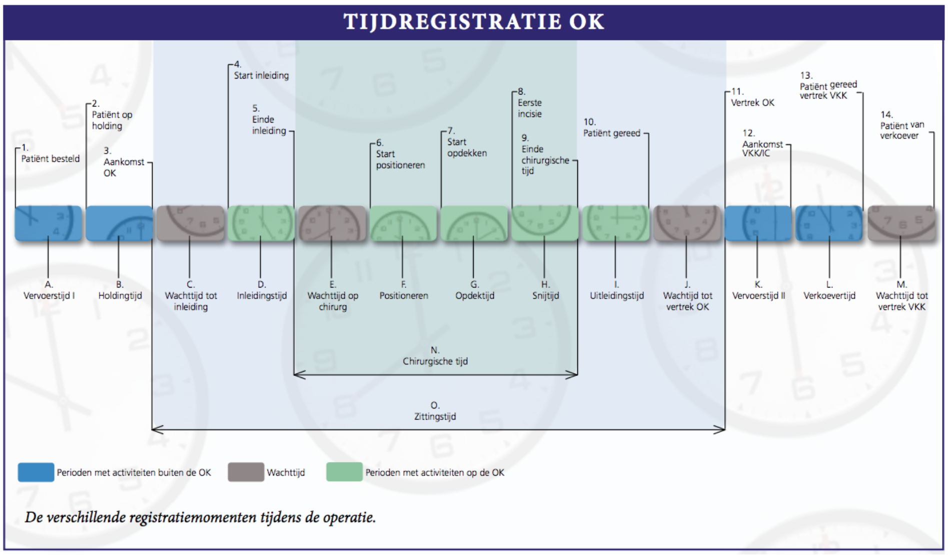


Figure 2.1: Time registration system created in the OR Benchmarking Project [van Houdenhoven, 2006].

3

Structure of Thesis

This thesis is structured into four distinct parts, each addressing specific subquestions outlined in section 1.2. In Part 1, the foundation of a decision support system tailored to the OR workflow on the day of surgery is established through an analysis of an OR policy document. Part 2 validates the findings of Part 1 through interviews with OR personnel. Part 3 focuses on the analysis of hospital data to create databases from which the decision support system can extract necessary information. Finally, Part 4 describes the revised decision support system utilizing the hospital data analyzed in Part 3 and evaluates its performance. Each part of the thesis includes its own objectives and subquestions, methods, and results.

Figure 3.1, on the next page, serves as a reading guide for this thesis. It shows how various sections are interlinked and helps to clarifies the progression from one part to the next.

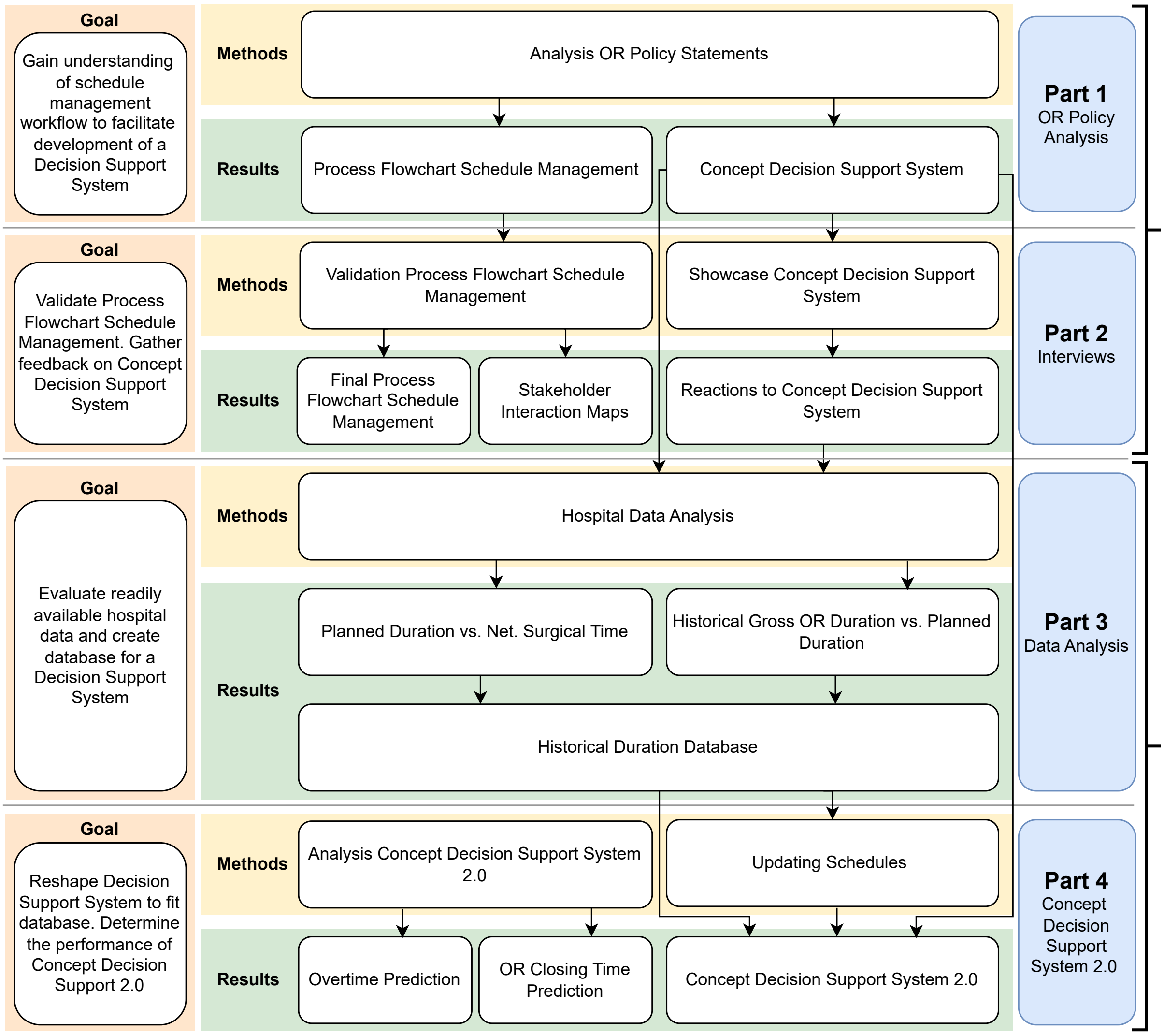


Figure 3.1: Thesis reading guide.

4

Part 1 - OR Policy Analysis

To develop a decision support system suitable for OR coordinators, alignment with existing workflows and policies within the OR complex is crucial [Schoville and Titler, 2020]. The OR policy document of a Medical Center serves as a valuable resource, outlining practical information, guidelines, and workflow for both schedule creation and schedule management of the OR. Through analysis detailed in the methods section, the OR policy document of the LUMC is scrutinized, to reveal differences and similarities across University Medical Centers' OR policies.

Moreover, leveraging insights gained from the analysis, the workflow leading to scheduling decisions on the day of surgery by an OR coordinator was visualized through a process flowchart. This visualization offers valuable insight into work practices, serving as a foundation for developing a decision support system tailored to fit seamlessly into existing workflows.

Finally, a preliminary outline of a concept decision support system was crafted based on the information gathered from the policy analysis. A mock-up of this concept was created for presentation to OR coordinators in later stages of development.

4.1. Objectives and Subquestions

The aim of OR policy analysis is to gain an understanding of schedule management workflow and decision-making processes related to scheduling on the day of surgery. Additionally, policy similarities and differences are evaluated to improve the applicability of outcomes to other UMCs. Through systematic translation of information extracted from the policy document, the following objectives are targeted;

Objectives

- Evaluate differences and similarities in OR policy among Dutch UMCs
- Understand the schedule management workflow and decision making of OR coordinators
- Design Decision Support System

The objectives have been translated into subquestions that will facilitate answering the main research question of this thesis.

Subquestions

- What are the implications of differences and similarities in OR policies for the development of a universally applicable decision support system?
- What are the steps involved in the OR coordinator's workflow when making scheduling decisions on the day of surgery?

4.2. Methods

To develop a decision support system for schedule management, practical information about hospital procedures and the pre-established schedule are collected. This data will offer insights into the daily management of the OR schedule, which is outlined in the OR policy of the LUMC. This policy document is available upon request to the researcher.

Each statement extracted from the policy document receives a reference number to facilitate easy referencing in future analyses. Additionally, the page number corresponding to each statement was recorded, and statements are translated to English. The analysis of the OR policy involves two steps. The analysis of the statements extracted from the OR policy document involves two steps. Firstly, relevant statements from the policy document are extracted and assigned labels indicating their relevance to different aspects of the decision support system. Labeling is described in section 4.2.1. Next, a statements are categorized to identify those applicable to other University Medical Centers in the Netherlands, as well as those specific to the LUMC. This process is detailed in section 4.2.2.

4.2.1. Labeling

Each statement is labeled to indicate its relevance to the decision support model. Ten different labels are used for this purpose. Table 4.1 presents all the labels along with explanations of their significance.

Table 4.1: Labels indicating relation of statements to a decision support system.

Label	Explanation
Background	Statements describe background information about the situation or context that the decision support system will be used in
Cancellation	Statements describe rules for cancelling surgery that the decision support system should take into account
Delay	Statements describe rescheduling procedures after delays have occurred
Emergency	Statements describe scheduling procedures of emergency surgeries
Guideline	Statements describe common guidelines or rules that are used in creation of new schedules
Input	Statements describe input that is needed for the decision support system to evaluate the current schedule
Performance Metric	Statements describe a performance metric used by the hospital
Performance Norm	Statements describe norms or benchmarks to which a performance metric is compared
Time Calculation	Statements describe calculation of duration of actions relevant for reporting and administration
Time Stamp	Statements describe time stamps that are recorded on the day of surgery

4.2.2. Difference and Similarities

To distinguish between information relevant in general and information specifically applicable to the LUMC, another classification method is introduced. Statements are categorized as 'Difference' when they were only relevant to the LUMC or specific situations, while statements are categorized as 'Similarity' if they apply in other UMCs as well.

Classification of statements is based on the researcher's interpretation and supported by additional evidence, such as anecdotal evidence from the workforce, testimony from the project manager of the OR Benchmarking project, or academic sources. This information is presented in table A.1 of Appendix A.

4.3. Results

Appendix A, Table A.1, contains all extracted statements related to the daily management of the OR schedule, including page numbers, an English translation of the statement, received label, difference or similarity category and an accompanying explanation for that categorization.

Statements used in the creation of the flowchart and/or concept DSS are presented in Table 4.2, including reference number, label and category. Subsequent sections will refer to the reference numbers of statements when they are used in the flowchart or incorporated into components of the concept DSS.

Table 4.2: Statements utilized for constructing the decision-making process flowchart and conceptual design of the decision support system. Labels denote the statement's relevance to the decision support system, while categories signify differences and similarities in policy approaches compared to other UMCs.

Ref. Nr.	Statement	Label	Category
4	Physical capacity OR Center; - 20 ORs, - 1 baby nursery (2 workstations) - 1 relief operations room - 6 Childrens recovery beds - 7 Holding beds - 6 PACU beds (5 active) - 14 Recovery beds - 1 Organtransplantation room	Input	Difference
5	Business hours start at 8:00 and end at 16:00 (= 1 session). Except for the first Tuesday of the month (8:30-16:00)	Input	Similarity
6	OR schedule is available in HiX	Input	Similarity
7	Anesthesiateams have responsibilities outside the OR Complex. Therefore, the OR Coordinator can decide to use less OR capacity because of need for anesthesiologist in other locations	Background	Similarity
8	Extended business hours; some medical specialists are allowed to work beyond 16:00. It is possible to request prolonged business hours for certain interventions.	Background	Similarity
18	HiX Registration moments - Patient Ordered - Patient at Holding - Patient in OR - Stopmoment 5b = Briefing - Start Anesthesia - End Induction - Start Surgical Preparation - Start Surgery - End Surgery - First Postop. Temperature - End Anesthesia - Departure OR	Time Stamp	Similarity
19	Goal of the OR Coordination Team = Oversee proceedings of planned surgeries & optimal use of emergency capacity	Background	Similarity
20	Surgery will not be cancelled if the patient has already arrived at the OR Complex (in Holding)	Cancellation	Similarity

Table 4.2 continued from previous page

Ref. Nr.	Statement	Label	Category
21	Cancellation of surgery of a patient in holding can be done in the following cases; - Immediate capacity problems (due to calamity) - If the patient was ordered by the surgeon without approval, or against the will of, the OR Coordination Team - Unexpected delay in surgery duration of the previously planned patient	Cancellation	Similarity
22	Patients can be cancelled by the OR Coordination Team or by the surgical specialty	Background	Similarity
23	The OR Coordinator is qualified to make decisions about the planning in consult with daytime coordinators and surgical specialties. They keep business hours and other locations in mind	Background	Similarity
25	In case of unexpected delays in planned surgery duration, a patient of the pending program will need to be rescheduled	Delay	Similarity
26	A surgery that needs to be rescheduled due to unexpected delays in previous cases, can be scheduled in another timeslot that has freed up	Delay	Similarity
28	Surgery information of the emergency is entered in HiX by the medical specialist. The medical specialist declares the urgency class (A(S1), B(S2), C(S3) or D(S4)) and the planned intervention to the OR Coordinator	Emergency	Similarity
29	Urgency class; - A(S1): Needs to be operated on within 1 hour - B(S2): Needs to be operated on within the day (8 hours max) - C(S3): Needs to be operated on within 24 hours. Preferably planned during business hours, and in the program of the related surgical specialty - D(S4): Needs to be operated on within a couple of days (between 24 and 72 hours). Is planned in the program of the related surgical specialty in regular business hours	Emergency	Similarity
30	Urgency class AS1 is scheduled in the first available OR (also when the OR is occupied by a different surgical specialty)	Emergency	Similarity
31	When urgency class emergency surgeries are planned in ORs where the program of the specialty was interrupted. The specialty and OR Coordination Team deliberate how to procede and when to reschedule pending patients	Emergency	Similarity
32	Dedicated emergency ORs are for Emergency cases only. However, in case of impending overtime or not to be planned elective or semi-electives the OR Coordinator can decide to deviate from this policy	Guideline	Difference

Table 4.2 continued from previous page

Ref. Nr.	Statement	Label	Category
33	For every planned patient a surgery application form is filled out and available in HiX. This form consists of; - Name Head Surgeon - Treatment code - Operation code(s) - Priority - Anesthesia technique - Positioning - Planned duration = net. surgical time (max 360 min) - Special points of attention/supplies - Special materials/equipment - Radiology/C-arch - Post-operative destination	Input	Similarity

4.3.1. Differences and Similarities

One of the goals in developing the decision support system is its transferability to other University Medical Centers. Hence, a differentiation has been established between statements pertaining to rules and factors applicable universally across University Medical Centers, and those specific to the LUMC. This distinction informs the development of differing functionalities within the decision support system to ensure its universal applicability.

Table 4.3 provides a summary of statements categorized based on their reference numbers. Remarkably, the majority of statements address issues perceived similarly across other UMCs.

Table 4.3: Reference numbers of OR policy statements devided in difference or similarity category.

Difference	Similarity
1, 2, 4, 11, 12, 13, 14, 15, 24, 27, 32, 34	3, 5, 6, 7, 8, 9, 10, 16, 17, 18, 19, 20, 21, 22, 23, 25, 26, 28, 29, 30, 31, 33, 35, 36, 37, 38, 39, 40, 41, 42

Focusing on statements categorized as differences, they have been assigned one of three labels: Guideline, Input, or Background. While many statements initially indicate policy or practical differences, upon closer examination, several can be reformulated to convey information applicable to a standardized decision support system. For instance, consider statement 4, which delineates the physical capacity of the OR complex. By incorporating the physical capacity of the OR as an input into the DSS, which can be tailored to each UMC, the DSS can still be utilized effectively across different centers.

4.3.2. Process Flowchart Schedule Management

To ensure high acceptance of the DSS, it must align with the current workflow and environment. Understanding the actions taken on the day of surgery when uncertainty factors are introduced is crucial for guiding the creation of such a system. Drawing from insights gleaned from the OR policy analysis, descriptions of uncertainty factors, Dutch healthcare guidelines, and relevant research papers on day of surgery decision-making, an outline is formulated detailing how scheduling decisions are typically made in the presence of uncertainty. The flowchart depicted in Figure 4.1 illustrates the sequence of steps leading to schedule adjustments.

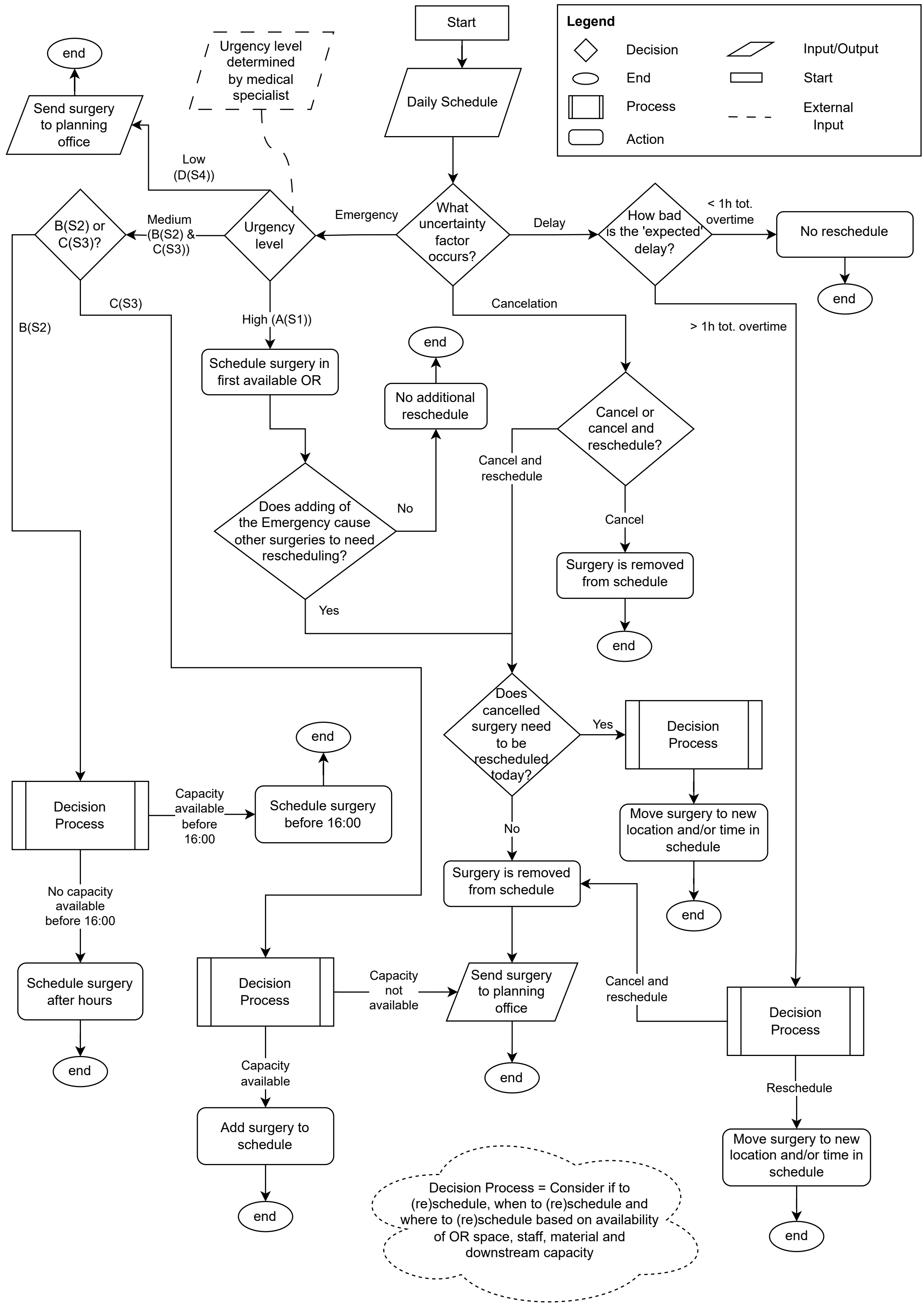


Figure 4.1: Process flowchart describes the decisions or actions an OR coordinator makes when an uncertainty factor introduces a disruption of the current schedule. The OR policy document of the LUMC and supporting scientific research forms the foundation of this flowchart.

Statements 5, 7, 8, 19, 20, 21, 22, 23, 25, 26, 28, 29, 30, 31, and 32 from Table 4.2 form the foundational framework of the flowchart (see Appendix A for all statements). This flowchart predominantly relies on statements categorized as similar, ensuring its relevance across Dutch UMCs. By emphasizing broad processes over intricate details in the design of the flowchart, I aim to enhance its application across Dutch UMCs.

The flowchart begins by considering the daily schedule. When an uncertainty factor arises, the OR coordinator navigates the decision-making process accordingly. Subsequently, the surgery may be rescheduled on the same day, removed from the schedule entirely, or removed from the schedule and forwarded to the planning office for rescheduling at a later time. Certain aspects of the flowchart warrant further elaboration. Subsequent sections will elucidate notable distinctions or details within the flowchart and reference relevant statements and research supporting its structure.

Delay - Overtime Cut-Off

The Delay path of the flowchart is supported by statements 5, 8, 25, and 26. When a Delay is identified as the uncertainty factor, the OR coordinator must assess the severity of the expected delay and its implications for the schedule. Based on this assessment, a decision is made whether to explore alternative scheduling options or not. In this flowchart, a 1-hour overtime cut-off has been utilized as a threshold to proceed with the rescheduling process or to terminate it and opt not to reschedule. The scientific rationale behind the 1-hour overtime cut-off is outlined in a paper by Dexter (2003). This paper reports findings from an internet-based survey conducted among attendees of courses provided by the Association of Anesthesia Clinical Directors (AACD). Participants were asked whether they would move a case if they expected to save a certain number of hours of over-utilized OR time. The majority of respondents indicated they would consider moving a case to save at least one over-utilized hour. Hence, it is inferred that there needs to be at least one hour of accumulated over-utilized time before physicians would contemplate rescheduling or canceling a case.

Given the lack of recent updates or research on this topic, the 1-hour cut-off is adopted in the flowchart. However, during the validation of the flowchart, OR coordinators will be consulted to provide their perspective on the appropriate time cut-off. Due to the anticipated variations in individual assessments of the cut-off time required for rescheduling, the DSS must be equipped to accommodate these variations in willingness to reschedule and set an appropriate cut-off threshold or offer a manual workaround.

Cancellation - Cancellation Options

When a cancellation is identified, the OR coordinator must ascertain whether the surgery is definitively canceled or if it needs to be canceled and rescheduled. The cancellation path is delineated based on statements 19, 20, 21, and 22.

While it may appear unusual to include a definitive cancellation in the process flowchart, as most canceled cases necessitate rescheduling due to delays or patient unfitness [Dimitriadis et al., 2013, Kaddoum et al., 2016, Koh et al., 2021], there are instances where surgery is no longer required [Scheenstra et al., 2022, Dexter et al., 2016]. Given that the aim of the flowchart is to illustrate the OR coordinator's workflow when cancellations occur, accounting for full cancellation as an option is valid and therefore included in the flowchart.

Emergency - Urgency Levels

Statements 28, 29, 30, and 31 form the basis of the Emergency path. When an Emergency surgery needs to be incorporated into the OR schedule, the OR coordinator must decide where in the schedule to place the surgery. Initially, the urgency level of the emergency is assessed and communicated to the OR coordinator by the medical specialist. The medical specialist determines the urgency level based on the patient's condition.

For estimating urgency levels, hospitals often use emergency lists, or "Spoedlijsten," which categorize interventions per surgical specialty into urgency categories. The Dutch Standards Institute for Medical Specialists (Kennisinstituut van de Federatie Medisch Specialisten [2019]) provides general guidelines for these lists, but hospitals are permitted to make adjustments. A comparison of the standardized guidelines to the list used in the LUMC (found on pages 21 to 35 of the OR policy document) revealed that hospitals often modify the list by elevating the urgency level of certain interventions. It is important to accommodate such deviations from standardized guidelines in a future implementation of a decision support system.

The OR coordinator then considers only the attributed urgency level of the surgery in the subsequent steps of the process. The urgency levels A, B, C, D (S1, S2, S3, S4) used in the process flowchart are defined by the Dutch Association of Surgery (Nederlandse Vereniging voor Heelkunde [2018]). Each level corresponds to a required time of service for a patient, as indicated in table 4.2 by statement 29 of the OR policy analysis. Based on the differences in service times and the hospital's preference, in this case, the LUMC's preference for scheduling patients within business hours for certain urgency levels, the subsequent steps lead to different outcomes.

Decision Process

Following the flowchart leads to a Decision Process. This process is briefly outlined in the cloud symbol of the flowchart, it lacks a standardized structure or procedure. Instead, it relies on the information available to the OR coordinator and their expertise to make decisions regarding if, when, and where to accommodate the surgery. This decision-making process cannot be rigidly structured, as it involves various considerations each time, such as staff availability, material availability, downstream effects, and OR capacity. Statements 7, 23, 26, and 32 describe the freedoms and restrictions inherent in the daily management of the schedule by the OR Coordinator.

4.3.3. Concept Decision Support System

The OR policy analysis has informed the design of a mock-up for the decision support system, which includes options for optimizing the schedule and presents the changing schedule throughout the day. The DSS outline is developed with the process flowchart in mind and is primarily based on statements applicable across multiple UMCs to ensure its generalizability. By presenting multiple options for schedule optimization, the aim is to alleviate some of the decision-making burden for the OR coordinator while maintaining their authority. The following sections detail the key components of the mock-up. For access to the interactive mock-up, please refer to Appendix B, section B.1, which provides a link to the mock-up.

Input

The input for the DSS comprises the original schedule used in the OR on the day of surgery, which includes start times, surgery types, planned durations, and OR locations (see statements 4, 5, 6, and 8). Additionally, surgical interventions should contain the same information, as outlined in statement 33. Turnover times in the schedule are assumed to be 30 minutes, reflecting the average turnover in Dutch UMCs [van Veen-Berkx et al., 2016]. Finally, the duration of surgeries in the DSS should be based on historical data to reflect the evolving schedule throughout the day.

The mock-up depicted in Figure 4.2 illustrates the appearance of the DSS, inspired by examples from Ito et al. [2016] and Levine and Dunn [2015]. Different stages of the patient journey are indicated by colors, aligning with the stages described in statement 18 of the OR policy analysis.

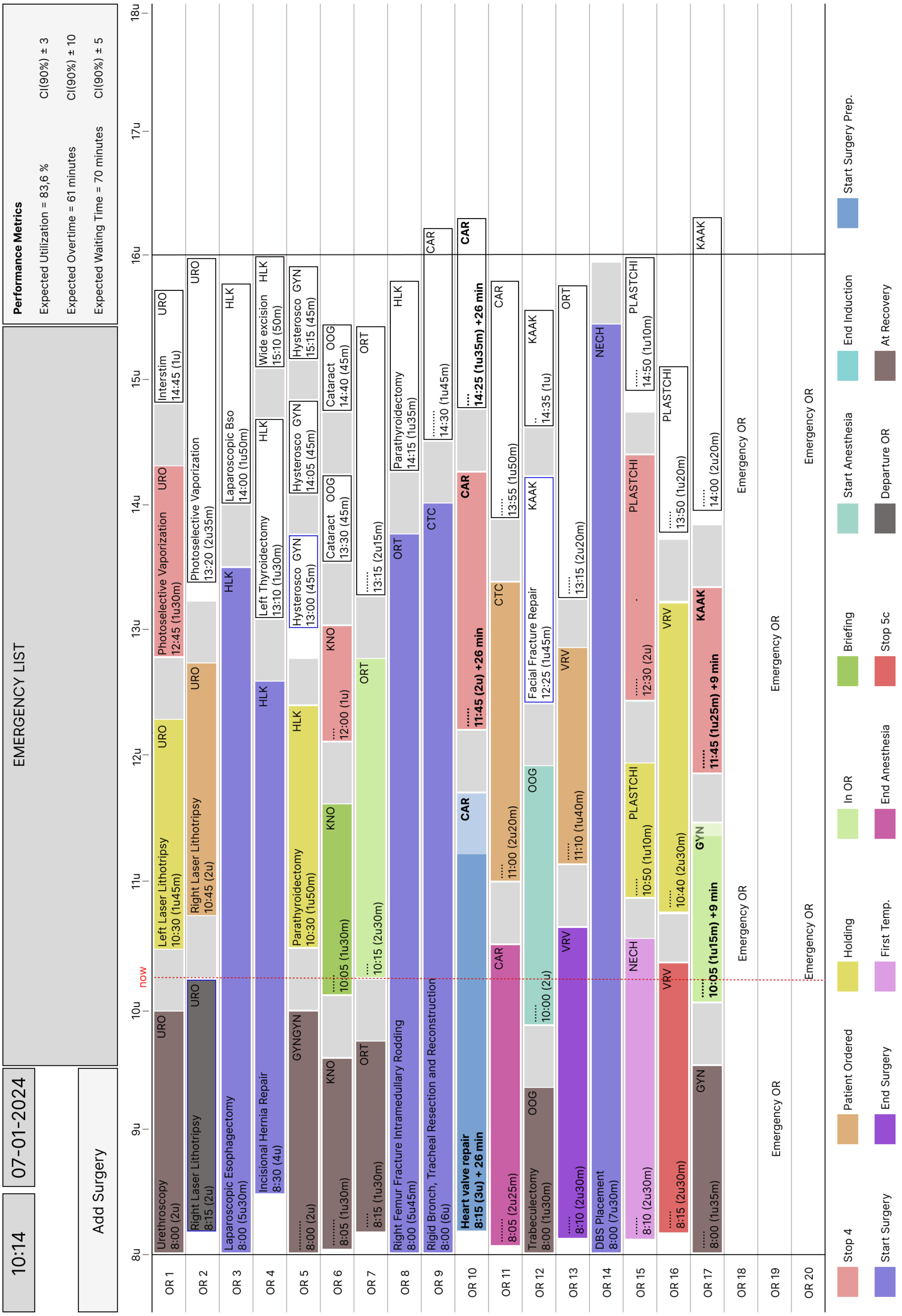


Figure 4.2: Mock-up schedule display of the concept Decision Support System

Performance Metrics

To enhance decision-making, the DSS incorporates performance metrics indicative of the OR complex's performance for the day. Three metrics have been selected, each relevant to a specific stakeholder within the hospital. Options for other performance metrics tailored to a hospital's preference should be facilitated in later versions. Section 2.2 has described each metric in detail. Table 4.4 summarizes the definition and calculation of the metrics as applicable for the evaluation of OR performance in the DSS.

Table 4.4: Definition and calculation of performance metrics applicable to OR performance evaluation in the concept Decision Support System

Performance Metric	Definition	Calculation
Utilization	Used OR capacity by surgical procedure within the time that was allocated to be used. (ie. used OR capacity in overtime, or opening of extra ORs is not part of utilization)	Allocated OR time used for surgical procedures / Total OR time allocated for surgical procedures
Overtime	Time used for surgical procedure past OR closing time	Sum of time used for surgical procedures past OR closing time
Patient Waiting Time	Waiting time of a patient admitted to the hospital until execution of surgical procedure	Original scheduled starttime of surgical procedure - actual starttime of surgical procedure

Changing Schedule

Changes to the schedule stem from one of three uncertainty factors: delays, cancellations, or emergency surgeries. Delays are automatically identified through timestamps recorded throughout the patient's journey in the OR complex (statement 18). Cancellations are communicated from external sources or identified by the OR coordinator, the OR Coordinator can utilize the DSS to manage cancellations as needed. Emergency surgeries are received via external integration with HiX, where emergency surgeries are registered (statement 28). Appendix B includes a flowchart detailing the internal process flow and structure of the DSS, highlighting areas where input from the OR Coordinator is required.

Optimization Choices

The decision support system aims to dynamically adjust the schedule based on real-time time registrations (statement 18). Furthermore, it will propose schedule optimizations using updated time registrations, historical hospital data and external schedule adjustments. For instance, if a cancellation occurs, the optimization feature may activate and identify improvement opportunities. It generates alternative schedules considering performance metrics, assumptions regarding surgeon and patient availability. Regarding surgeon availability, the system assumes surgeons are available up to approximately one hour before the originally scheduled procedure start time, up to two hours after the original start time, and immediately available if they performed surgery on the preceding patient. For patient availability, it assumes patients are available up to two hours before the originally scheduled procedure start time, as most patients must be in the hospital by this time.

Figure 4.3 illustrates the alternative schedules presented by the optimization mock-up to the OR Coordinator, along with the anticipated performance enhancements for each alternative schedule. As the optimization does not factor in equipment usage, availability of anesthesiologists, operating room assistants, and other pertinent factors, there must always be an option to maintain the current schedule. This option is depicted in the upper left quadrant of figure 4.3.

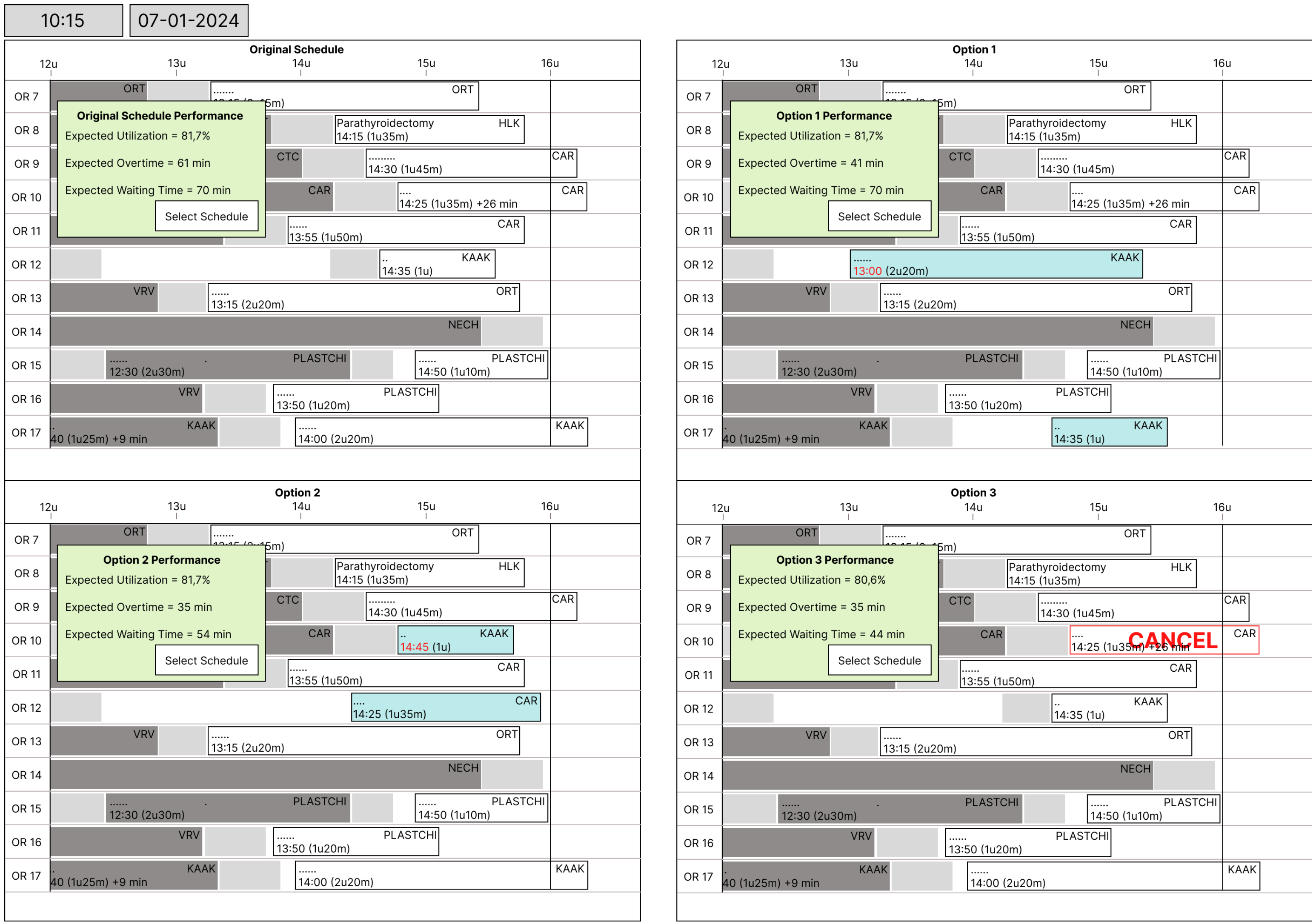


Figure 4.3: Mock-up of optimization options presented by the decision support system when alternative scheduling options are available. The expected performance for each option is indicated in the green squares. Changes to the schedule in each option are represented by turning the block corresponding to an intervention turquoise or displaying "CANCEL" across a block.

4.3.4. Implementation Strategy

To ensure smooth implementation of the DSS, it has been developed with the Process Flowchart Schedule Management in mind. Appendix B section B.2 features a flowchart detailing the functionality of the DSS in relation to the user, specifically the OR Coordinator. This flowchart incorporates elements from the flowchart in figure 4.1 while also expanding its capabilities beyond what has been previously discussed.

Since the optimization function does not consider equipment availability and the availability of supporting OR staff when suggesting schedule alternatives, there may be instances where the suggested options are not feasible despite the need for rescheduling. In such cases, the OR coordinator should have the ability to manually adjust interventions in the schedule. This functionality will need to be integrated into the final product and is depicted in Appendix B figure B.1.

Additional Functionalities Decision Support System

In addition to functionalities aimed at facilitating implementation, other relevant features must be incorporated to ensure successful adoption, even though they do not directly contribute to the core function of the decision support system, which is suggesting alternative schedules. Here, we summarize several functionalities that are considered highly valuable:

- *Manual Rescheduling Function*: A separate function that allows manual rescheduling without the need to follow the entire process flow up until the optimization process is required. This is important because an OR Coordinator may need to reschedule a surgery for reasons that have not been accounted for in the optimization of the DSS.
- *Version Control*: To prevent errors and loss of oversight, there should be a function to revert to the original or a previous version of the schedule after selecting one of the alternative schedules or making manual changes. Similar to version back-ups of documents, this feature ensures traceability and accuracy in scheduling decisions.
- *Recording and Evaluation Function*: The system should record all options presented and all choices for alternative schedules made throughout a day. This data can be evaluated by OR staff and management retrospectively to continuously improve the decision support system, and analyse the influence it has on schedules and decisions that have been made. Additionally, it helps identify weak points of the system or any unconscious errors or biases that may have been introduced.

By incorporating these functionalities into the decision support system, I expect it to become more robust, user-friendly, and capable of supporting efficient decision-making processes in the OR complex.

4.4. Preliminary Conclusions

Identifying differences and similarities in daily management policies among UMCs can enhance the adoption and implementation of a decision support system, as understanding variations allows for flexible design in areas where differences exist. As shown in table 4.2, a significant number of statements related to daily schedule management were categorized as similar, with only a few indicating policy differences. Upon closer examination of these differences, many of them can be incorporated in the design of a decision support system with relative ease. Therefore, I suggest that creating a decision support system suitable for multiple centers is feasible.

Considering the statements from the OR policy document of the LUMC and our analysis, figure 4.1 provides an overview of the workflow of an OR coordinator. To enhance application of the flowchart in Dutch UMCs it captures the workflow at a more generalized level and it primarily incorporates statements from the OR policy document categorized as similar. In the next phase, the flowchart, currently grounded in a theoretical understanding, will undergo validation through interviews. This process may unveil new insights and necessitate adjustments to the process flow.

5

Part 2 - Interviews

Part 2 of this thesis presents the findings from interviews conducted with OR staff from the LUMC. These interviews served to validate the decision-making flowchart introduced in Part 1 (see section 4.3.2). Additionally, OR staff shared insights into their daily interactions with stakeholders during the (re)scheduling of surgical interventions and provided feedback on a mock-up of the proposed decision support system and its functionalities. The interviews aim to demonstrate how theoretical concepts translate into real-world scenarios, providing valuable insights for the development of a decision support system.

5.1. Objectives and Subquestions

The interviews in this chapter aim to achieve two main objectives. Firstly, to evaluate whether the created process flowchart accurately reflects reality. Lastly, to gather feedback from OR coordination staff on the mock-up decision support system to evaluate its suitability for their needs. These objectives are formulated as follows:

Objectives

- Validate decision making process flowchart
- Showcase concept decision support system

Through validation of the decision making process answers to subquestions 1 and 2 of Part 1 will be finalized. Those were; *What are the implications of differences and similarities in OR policies for the development of universally applicable decision support system?* and *What does the current workflow of the OR coordinator look like when making scheduling decisions on the day of surgery?*.

To reach the other objective of Part 2 and answering our main research question the following subquestion has been constructed;

Subquestion

- How does the concept DSS fulfill the needs of and OR Coordinator for decision making on the day of surgery?

5.2. Methods

Semi-structured interviews were conducted with two regie-anesthesiologists, a planning specialist, and a team leader of anesthesiology staff from the LUMC. The regie-anesthesiologists were interviewed separately to minimize the influence of others' responses. The planning specialist and team leader were interviewed together, as this arrangement evolved naturally during the session. Data saturation was achieved after three interviews. The interviews were recorded using an iPhone and transcribed by the researcher. Prior to the interview, all participants were asked if they objected to being recorded and were informed that quotes would be anonymized.

The interview comprised two parts. In the first part, the decision-making process flowchart was validated. The methods used to construct the results of this part are described in sections 5.2.1 and 5.2.2. The second part involved presenting the concept DSS to the participants and eliciting their reactions. They provided insights into the information requirements for decision-making and evaluated how well current systems meet those needs. The comments from participants in the second part are interpreted in the accompanying results section (section 5.3.4).

5.2.1. Validation Process Flowchart

Validation involved conducting a semi-structured interview where the process flowchart was presented and its functionality was discussed. Prior to the interview, participants were encouraged to ask questions if any explanations were unclear and to provide their views on components whenever they deemed it necessary. Additionally, participants were explicitly asked during the interview to specify the cut-off time for expected overtime at which they would typically take action to adjust the schedule and reduce overtime. Comments on the flowchart were categorized based on the uncertainty factor, indicating the section of the flowchart to which the comment pertained. The final version of the flowchart was created based on the comments made by participants during the validation interview (see section 5.3.2). The final process flowchart was informally validated with the help of the project manager of the OR Benchmarking Project.

5.2.2. Stakeholder Analysis

During the validation of the flowchart, participants identified instances where certain actions outlined in the flowchart required interaction with other stakeholders. OR coordinators sometimes described actions that were simultaneously carried out by another stakeholder. To visually illustrate these interactions among stakeholders within the hospital in specific scheduling scenarios, stakeholder interaction maps were created. These maps and accompanying comments describing the interactions were categorized into one of three groups based on the initiator of contact: the surgeon, the OR coordinator, or the admissions office.

5.3. Results

The results from the validation of the process flowchart and the stakeholder analysis contribute to addressing subquestions 1 and 2. The stakeholder analysis sheds light on the decision support system's requirements and the information needed by other stakeholders to facilitate seamless adoption and implementation in a University Medical Center. Reactions to the concept DSS offer insights into the needs of the OR Coordinator and are expected to guide the further development of the DSS.

5.3.1. Validation Process Flowchart

The subsequent sections each detail a distinct part of the flowchart that underwent modifications following the interview outcomes. Comments regarding the correct structure of the flowchart were excluded, as they did not contribute to meaningful adjustments aimed at aligning the flowchart with workflow reality.

Input

In the existing flowchart, the input information is solely derived from the daily schedule. However, validation interviews revealed that the OR coordinator receives input not only from the daily schedule but also through various other communication channels.

"You have to imagine that an OR coordinator is walking around the OR with a printed version of the ***daily schedule****, on the backside of this paper they record information that they have received through* ***phone calls****. ... Also near the end of the day, an OR coordinator makes a* ***phone call*** *to the OR to ask how far along the surgery is."* - Planning Specialist (1)

"So you have got your printed-out ***daily schedule****, because I am walking around the OR complex all day long. And in the meantime, I check HiX to see if there have been entries to the* ***emergency list*** *in HiX... For emergency surgery the surgeon always* ***calls*** *me to provide information about the surgery that is required, and after he (the surgeon) also registers the surgery in HiX."* - OR Coordinator 1 (2)

"Lost of communication is ***handled by phone****. Additionally, the OR coordinator is continuously checking what is happening in the ORs that are in business to see if things are still on track. I am also in contact with the other members of the Regie-team ... A lot is communicated by* ***phone****, but also through* ***physical contact*** *with colleagues"* - OR Coordinator 2 (3)

These quotes highlight the necessity of updating the input information for the flowchart to accurately reflect real situations. OR Coordinators not only rely on the information provided by the daily schedule (quotes 1 and 2), but also consult the emergency list (quote 2) and frequently receive external information via phone or face-to-face interactions with colleagues (quotes 1, 2, and 3). Figure 5.1 depicts the changes made to the flowchart based on these quotes.

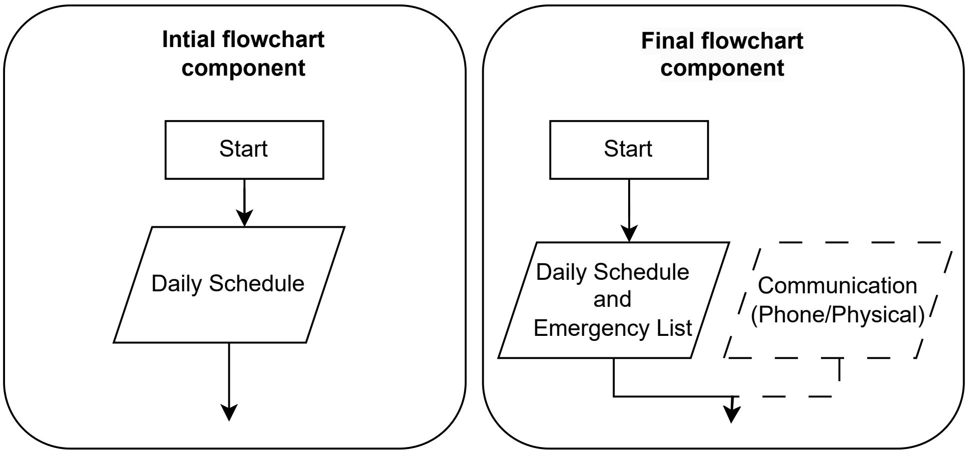


Figure 5.1: Illustration of the revisions made to the original flowchart to better align with real-world scenarios. The left side displays the initial flowchart components created based on OR policy statements, while the right side depicts the improved version of the flowchart component based on feedback from OR staff.

Emergency Classification and Emergency List

In the initial process flowchart, urgency classes B (S2) and C (S3) were grouped together as the OR policy document suggested a similar approach for categorizing patients in these classes. However, during interviews with the OR coordinators, it became evident that a different grouping method was more appropriate. The OR coordinators mentioned that S3 and S4 patients are often placed on an emergency list for the following day if they have not been accommodated yet. The coordination team uses this list to assess where to schedule these patients for the next day.

"If an S3 surgery cannot be performed today then it is added to the emergency list, and the following morning the coordinating team again tries to find space in the OR for the patient to be treated." - OR Coordinator 1 (4)

"Well, S4 labeled patients need to be operated on somewhere in the coming week. He/She is placed on the emergency list, and the team tries to plan the patient on the day, but it also happens quite often that the surgery is pushed for multiple days because the elective program is totally full and the emergency list is quite long." - OR Coordinator 1 (5)

As indicated in quote 5, the time frame specified by the urgency classification appears to be more flexible. A similar observation was also made by another OR Coordinator regarding S3-labeled patients.

> *"From an urgency indication that is 24 hours and up, it does not really matter if the patient is helped within 24 hours, or if that time frame is extended to 48 hours. The time frame starts to really matter when we are talking about right now, or within the hour, or a couple of hours. But 24 hours... It is of course not very patient-friendly, but sometimes you are forced to push patients to the next day, or even the day after. "* - OR Coordinator 2 (6)

Building on the preceding quotes, the process flowchart has been revised to better reflect reality. Figure 5.2 illustrates the structure of the final process flowchart concerning the emergency list and alterations in the clustering of urgency classes.

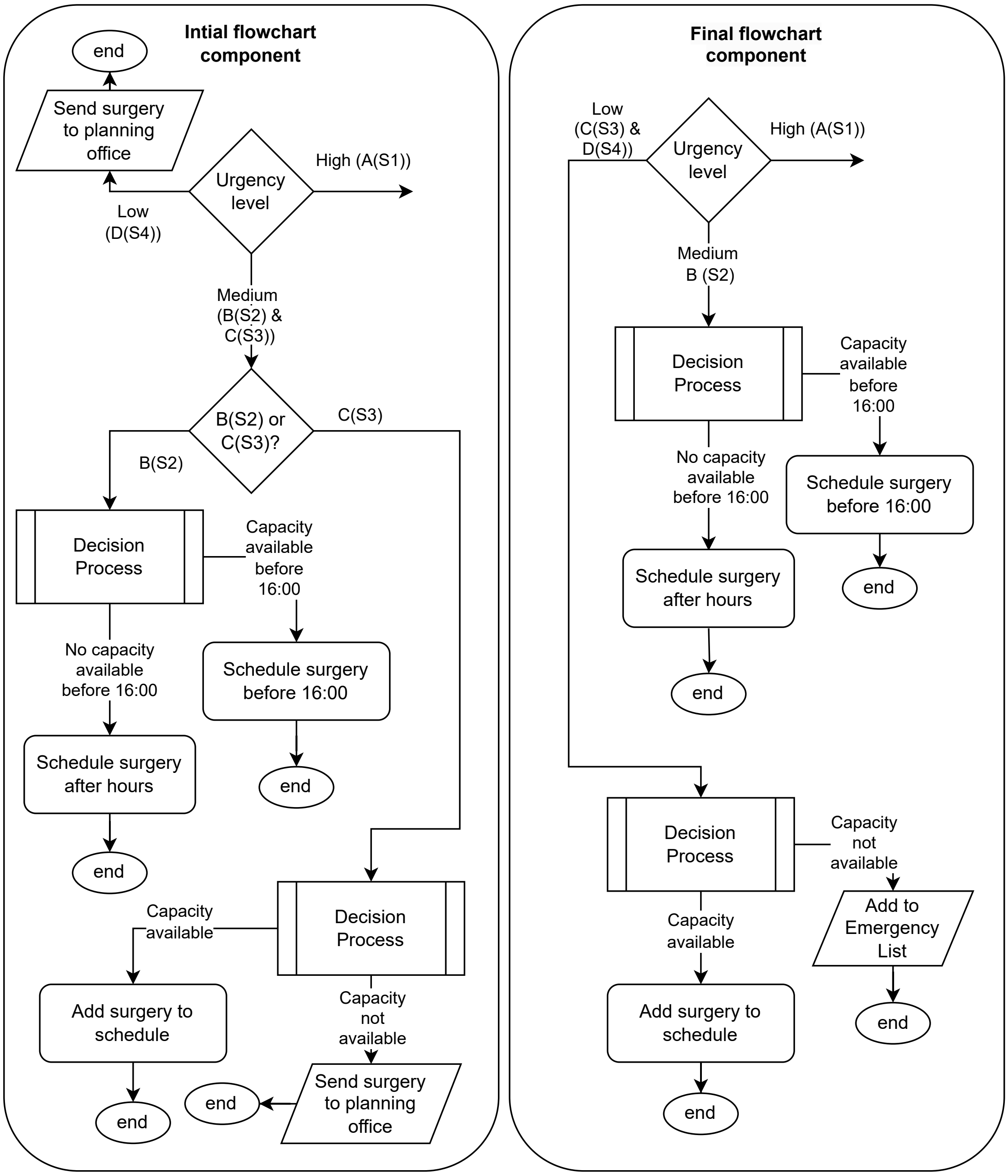


Figure 5.2: Illustration of the modifications made to the Emergency component of the flowchart. The left side depicts the initial flowchart components, while the right side displays the final flowchart components.

Overtime Cut-off

The initial process flowchart incorporated an overtime cut-off of 1 hour, as informed by the research of Dexter et al. [2003]. During the interviews, OR Coordinators were queried about the threshold they use to decide when to intervene in the schedule during delays. The OR coordinators shared the following insights;

> *"In essence, our rule is to allow a maximum of 6 ORs going into overtime. We operate with 6 teams, one of which is typically reserved for the dinner shift. However, if at least 4 out of the 6 teams complete their work by 18:00, we can still utilize one of them for the dinner shift. Any additional work beyond this point, such as the 7th OR going past 16:00, would require either more overtime or cancellation... As a standard practice, we schedule 4 teams - one until 21:00 and three until 18:00 - leaving us with only 2 extra instances of unplanned overtime. When we expect to go beyond that, we will evaluate whether we will reschedule or cancel interventions to keep the maximum of 6 ORs running past 16:00."* - OR Coordinator 1 (7)

> *"I must admit, I no longer keep track of that number 6 because it keeps changing... Sometimes it's 7, sometimes 6, sometimes 5, and occasionally it's 4 due to sick staff. But around 6 is generally accurate. As the management team, our aim is to, ideally have no ongoing surgeries, but at most 6 ORs open by the end of the day, around 4:00 PM. This is because we have 6 teams. If we have 7 ongoing surgeries but only 6 teams available, it simply doesn't work. In such cases, people have to stay and work overtime, which is not ideal for a hospital. However, we understand that some overrun is inevitable, therefore we have agreed on a maximum of 6 ORs running past 16:00."* - OR Coordinator 2 (8)

In light of quotes 7 and 8, the process flowchart has been revised to incorporate the limit of 6 OR overrun threshold. Figure 5.3 depicts the final process flowchart reflecting the cut-off employed by LUMC OR coordinators. It's important to note that different thresholds for decision-making may be applicable for other UMCs.

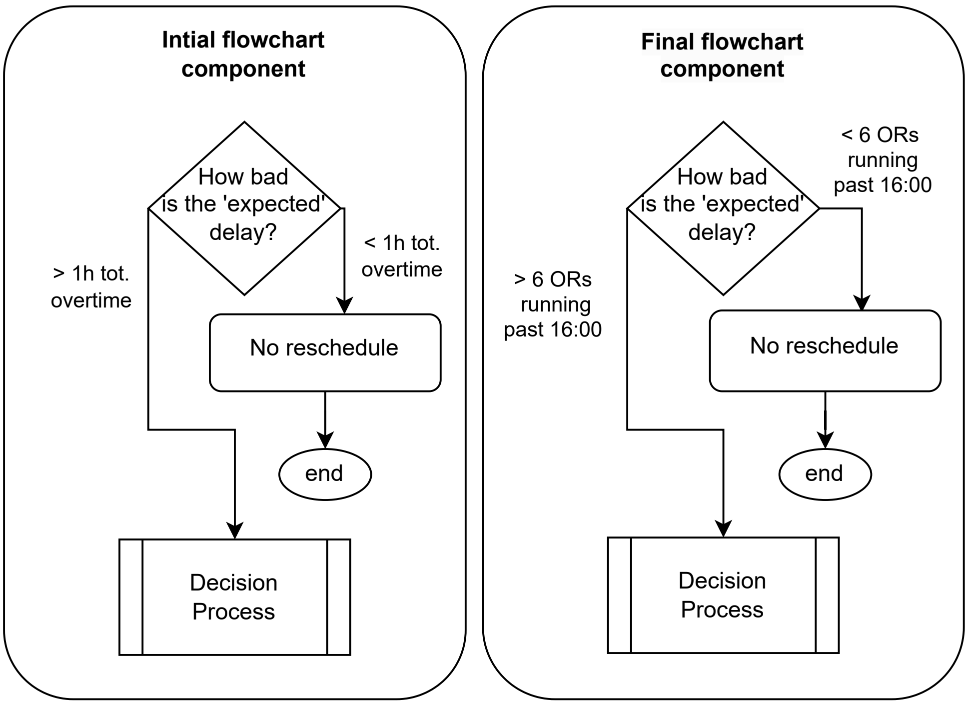


Figure 5.3: Illustration of the modifications made to the delay decision threshold of the flowchart. The left side depicts the initial flowchart components, while the right side shows the final flowchart components. These modifications are specific to the LUMC.

5.3.2. Final Process Flowchart Schedule Management

The feedback from the OR Coordinators, Planning Specialist and Teamleader Anesthesiology has resulted in an enhanced version of the schedule management process flowchart (see Figure 5.4, on the next page). In general, the flowchart aligns with the processes in other UMCs, as informally confirmed by the project manager of the OR Benchmarking Project. Minor adjustments to the flowchart may be required for its applicability to other UMCs. Of particular importance is the decision-making threshold in the event of delays, which needs to be determined separately for each UMC.

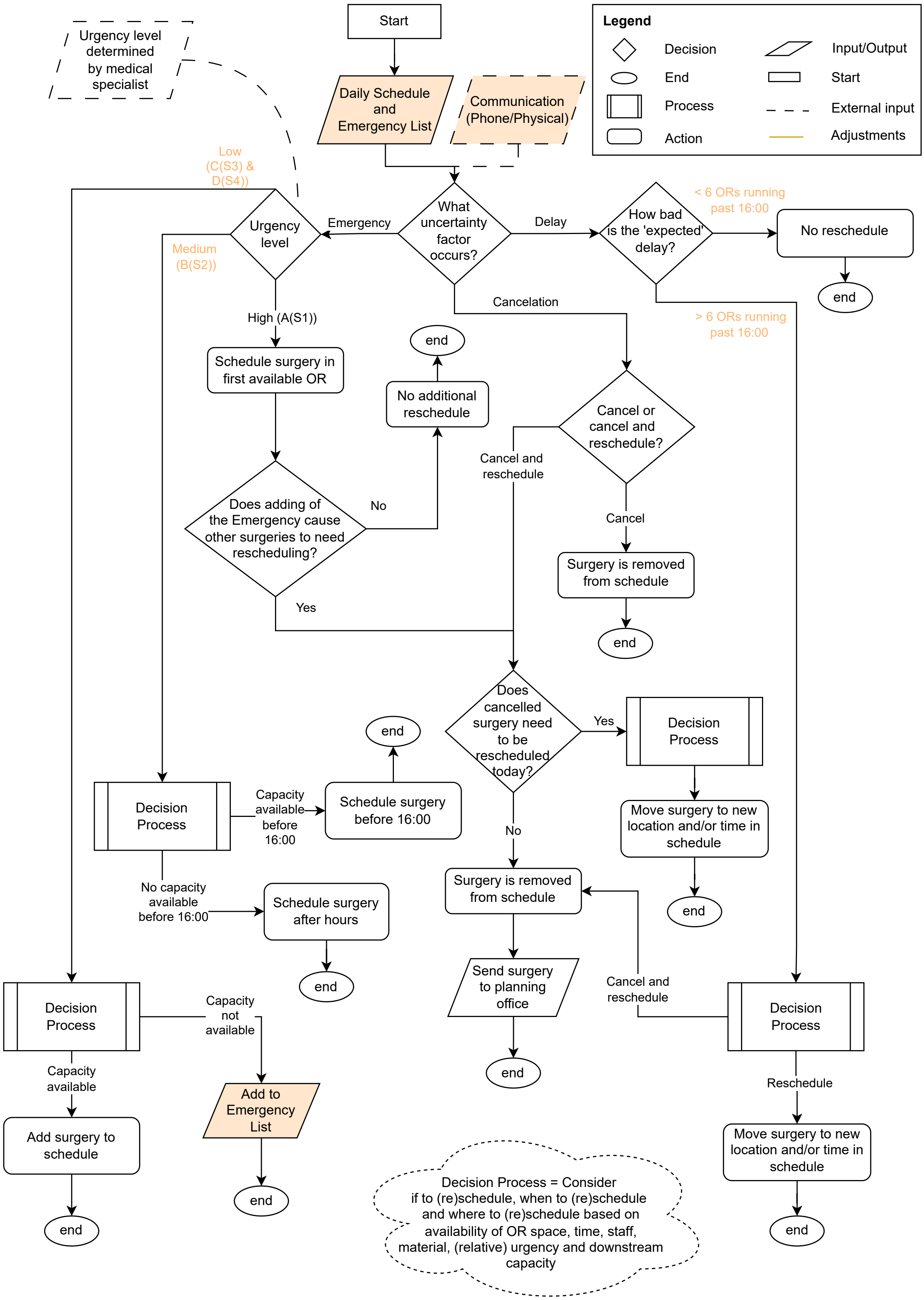


Figure 5.4: The flowchart delineates the workflow of an OR Coordinator at the LUMC on the day of surgery. Adjustments made to the initial flowchart are depicted by orange components. Minor modifications may be needed to adapt it for general use in other Dutch UMCs, particularly regarding the delay threshold, which will require adjustment.

5.3.3. Stakeholder Interaction Maps

During the interviews, OR staff repeatedly pointed out that certain actions in the process of making scheduling decisions necessitated interaction or involvement by other stakeholders in the hospital. These interactions and actions have been documented in stakeholder interaction maps. Each map is categorized based on the initiator of contact in various scenarios. The following sections present comments and interaction maps constructed based on these remarks.

Situation 1; OR Coordinator Initiates Contact

Situations in which the OR Coordinator is the initiator of contact, typically occur when a delay arises, often prompting the need to decide whether to cancel a surgery. The following quotes exemplify situations where the OR Coordinator initiates contact with other stakeholders.

> *"Let's say this patient's procedure is significantly delayed, and Dr. H. is assigned to this case. In such a situation, we need to give Dr. H. a call. Although the procedure was scheduled for 3 hours, we only have 1.5 hours remaining, which isn't feasible. Therefore, we have to cancel it and inform the doctor, saying, "Sorry, we won't be able to proceed with this patient today." Consequently, the patient is placed back on the waiting list. Most of the time, this communication happens when the OR Coordinator contacts the OR secretariat, instructing them to place patient X back on the waiting list."*
> - Planning Specialist (9)

> *"If the patient doesn't need to undergo the procedure on the scheduled day, they are removed from the schedule by the OR secretariat. Subsequently, the appointment is sent back to the admissions office, where a new appointment is arranged with the patient. The admissions office coordinates with the surgeon's schedule, ensuring they know when an operating room is available. They then contact the patient to confirm their availability for a new appointment."* - OR Coordinator 2 (10)

Quotes 9 and 10 illustrate the steps taken by the OR Coordinator to notify the surgeon of the cancellation and subsequently inform the OR secretariat. The OR secretariat fulfills an administrative role, responsible for notifying the admissions office and recording the reason for cancellation, as demonstrated by the following quote;

> *"We're keen to understand the reason for the cancellation because we aim to address it proactively, therefore the OR secretariat records the reason for cancellation. Currently, what happens is that the coordination team informs the secretariat, saying, 'Mrs. Y. needs to be placed back on the waiting list due to these specific reasons'."* - Planning Specialist (11)

Conversely, there are instances where it is determined that the patient is unfit for surgery upon arrival in the holding area. In such cases, contact is also initiated by the OR Coordinator. The following quote describes such an interaction.

> *"Sometimes, a patient is scheduled to arrive, but upon examination, issues arise that prevent the procedure from proceeding, such as elevated blood pressure or abnormal heart rhythms. In such cases, the patient has already arrived, but we must cancel the procedure. This cancellation process is managed through our OR secretariat. Typically, when we determine a patient is not suitable for surgery, we communicate directly with the surgeon to inform them. All administrative and scheduling tasks are then handled by the secretariat, who liaise with the admissions office."* - OR Coordinator 2 (12)

The preceding quote delineates the actions required by the admissions office to arrange follow-up appointments with the surgeon and the patient, ensuring another appointment is scheduled in the future, as also articulated in quote 10. Figure 5.5 illustrates the interactions between stakeholders when the OR Coordinator initiates contact to make changes to the schedule.

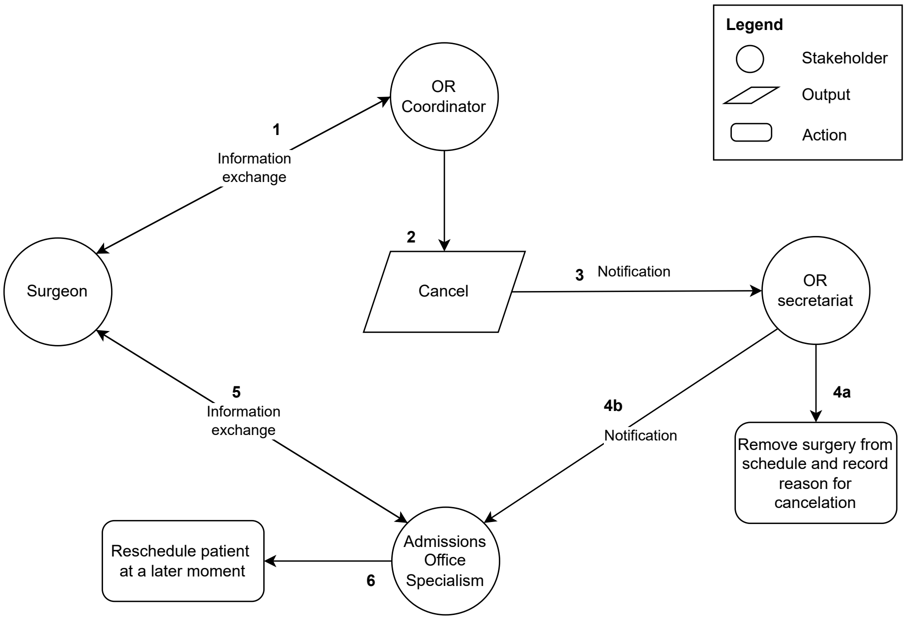


Figure 5.5: Schematic representation of situations in which the OR Coordinator initiates contact with others to cancel a surgery. The numbers denote the sequence of actions taken. Following information exchanges with the surgeon, the OR Coordinator notifies the OR secretariat, who records the reason for cancellation and informs the admissions office, responsible for rescheduling the patient.

Situation 1a; OR Coordinator Initiates Contact

When delays result in excessive overtime, the OR Coordinator may opt to relocate an intervention to another OR or reschedule it for a different time. The following quotes elucidate the interactions stakeholders engage in when such a scenario arises.

> *"If we have an opening in another OR session due to a patient cancellation, we allocate the slot to another patient. Then, we make a few calls to check the availability of a surgeon. Next, the coordination team whether other OR staff is also available."* - OR Coordinator 1 (13)

> *"The coordination team could facilitate the process by contacting the surgeon of the patient yet to arrive and suggesting, "Hey, could you perform this surgery in a different OR?" Then, they can proceed with the patient in OR 2 alongside the team originally assigned to OR 1. This kind of arrangement is a daily occurrence."* - Planning Specialist (14)

Quotes 13 and 14 demonstrate how an exchange of information between the surgeon and the OR Coordinator results in the rescheduling of a surgery in terms of time or location on the day of surgery. Figure 5.6 depicts the interactions among stakeholders in this scenario, with the OR Coordinator serving as the initiator.

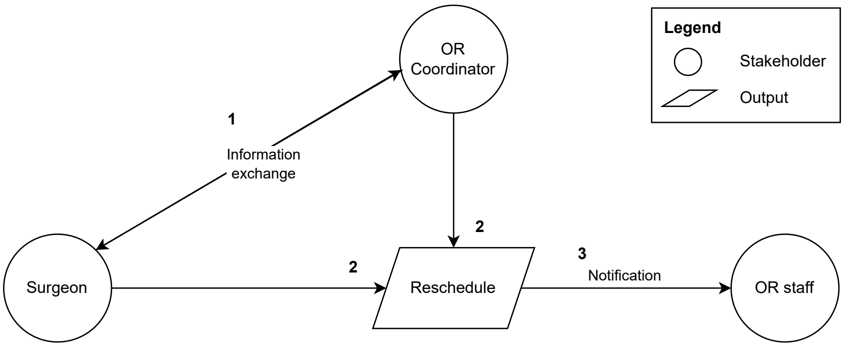


Figure 5.6: Schematic representation of a scenario in which the OR Coordinator initiates contact with other stakeholders when a surgery is rescheduled to another time or place on the day of surgery. The numbers denote the sequence of actions taken. Following information exchanges with the surgeon, the OR Coordinator notifies other OR staff required for the execution of surgery in the new location or time slot.

Situation 2: Admissions Office Initiates Contact
In situations where the patient falls ill, the cancellation of surgery is instigated either by the patient themselves or, if they are already admitted to the hospital, by the admissions office. The following quotes exemplify this circumstance:;

> *"...Patients, who are unwell, call the admissions office in the morning saying, "I have a fever, I won't be able to come.""* - Planning Specialist (15)

> *"If the patient is ill, it results in a complete cancellation, and they don't even come to the operating room. We receive a call from the admissions office notifying us, or via the OR secretariat, "The patient is unwell and has a fever, so we won't be coming to the OR." Subsequently, the admissions office updates the appointment schedules and plans for the upcoming weeks accordingly."* - OR Coordinator 2 (16)

Figure 5.7 illustrates the interactions outlined in the preceding quotes. In this interaction scenario, the admissions office serves as the initiator of contact within the hospital. Therefore, the admissions office is depicted as the starting point of interaction in the schematic in Figure 5.7. The actions they undertake to arrange new appointments with patients were previously described in quote 10.

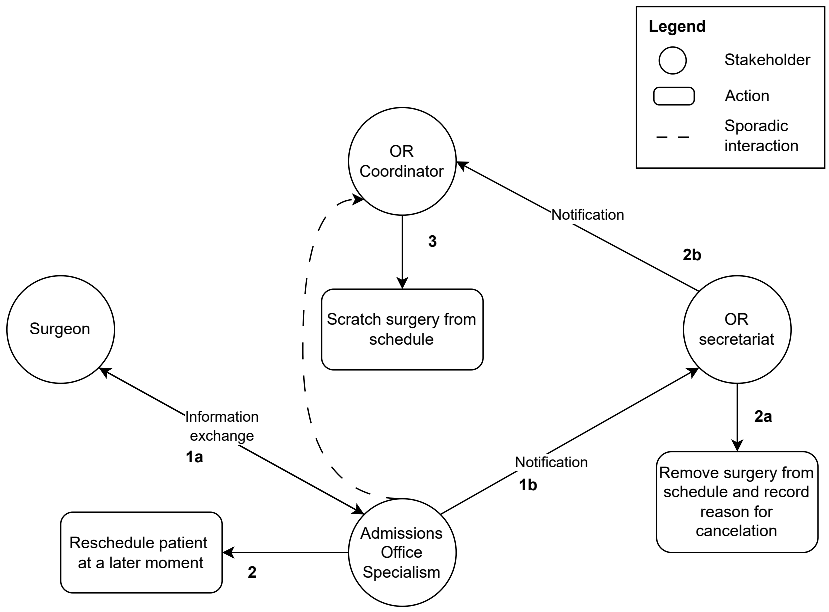


Figure 5.7: Schematic representation of a scenario in which the admissions office initiates contact within the hospital with other stakeholders, resulting in changes to a schedule.

Situation 3: Surgeon Initiates Contact
When planning emergency surgeries, multiple stakeholders are involved in the process. The following quotes illustrate actions of stakeholders during this process.

> *"Emergency admissions are always handled directly by the surgeon themselves because they also need to provide explanations for what and why. We have a protocol in place for this purpose. There are several pieces of information they must convey, such as the patient's date of birth, LUMC number, type of surgery, operating surgeon, duration, and required equipment... Along with this information often comes an assessment of 'okay, we need to make an effort here.' For instance, if it's a highly complex procedure, we prefer to schedule it during regular hours or early evening, rather than late at night or early morning."* - OR Coordinator 1 (17)

> *"At times I get called by a surgeon who asks me 'You can see on the Emergency List that I have registered my urgency category A (S1) patient for surgery at 10:00, it is now 12:30 and I can see that OR 4 is not in use, what is the deal here?'"* - OR Coordinator 2 (18)

Quotes 17 and 18 demonstrate that the surgeon takes the lead when an emergency surgery arises, initiating the initial contact with the OR coordinator. Subsequently, the surgeon provides relevant information, and together with the OR Coordinator, they establish the timeframe for the patient's operation.

> *"So, if there's no time available on the schedule and you inform the surgeon, the first thing they'll ask is 'Okay, but when is there time?' Then, for instance, I might say 'Well, not until 11 o'clock,' to which the surgeon might respond, 'I'm not going to operate at night; it's not urgent enough. I'll have the patient eat and put them on the emergency list for tomorrow."* - OR Coordinator 2 (19)

As demonstrated in quote 19, the surgeon can exert influence and authority over the timing of a procedure by opting not to proceed with an emergency surgery.

> *"In theory, a simple call to the supervising anesthesiologist should suffice, as we inform the operating room assistants and anesthesia staff. However, quite often, they (surgeon) also contact the operating room assistants to specify the exact equipment they require."* - OR Coordinator 1 (20)

> *"So, I'll ask employee X to go to location Y, and employee Z that they're needed at location W... The Regie-anesthesiologist serves as the primary point of contact for all working anesthesiologists. Similarly, the operating room assistant coordinator does so for all operating room assistants, and the anesthesia coordinator for all anesthesia staff."* - OR Coordinator 2 (21)

Finally, the OR coordination team communicates to with supporting OR staff regarding their required presence and timing for the emergency surgery. Occasionally, the surgeon directly contacts staff to convey specific requirements for the intervention.

> *"However, handling emergencies is a different challenge altogether. It's a fairly impromptu moment when you think, 'Oh, that appointment fell through, and they're almost finished in that operating room, so we can fit the emergency case in there.' Then you start calling the referring physician, who then has to reach out to a colleague to see if someone can handle it. They get back to me saying, 'Well, I've found someone now, or it'll be another half an hour,' and only then do we proceed to schedule the patient. It's crucial to ensure we have an available surgeon before confirming anything."* - OR Coordinator 1 (22)

At times, the OR coordination team identifies a gap in the schedule, providing an opportunity to accommodate the emergency surgery within this window. However, if the surgeon is unavailable during this time, it is their responsibility to reach out to colleagues who may be able to fill in. Figure 5.8 illustrates the interactions among various stakeholders involved in emergency surgery planning.

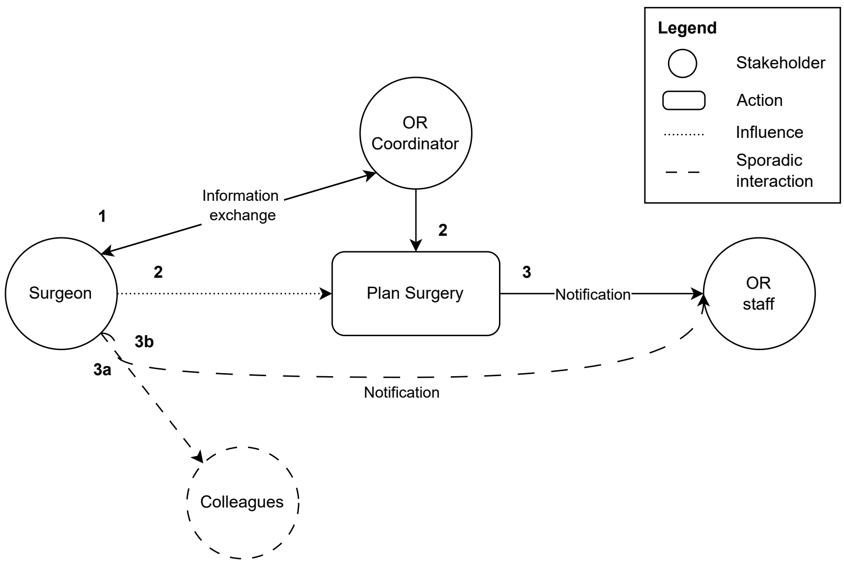


Figure 5.8: Schematic representation of interactions among stakeholders when scheduling emergency surgeries on the day of execution. The dotted line signifies the influence of a surgeon on the start time of the emergency surgery. The dashed line represents interactions that occur sporadically between the surgeon and supporting OR staff.

5.3.4. Reactions to Concept Decision Support System

During the interviews, participants were presented with a mock-up of the decision support system to visualize how the schedule would be presented and options would appear. Initially, participants provided feedback on the visualization of the schedule within the DSS.

> *"What makes this clearer is that it's online. So, you can see the progress over time. Right now, we don't have that; all we see is the minutes ticking away. It's not as visually intuitive. But online, you can easily track your position. For instance, if you know the start and end times of the day, you can quickly see that OR 14 ending earlier compared to the schedule of OR 1, with only a short time left until it's 4:00 PM."* - OR Coordinator 2 (23)

> *"I find the Schiphol-style board with more information and colors quite appealing. And also that it has a legend at the bottom for me to check at which registered time the process is at. Right now, we also have colors indicating process progress, but I have no clue what color belongs to what part of the process, and there is no way for me to quickly find out what is what."* - OR Coordinator 1 (24)

> *"It's quite a lot of information that we have to follow up on by making calls, but it would be much more convenient if we had it readily available in one frame. Currently, we spend a lot of time making calls, checking, and wandering around to figure out where, for example certain equipment is being used."* - OR Coordinator 1 (25)

Clearly, the visualisation of the schedule in the mock-up is regarded as an improvement to the current situation. Participants not only acknowledge that the visual representation offers a clearer and more comprehensive overview. They also highlight that all necessary information to comprehend the schedule is consolidated within a single frame. Additionally, OR staff mentions ongoing challenges with missing or insufficient data in the current system.

> *"The estimations of procedure duration are often inadequate, especially for emergency cases. It's slightly better for elective surgeries but still not entirely reliable. Sometimes, there's no estimation at all; for instance, a patient may be scheduled for an appendectomy, and a placeholder of 0 or 1 is entered, which isn't helpful at all. In such cases, you have to rely on your own experience to make an estimate, which can be quite challenging."* - OR Coordinator 2 (26)

> *"The surgeon for this procedure is Dr. L. in this case. However, that doesn't necessarily mean that this doctor will be the one performing it... You would think that if you schedule a surgery, you would actually perform it. But it doesn't work that way, and what also happens sometimes is that the surgical order is created under the supervisor's name, but the assistant ends up being the lead surgeon."* - Planning Specialist (27)

Addressing problems stemming from missing or inadequate data will require additional attention in the further development of the DSS. Despite these challenges, OR staff recognize the value of optimization and have presented alternative schedules, as outlined in the following quotes;

> *"That's quite valuable because currently, we handle it on an ad hoc basis, and I must say, with six pairs of eyes, you see a lot, but you also sometimes forget or overlook things. Especially because I believe we miss many solutions during the day simply because we don't see them. It's always better to see them and then decide not to proceed, because at least you've seen them... And it is also quite nice to be able to show the surgeon or even the patient why a decision was made and between which options we have had to choose."* - OR Coordinator 2 (28)

> *"When talking to the surgeon, I would definitely rely on the system. It serves as a backup, and allows me to communicate that 'Hey, I didn't come up with this myself, it's not just my opinion, it's the data that's speaking.'"* - Teamleader Anesthesiology (29)

> *"I also appreciate having suggestions because currently, you have to come up with ideas yourself. But especially if it can be further developed to include considerations for staff and equipment, that would be even better. The program could then suggest, 'No, that's not possible because you're missing this' or it could provide a suggestion with a 'watch out' or say, 'Hey, it's not possible because...'."* - OR Coordinator 1 (30)

While enthusiasm for the DSS is evident, it's important to note that the system is not yet fully operational, lacking key information such as special equipment and staffing considerations in the optimization process. Despite this, OR staff show keen interest in further development of the DSS, as indicated in quote 30. Moreover, they provide additional suggestions for the enhancement of such a system.

> *"In the past, we also had a time registration for closure. That meant that the surgeon was closing the wound, then you basically know that the end is in sight and we (OR Coordinators) know how long that is going to take approximately. However, that information is no longer available to us; it's now the start of the surgery and the end of the surgery. So, you have to call and ask how far they are. And sometimes you can tell by certain medication that is registered from the anesthesia that they're almost done. And it's, of course, very insightful to see if they still have to start or if the operation is almost over... So, as far as I'm concerned, closure should also be reintroduced."* - OR Coordinator 1 (31)

> *"Another useful addition would be to provide a suggestion regarding which emergency case should be prioritized first. For example, if there are 10 patients on the emergency list, each with different surgeons and varying wait times, the tool could consider the number of days or hours each patient has been waiting and suggest prioritizing those who have been waiting longer. This additional suggestion regarding the order of emergencies would provide us with more guidance for explaining our decision-making process to the surgeon."* - OR Coordinator 2 (32)

5.4. Preliminary Conclusions

The results from the validation interviews indicate that only minor adjustments were made to the process flowchart. This suggests that a thorough analysis of OR policy documents can provide valuable insights into the functioning of an OR complex. Based on the analysis and the methodology used to create the process flowchart, it is hypothesized that it effectively captures the workflow for making scheduling decisions in all Dutch UMCs. However, it is advisable to conduct additional validation of the flowchart in other UMCs.

The concept DSS was developed based on current practices and policies extracted from the OR policy document. Reactions to it were generally positive and seem to fill an information gap. However, further development is needed, particularly scheduling alternatives need to consider equipment and staff availability. Their willingness to provide input to improve the system are interpreted as enthusiasm and will help in pushing development to a higher level.

Furthermore, attention should be payed to incorporating the needs of other stakeholders in the scheduling process. Given the need for interactions and information exchanges among stakeholders, the DSS cannot be fully automated but should serve as a support tool which aids a decision maker and strengthens their position.

Based on the findings in this chapter I recommend providing the Decision Support System to the OR Coordinator and granting them the authority to modify the schedule. This would give them control over schedule adjustments and the flexibility to explore different scenarios in real-time. As a result, the OR Coordinator could quickly gain insights into impact of decisions on the schedule and be responsible for administrative tasks, such as rearranging or cancelling surgeries. The primary responsibility for rescheduling decisions would remain unchanged with the original stakeholders. Other stakeholders would have read-only access to the schedule of the decision support system as this is required to sustain collaboration between stakeholders.

As indicated by OR staff in interviews, there are occasional issues with missing or incomplete data. This data provides crucial information to the OR coordinator in decision making. In the next phase, data evaluation will be crucial to determine effective use of it for a functional decision support system.

6
Part 3 - Data Analysis

To develop a decision support system capable of providing meaningful information to an OR coordinator for decision-making using currently available data, a thorough analysis of this data is required. This analysis aims to construct a database of average durations of surgical interventions, from which the decision support system can extract relevant data. Understanding the structure and shortcomings of the data is essential to ensure its suitability for supporting OR coordinators with scheduling decisions.

6.1. Objectives and Subquestions

The goal of this thesis is to create a decision support system accessible to the OR coordinator. In this part of thesis an emphasis is placed on the utilization of existing hospital data within the decision support system. Accordingly, the following objectives are established to enable the utilization of hospital data;

Objectives

- Evaluate hospital data LUMC
- Create database for decision support system

The initial objective aims to outline the current state of affairs, laying the groundwork for achieving the second objective, which represents a milestone in the development of the decision support system. These interconnected goals will aid in the evaluation of the following research question;

Subquestion

- To what extent can current hospital data be used to create reliable schedules?

6.2. Methods

To assess hospital data and derive average durations for interventions, it's necessary to acquire and prepare the data, addressing any missing information as necessary. Analyzing the data enables the generation of datasets that the decision support system can use to extract information for creating schedules. Appendix D section D.1 includes the MATLAB code utilized for determining average durations categorized by planned duration for each specialty.

Ultimately, the reliability of using this data for scheduling is evaluated by examining the correlation between data-derived average durations and the actual durations of surgical interventions in 2024.

6.2.1. Data Acquisition

In order to develop the decision support system outlined in section 4.3.3, it's essential to base the schedule on historical data from which the average duration of surgeries can be derived. Consequently, timestamped data from all surgeries conducted in the year 2023 were gathered to extract the historical duration of surgeries. Figure 6.1 illustrates the collected timestamps recorded during surgery. The process of calculating subsections of durations from this dataset is elaborated upon in section 6.2.2.

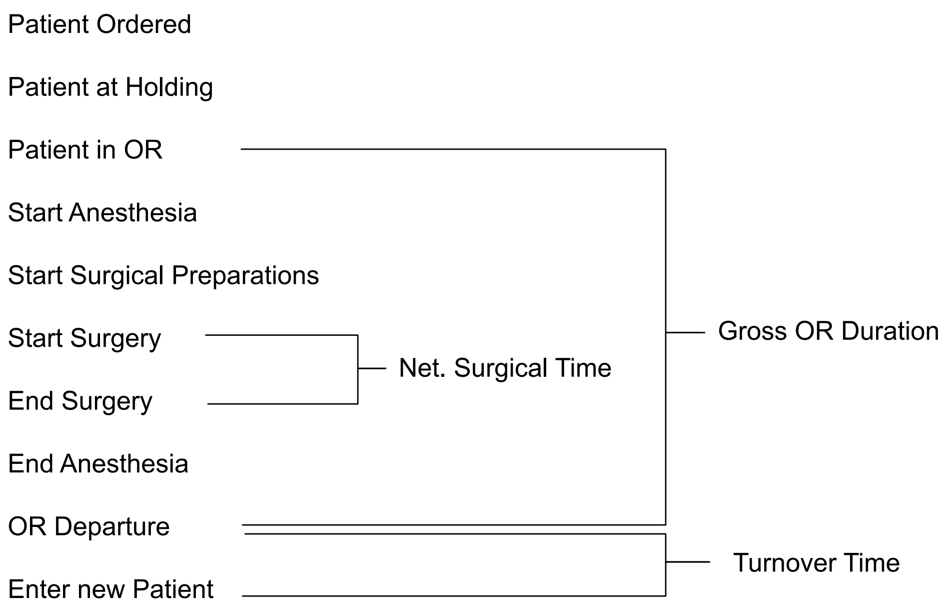


Figure 6.1: Timestamps registered during surgery in the electronic patient record as described by van Houdenhoven [2006]

6.2.2. Data Preparation

The average duration of surgeries was computed using a dataset from 2023, comprising all interventions recorded in HiX. Only elective surgeries with timestamped information for all registered timestamps were considered for calculating average gross OR durations. These timestamps are depicted in figure 6.1. An average gross OR duration was computed for each specialty relative to the planned duration registered for a surgery.

To facilitate updating the schedule throughout the day, averages of expected remaining duration for a surgery per specialty and planned duration were calculated based on timestamps captured in HiX. Only average durations derived from 10 or more datapoints (interventions) were utilized for updating the schedule. The historical durations per specialty, per planned duration, and per timestamp are detailed in Appendix C.

Missing Data

For surgeries where the planned duration is not present in the dataset of average gross OR duration for a specialty, a categorization approach was employed. Surgeries were grouped into three categories based on their planned duration: those with a planned duration under 90 minutes, those between 90 and 180 minutes, and those over 180 minutes.

For each of these groups, a multiplication factor is computed to be able to calculate remaining duration until 'OR Departure' of surgeries with certain planned duration at subsequent timestamps. These factors were determined by analyzing interventions from the surgical specialty falling into each group. For each intervention, the time elapsed for each timestamp until 'OR Departure' is recorded. The average of these elapsed times, along with the average of the planned duration for interventions in the group, was used to calculate the multiplication factor. These multiplication factors, detailed per specialty in Appendix C.

6.2.3. Data Analysis

To evaluate the suitability of current hospital data for creating reliable schedules, several analyses were conducted. First, the relationship between planned duration and net. surgical time is examined for each intervention, as planned duration is intended to reflect or provide an indication of net. surgical time. Verifying this relationship strengthens the rationale for using planned duration in subsequent steps to calculate average gross OR duration.

Next, differences between average gross OR durations and planned durations are calculated and visualized to understand the disparities. Additionally, the ratio of planned duration to average gross

OR duration for surgical specialties is plotted to assess the suitability of the current multiplication factor of 1.33 used to derive average gross OR duration.

To assess the accuracy of average gross OR durations categorized by planned duration and surgical specialty in capturing actual intervention durations, a comparison is made between the two values. The actual durations of all interventions from a two-week period in 2024 are compared to the calculated average gross OR durations from the 2023 dataset. Deviations of up to 10% are deemed acceptable based on the performance norm employed in the LUMC (as indicated in statement 40 of the OR Policy Analysis in Appendix A).

6.3. Results

In an ideal scenario, which is also preferred by the hospital, average duration of each surgical intervention would be calculated based on historical data and used to create the most reliable schedule. However, the current state of hospital data presents significant challenges, making this task nearly impossible. Surgical interventions of the same type are often not uniformly registered in the database, and important information may be missing or incorrect. As a result, an alternative approach is necessary to derive average durations of surgical interventions that can positively impact scheduling. The following sections outline the proposed approach and its outcomes, demonstrating how calculated averages can enhance scheduling processes.

6.3.1. Planned Duration vs. Average Net. Surgical Time

Given that current schedules are primarily based on the planned duration, which serves as an indicator of the expected net. surgical time, it's crucial to verify the relationship between planned duration and actual average net. surgical time for various surgical specialties.

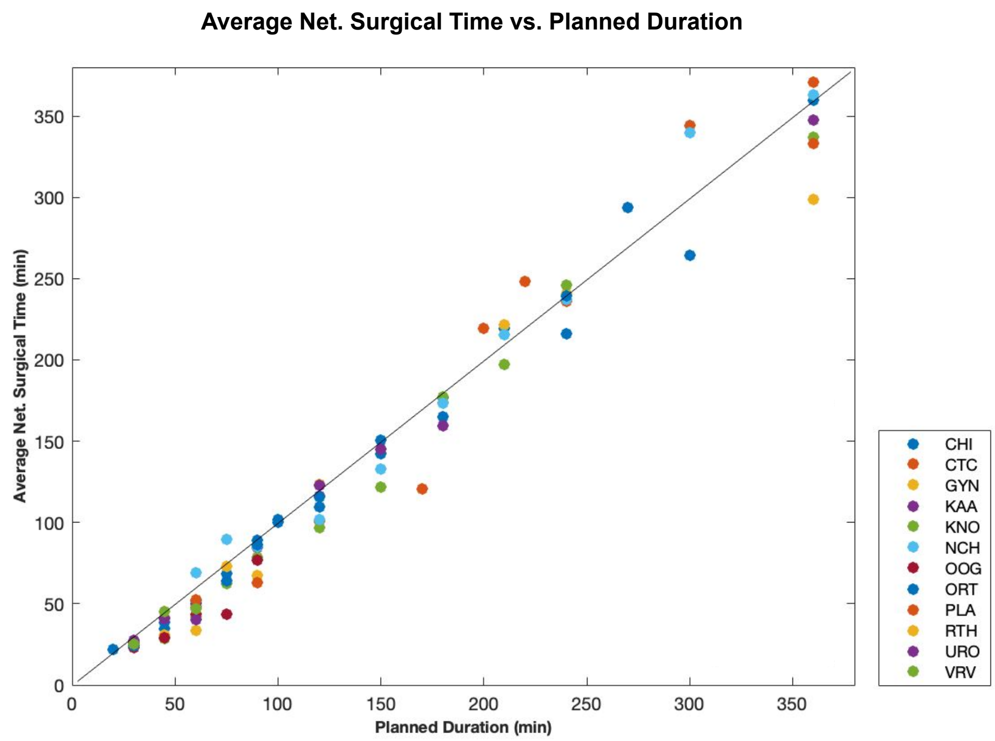


Figure 6.2: Average net. surgical time versus planned duration for multiple surgical specialties. Diagonal line represents a fully linear relationship between planned duration and average net. surgical time.

Figure 6.2 illustrates that the average net. surgical time of all specialties closely aligns with the diagonal, suggesting a linear relationship between average net. surgical time and planned duration. Moreover, the majority of points fall below the diagonal, indicating that planned durations tend to exceed net. surgical times on average. This suggests that surgeons typically complete procedures more quickly than planned. Consequently, planned durations may allow for potential delays in total OR time for patients.

However, some surgical specialties provide less accurate indications for planned durations than others, particularly beyond the 200-minute mark. Beyond this threshold, there is an increasing challenge in accurately estimating the required planned duration for surgery. Notably, points above the diagonal indicate instances where interventions take longer on average than the planned duration, posing a potential scheduling challenge.

6.3.2. Historical Gross OR Duration vs. Planned Duration

To generate schedules utilizing historical data, average gross OR durations for surgeries categorized by their planned duration within each surgical specialty are computed. Table 6.1 presents results for a subset of surgical specialties, including differences between planned duration and historical duration. Comprehensive data on average durations for surgeries across all surgical specialties is available in the Historical Duration Database which is found in Appendix C of this thesis.

Table 6.1: Overview of average gross OR durations compared to the planned durations across different surgical specialties of data from 2023.

(a) CTC

Planned Duration (min)	Avg. Gross OR Duration (min)	Avg. Rounded Difference (min)
60	88	28
90	108	18
120	170	50
170	195	25
180	238	58
200	291	91
220	314	94
240	313	73
300	440	140
360	456	96

(b) ORT

Planned Duration (min)	Avg. Gross OR Duration (min)	Avg. Rounded Difference (min)
30	81	51
45	74	29
60	90	30
75	105	30
90	134	44
100	148	48
120	167	47
150	199	49
180	228	48
240	313	73

(c) GYN

Planned Duration (min)	Avg. Gross OR Duration (min)	Avg. Rounded Difference (min)
30	54	24
45	65	20
60	94	34
75	119	44
90	112	22
120	174	54
150	198	48
180	236	56
210	282	72
240	314	74
360	394	34

(d) URO

Planned Duration (min)	Avg. Gross OR Duration (min)	Avg. Rounded Difference (min)
30	62	32
45	71	26
60	79	19
120	175	55
150	203	53
180	221	41
360	413	53

The data from the previous table highlights significant differences between the planned duration and average gross OR durations within surgical specialties. Moreover, this disparity varies on occasion across surgical specialties for interventions with similar planned durations. For instance, in Cardiothoracic Surgery (CTC), an intervention with a planned duration of 90 minutes may have an average gross OR duration of 108 minutes, while in Orthopedic Surgery (ORT), the average gross OR duration for a similarly planned intervention could be 133 minutes. This discrepancy of 25 minutes between the average durations of procedures with similar is quite large. Though the majority of interventions with similar planned duration have similar gross OR duration, it is important not to overlook these variations which are relevant in subsequent use of data for schedule construction.

Ratios

Expressing the difference between planned duration and average gross OR durations as ratios is depicted in Figure 6.3. These ratios can serve as multiplication factors to calculate the gross OR duration of a surgical intervention based on its registered planned duration.

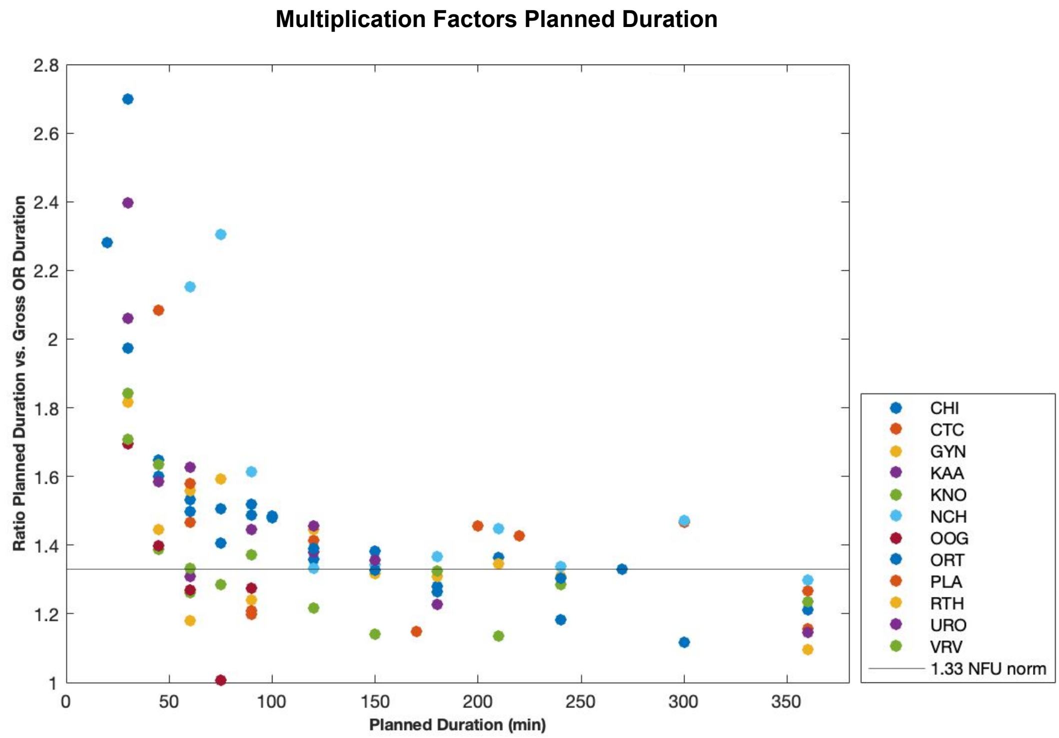


Figure 6.3: Ratios of planned durations to average gross OR durations for all surgical specialties. Ratios can be utilized as multiplication factors to obtain gross OR duration from planned duration. The NFU norm represents the current multiplication factor utilized to determine gross OR duration from the registered planned duration.

The current standard multiplication factor of 1.33 is utilized to convert planned duration into gross OR duration. However, as shown in Figure 6.3, employing a range of multiplication factors within and across surgical specialties would likely result in schedules that more accurately reflect reality.

6.3.3. Variation Historical Gross OR Durations 2023 and Actual Gross OR Durations 2024

Through analysis of 9 days in 2024 it has been established that historical durations are effective in predicting actual surgery durations within a 10% margin in approximately 27% of cases. Interestingly, historical average durations overestimate the duration of surgery in about 58% procedures. This implies that utilizing historical average durations in scheduling allows for more flexibility and reduces the likelihood of OR overtime.

While this may appear promising, it raises concerns about underutilization of the OR. Moreover, using historical durations still leads to an average of 8.1 interventions per day (24 % of all elective interventions per day) exceeding their scheduled duration by more than 20 minutes, with an average of 3.4 surgeries (10 % of all elective interventions per day) requiring an additional 50 minutes or more to finish. These interventions exceeding their expected duration based on historical averages can still lead to overtime.

6.4. Preliminary Conclusions

The current state of hospital data presents challenges for accurately calculating gross OR durations based on historical data for surgical procedures across all specialties. Variability in naming conventions and the lack of consistent additional characteristics make it difficult to precisely determine procedure durations. In response, I've opted to use planned durations as a starting point and group interventions with the same planned duration and surgical specialty. Given the linear relationship between planned durations and average net. surgical times, grouping interventions based on planned duration and calculating their average gross OR durations is believed to contribute to reliable schedules. Furthermore, analysis showed that current multiplication factor of 1.33, which is utilized to calculated gross OR duration from planned duration, may not be suitable. Instead, a range of factors specific to each surgical specialty and planned duration would offer a more appropriate approach.

Analysis revealed that relying solely on historical data for scheduling can still result in discrepancies between expected and actual durations (see section 6.3.3). Various uncertainties during surgeries contribute to this discrepancy, and while predictions may improve with more detailed specifications, for example with factors like surgeon speed and patient characteristics, current data limitations prevent this. As a solution, continuously tracking the OR schedule and updating expected OR closing time using intermediate time registrations is proposed. This approach is hypothesized to provide better insight into the real-time development of the schedule throughout the day.

7

Part 4 - Concept Decision Support System 2.0

Incorporating information from the daily schedule, historical durations database, and real-time data from HiX on the day of surgery, enables the generation of updated schedules with expected start times, average remaining durations, and expected surgery endtimes throughout the day. Continuous generation of updated schedules throughout a day forms the foundation of the revised decision support system (DSS) discussed in this chapter. The chapter elucidates how schedules are updated and outlines the concept of DSS 2.0. Additionally, an analysis of DSS 2.0 is conducted to evaluate its potential for tracking the schedule on the day of surgery and facilitating (earlier) decision-making. Through this analysis, areas for improvement crucial for the successful use and implementation of the system are pinpointed.

7.1. Objective and Subquestions

Part 3 has established a database of average durations for various points within surgeries until the end of the intervention. Utilizing this database, necessitates slight modifications to the original concept decision support system of Part 1. The adjustments to the decision support system are presented in this chapter. Furthermore, the performance of the revised concept with regard to overtime detection and prediction of OR closing time needs to be assessed. These two goals are described by the following two objectives;

Objectives

- Define concept 2.0 of decision support system
- Analyse performance of concept decision support system 2.0

The following subquestions have been constructed to facilitate reaching the objectives;

Subquestions

- How does hospital data shape the decision support system?
- To what extent does the decision support system offer insights that can guide scheduling decisions to prevent overtime?

7.2. Methods

To analyze the performance of the concept DSS 2.0, data is acquired and prepared to facilitate the generation of updated schedules throughout the day. Section 7.2.3 outlines the analysis conducted to evaluate the system's effectiveness in detecting overtime and approximating the actual closing time of the operating room.

7.2.1. Data Acquisition and Preparation

Two weeks' worth of data from previously completed schedules was gathered to generate expected schedules at specific points in time. Initial schedules, which included planned durations, surgery names, surgical specialties, and OR closing times, were collected in PDF format and transferred to Excel. Additionally, data on cancelled cases and timestamps collected during surgeries for all interventions on the same day were obtained and collected in a separate Excel file per day. The process of using this data to produce the expected schedules is detailed in section 7.2.2.

Data Preparation

Three days (09-01, 15-01, and 16-01) from the two week dataset were deemed suitable for generating expected schedules at specific points in time and will be referred to as 'Sample Days'. On some occasions intermediate timestamps in the process were missing, these were replaced by the next recorded timestamp in the process. One day (17-01) was excluded entirely due to an excessive number of faulty timestamps in the data, making it unreliable for obtaining outcomes for two ORs on the day of surgery.

Six other days (08-01, 10-01, 11-01, 12-01, 18-01, 19-01) required adjustments to the timestamps of one or two interventions on the day of surgery because they had been reassigned to different ORs on the day of execution. This adjustment meant that the timestamps received by the intervention could no longer accurately indicate whether the OR was going into overtime or not. The timestamps of these interventions were adjusted by changing the start time of the OR timestamps to 15 minutes (average turnover time) plus the finish time of the previous intervention in the original OR. The spacing between consecutive timestamps remained the same as originally recorded. Data from these days was only used for additional testing of the analysis as it had been manually manipulated, and will be referred to as 'Additional Days'.

7.2.2. Code for Updating Schedules

For the continuous updating of the schedule throughout the day, a MATLAB script was developed (see Appendix D section D.2 for full code). This script relies on several inputs, including the initial schedule, the current time, recorded timestamp data, and the average durations or multiplication factors of interventions from the historical database previously calculated in Part 3 (see Appendix C for the full dataset).

The script operates in a loop for each intervention in the schedule, generating a new schedule iteration at a given point in time. It updates start and finish times using the average durations from a specific timestamp to the end of the surgery, thereby reflecting the new expected closing time of the OR. The MATLAB code for this process can be found in the attached script accompanying this thesis. Figure 7.1, on the next page, provides a visual depiction of the code's operation.

In addition to updating the schedule by adjusting the time of day and related timestamp data, interventions were occasionally removed from the schedule if they had been cancelled at specific times during the day. This adjustment reflects the actual execution of the schedule.

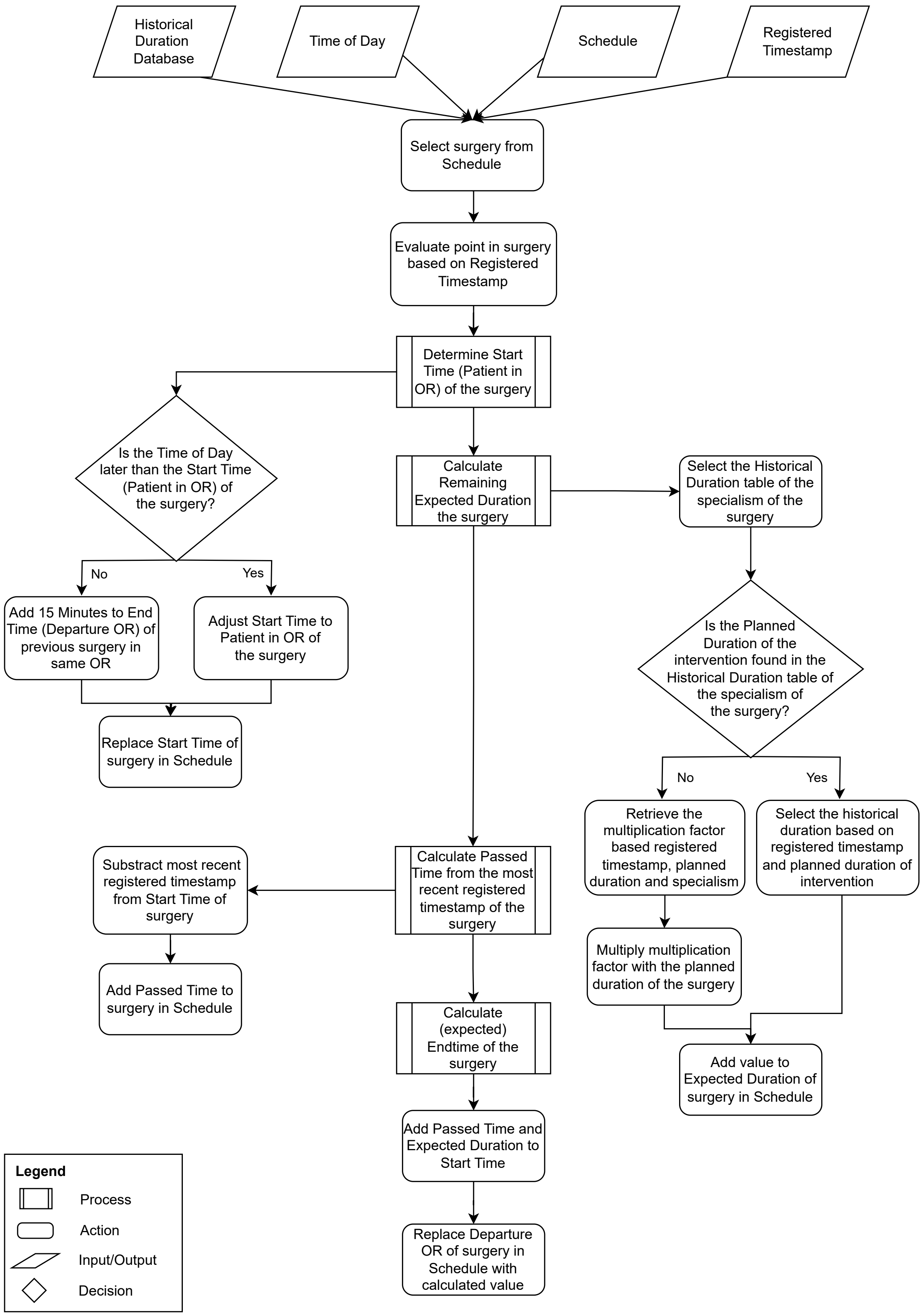


Figure 7.1: Schematic representation of the MATLAB code responsible for updating the OR Schedule at a given time. This process is applied iteratively to each intervention listed in the OR Schedule.

7.2.3. Analysis Concept Decision Support System 2.0

To assess the performance of Concept DSS 2.0, several analyses are conducted using MATLAB. These analyses are carried out for updated schedules at intervals of 10 minutes throughout the day. Schedules are updated according to the same principles as described in section 7.2.2.

Firstly, the system's ability to accurately identify ORs running into overtime using current hospital data was assessed. For simplicity, overtime was defined as any OR still in business past 16:00. The system's indication of ORs going into overtime or ending before 16:00 was compared to the actual ending times. Correct indications, as well as incorrect ones, were recorded. Additionally, the time frame before 12:30 in which the system was most accurate at predicting ORs going into overtime was identified. This analysis was performed using the sample days (9th, 15th, and 16th of January) to determine the time frame with the highest number of correct indications. The same tests were conducted on additional dates (8th, 10th, 11th, 12th, 18th, and 19th of January) for validation purposes.

Furthermore, the ability of concept DSS 2.0 to determine OR closing times was evaluated. This analysis involved plotting the expected OR closing time for each OR against the time of day. The actual OR closing time was also plotted on the same figure, and the relative difference between the expected and actual OR closing times was calculated and labeled. A difference of less than 30 minutes was considered good, a difference between 1 hour and 30 minutes was deemed acceptable, and a difference of more than 1 hour was considered poor.

7.3. Results

The revised DSS will no longer feature an optimization process or provide suggestions for schedule alterations to enhance OR performance. Current hospital data is inadequate to support such a system. Nevertheless, the concept DSS will offer insights into OR progress using available hospital data and flag ORs at risk of overtime, prompting necessary attention. To quantify the DSS's capability in this regard, performance analysis is conducted to assess its effectiveness and identify areas for further development.

7.3.1. Mock-Up Concept Decision Support System 2.0

Figure 7.2, on the next page, illustrates the integration of average remaining durations into the daily schedule in a mock-up version of the revised DSS concept. Although concept 2.0 lacks the optimization feature, it still provides valuable insight and an overview of the current schedule's progress. The schedule is updated according to the same principles as described in Figure 7.1 of section 7.2.2.

Adjustments to the concept decision support system were made to ensure compatibility with available hospital data. For instance, turnover times were adjusted to 15 minutes, reflecting the average turnover time between procedures in the LUMC. Additionally, modifications were made regarding timestamp updates, as there are fewer timestamps available for updating than initially anticipated based on OR policy analysis. The current database only includes timestamps from Figure 6.1, along with a timestamp indicating when the patient is admitted to the hospital.

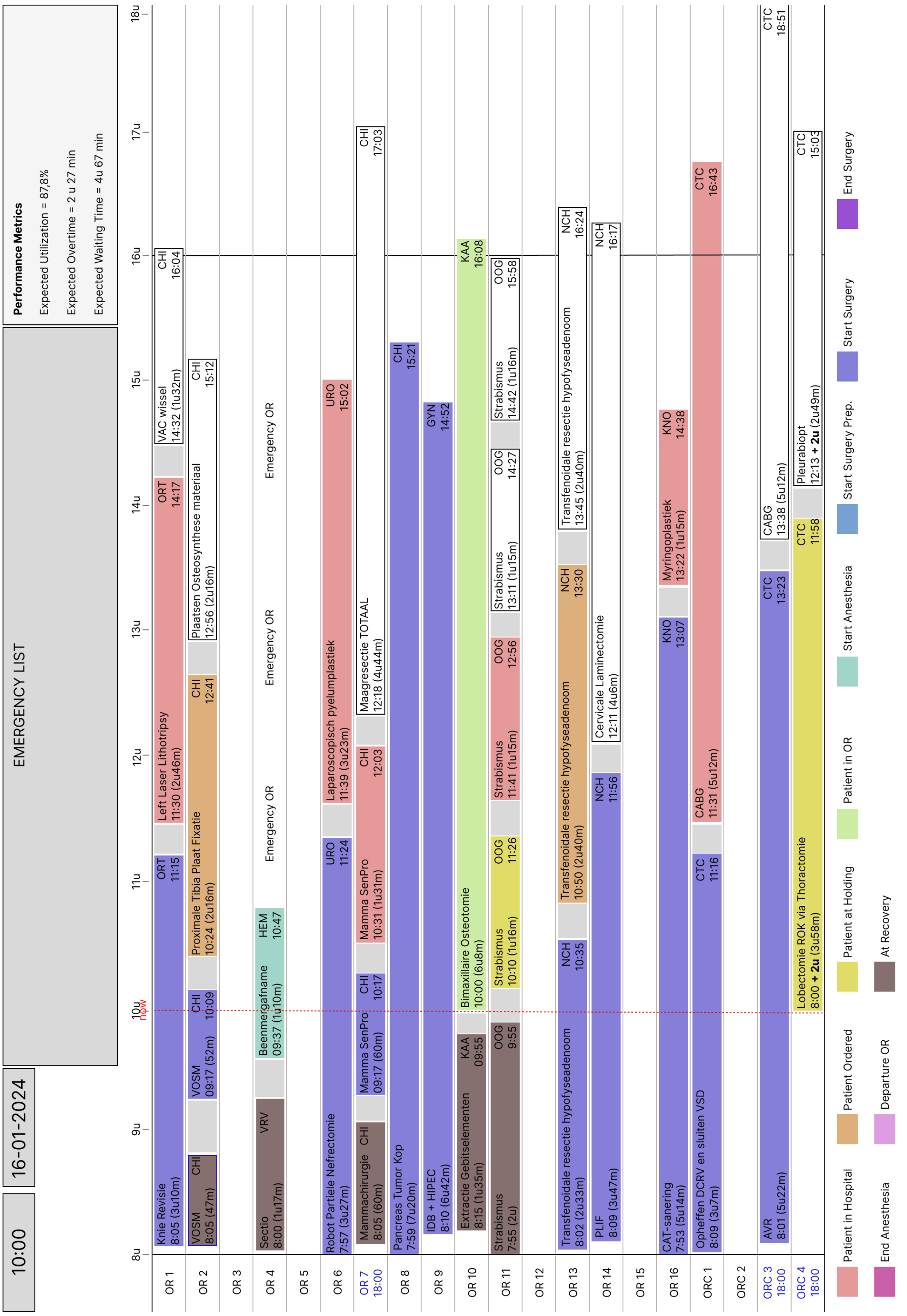
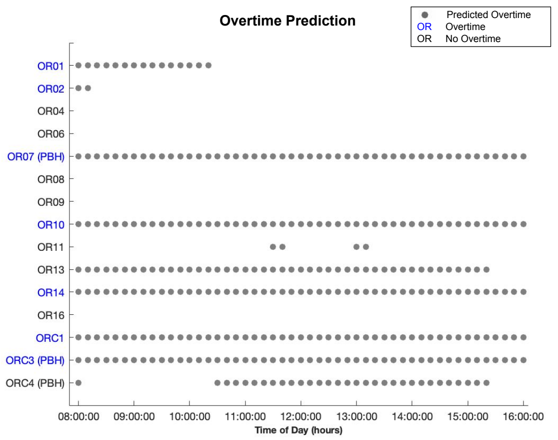


Figure 7.2: Mock-up concept Decision Support System 2.0

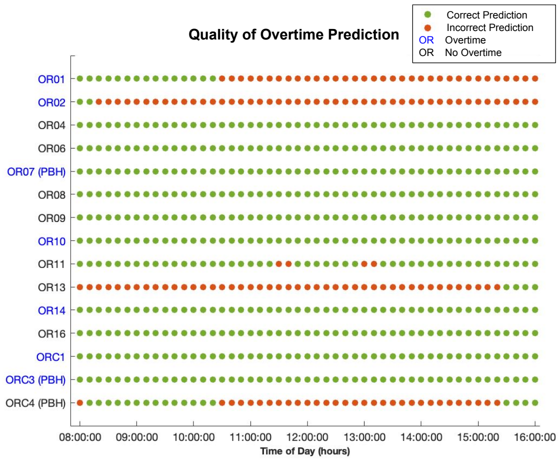
7.3.2. Overtime Prediction

Since the primary responsibility of an OR coordinator is to monitor the schedule's progression and minimize overtime, it's critical for the DSS to promptly identify ORs at risk of running into overtime. To assess the DSS's ability to predict overrunning ORs, an analysis was conducted by updating the schedules at 10-minute intervals throughout the day and identifying their expected OR closing time and subsequently comparing them with the actual OR closing times.

Figure 7.3a provides an example of overtime prediction on a surgery day. Circles cease to appear in the figure when the updated schedule, at a specific time of day, indicates an expected OR closing time earlier than 16:00.



(a) Gray circles represent the DSS's prediction of an OR going into overtime at a specific time of day. ORs on the Y-axis are labeled blue if they did go into overtime and black if they ended before 16:00. Additionally, some ORs were permitted to end after 16:00 due to prolonged business hours, as indicated by (PBH).



(b) Correct and incorrect prediction of ORs going overtime. ORs on the Y-axis are labeled blue if they did go into overtime and black if they ended before 16:00. Additionally, some ORs were permitted to end after 16:00 due to prolonged business hours, as indicated by (PBH).

Quality of Overtime Prediction

Figure 7.3b, which is related to Figure 7.3a, illustrates the quality of the prediction made by the system. Correct predictions are denoted by green dots, while incorrect ones are indicated by red dots. The system not only identifies ORs at risk of overrun but also those that are likely to finish on time. Recognizing gaps in the schedule enables the insertion of emergency surgeries or the relocation of elective surgeries to other ORs.

The accuracy of the prediction was assessed for the three sample days and is summarized in Table 7.1, showing the average percentage of correct predictions of ORs going into overtime throughout the day.

Table 7.1: Average correct overtime predictions for three sample days.

Sample Day Date	Average Correct Overtime Prediction Throughout Day%
09-01	80,4 %
15-01	90,3 %
16-01	78,1 %
Average	81,5 %

7.3.3. Optimal Schedule Intervention Window

At present, the critical period for decision-making on the day of surgery occurs between 13:00 and 14:00. However, OR coordinators have indicated that during this time frame, they often find themselves too late to make relevant changes to the schedule effectively. Consequently, I aim to identify an optimal intervention window earlier in the day (preferably before 12:30) using data from the three optimal sample days in the two-week period of 2024. Figure 7.4, on the next page, illustrates the quality of overtime prediction for these three sample days, enabling the establishment of an intervention window with the highest percentage of correct predictions for all three days between 09:40 and 10:20. Table 7.2 indicates the percentage of correct predictions of overtime on those days in the interval.

Table 7.2: Percentage of correct overtime predictions on the day of surgery within the optimal time interval for the three sample days.

Sample Day Date	Correct Overtime Prediction in Intervention Window %
09-01	86,7 %
15-01	100 %
16-01	86,7 %
Average	88,9 %

When comparing the percentages from Table 7.2 with those of Table 7.1, it becomes evident that the percentages in Table 7.2 are higher. This suggests that the DSS exhibits better predictive capabilities for overtime within the intervention window.

7.3.4. Overtime Prediction on Additional Dates

To validate findings from previous sections, the percentage of correct prediction of overtime for the additional dates of 2024 is calculated. The data from these dates were manually altered, as some interventions had been relocated to other ORs, leading to changes in registered timestamps. These alterations were made to simulate the day of surgery if these interventions had not been reallocated. Table 7.3 displays the percentages of correct predictions of overtime on additional dates in 2024.

Table 7.3: Percentage of correct overtime predictions throughout a day and within the defined optimal time interval for the days with adjusted data.

Additional Day Date	Average Correct Overtime Prediction Throughout a Day%	Correct Overtime Prediction in Intervention Window %
08-01	83,5%	81,4%
10-01	81,3%	78,8%
11-01	77,4%	65,7%
12-01	75,7%	68,6%
18-01	79,4%	78,6%
19-01	77,4%	61,5%
Average	79,1%	72,4%

Compared to Table 7.2 and Table 7.1, the percentages for both metrics are lower. Additionally, the percentages of the interval window are consequently lower than those that reflect the correct prediction throughout the day.

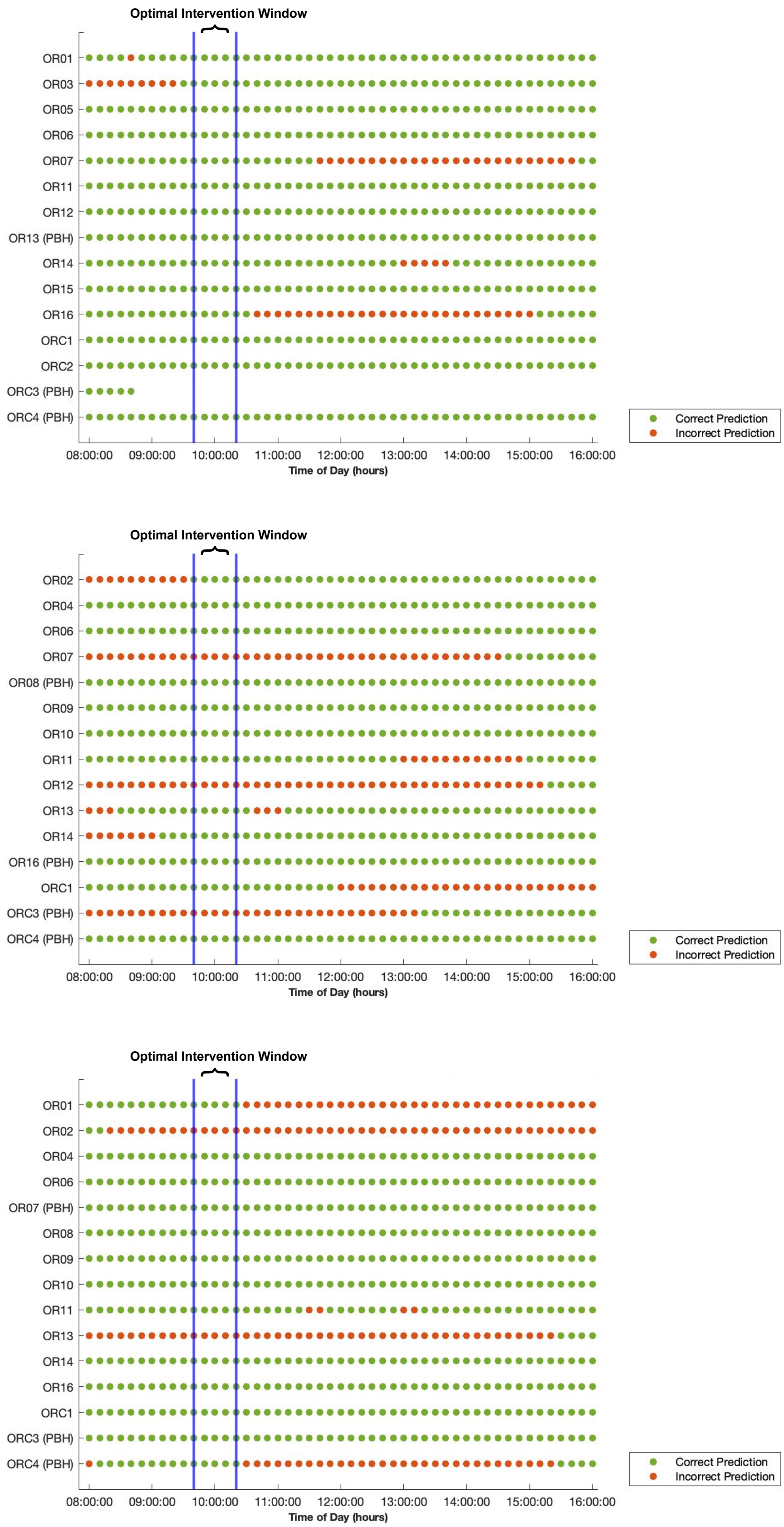


Figure 7.4: Drawing from the quality of overtime prediction figures from the three sample days, an optimal intervention window for schedule adjustments has been established. This window, with the highest percentage of correct predictions before 12:30 on the day of surgery, spans from 09:40 to 10:20.

7.3.5. Accuracy of Expected OR Closing Time Prediction

To enhance the utility of the DSS, accurate prediction of OR closing times is essential. Previous analyses focused on the DSS's ability to predict whether an OR would finish before or after 16:00. However, predicting the precise ending time enables the OR coordinator to identify gaps in the schedule which can be used in reallocation of elective surgery or allocation of emergency surgery. To assess the DSS's capability to approximate expected OR closing time, the expected OR closing time throughout a surgery day is tracked and compared to the actual closing time.

Good Prediction OR Closing Time

There were instances where the DSS accurately predicted the OR closing time within a 30-minute window, particularly when the OR program comprised surgeries with large planned durations and minimal deviations from their gross OR durations. Conversely, there were instances where the DSS poorly estimated the OR closing time for ORs with similar characteristics. However, these findings, based on random chance, do not provide substantial insights into the DSS's functionality and the potential for schedule updates to improve OR closing time prediction.

Fortunately, the DSS made accurate predictions for ORs with programs consisting of multiple surgeries with relatively short planned durations, as well as when the OR program included surgeries with large planned durations followed by shorter ones.

Multiple Surgeries with Short Duration

The model demonstrates its highest predictive accuracy for ORs featuring a program filled with multiple short surgeries. In such cases, the schedule can be updated frequently due to the relatively large number of data points available throughout the day. Figure 7.5 illustrates three examples depicting the progression of an OR with multiple short surgeries.

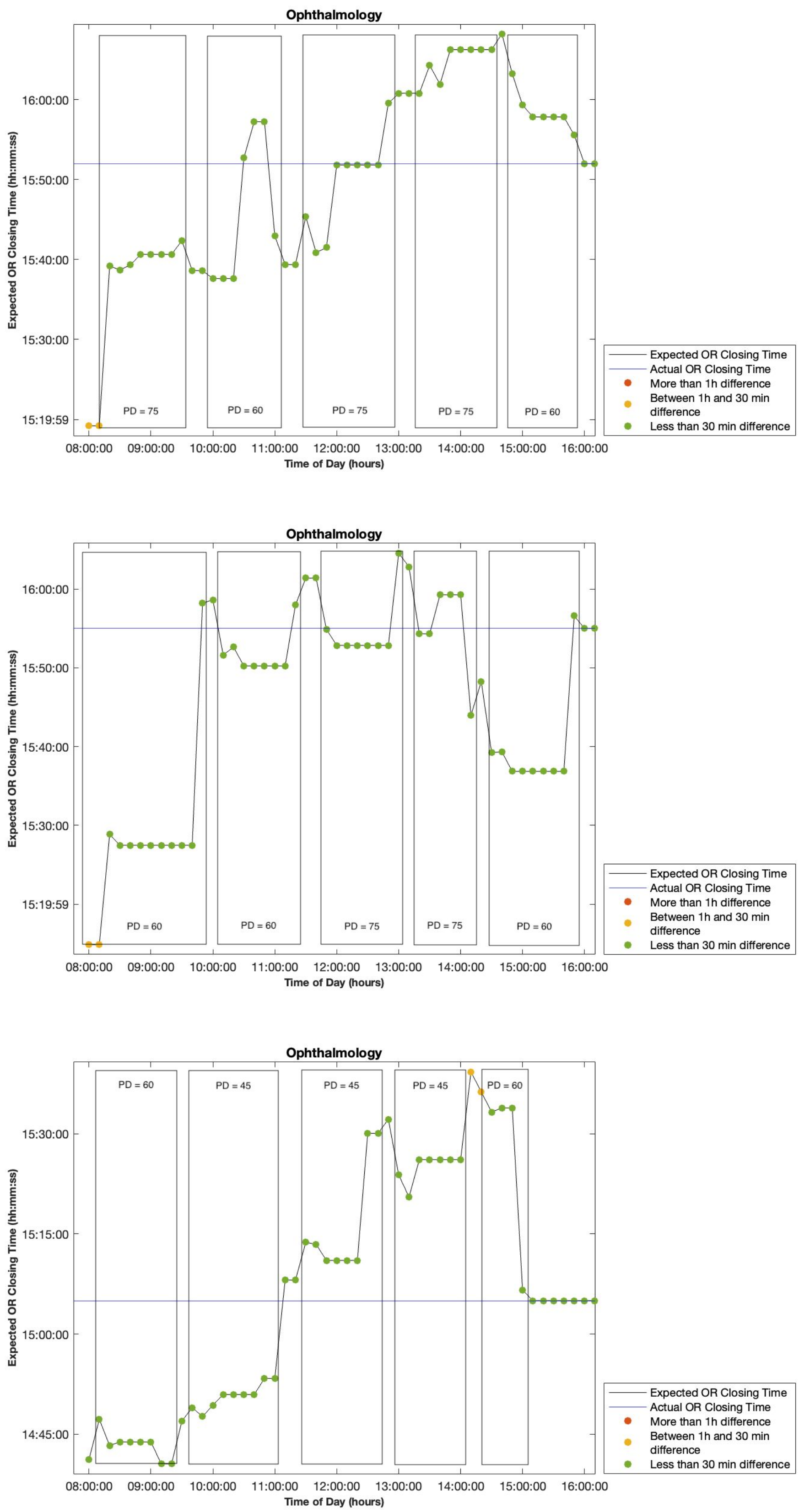


Figure 7.5: Expected OR closing time of three ORs with multiple surgeries with short planned duration. Blocks represent the gross OR duration of the surgeries and their planned duration in minutes is indicated by PD. With each registered time update the expected OR closing time is altered leading to its shift in the figure.

It's worth noting that the ORs depicted in Figure 7.5 include surgeries with fairly accurate gross OR durations due to accurate estimations of planned durations. Consequently, a relatively precise estimation of their actual duration is possible. This contributes to the close alignment between the expected and actual OR closing times throughout the day. However, in cases where planned durations have not been accurately estimated, and historical durations fail to capture the actual duration with sufficient accuracy, the progress throughout the day may differ significantly. For an illustration of such a scenario, refer to Figure 7.6.

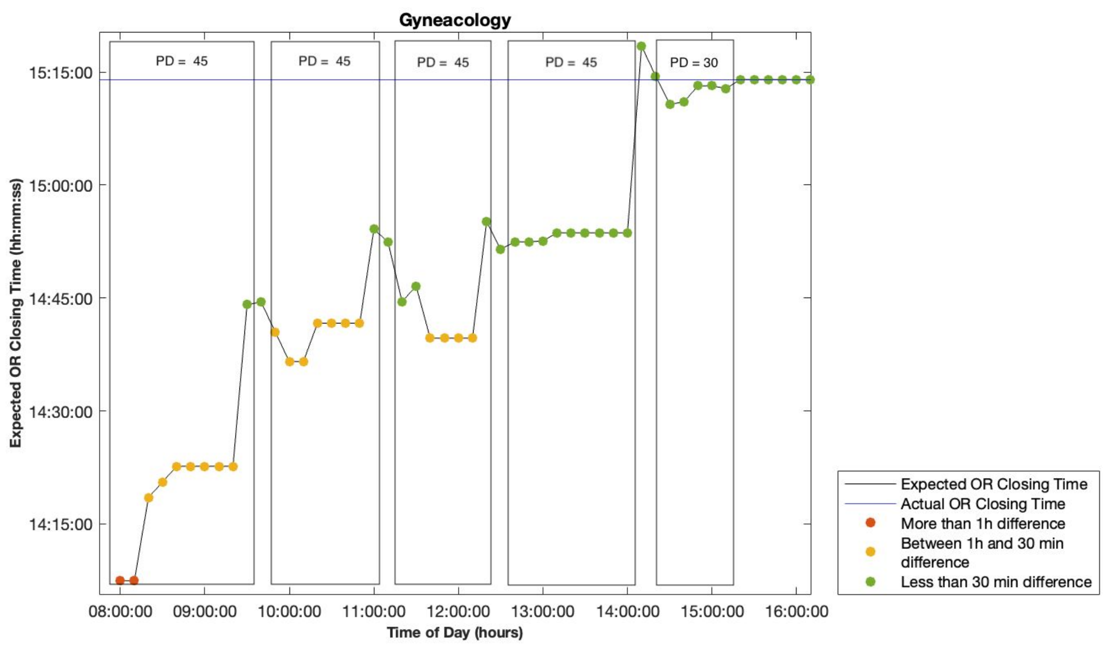


Figure 7.6: Expected OR closing time updates for an OR with multiple surgeries with short planned duration. Blocks represent the gross OR duration of the surgeries and their planned duration in minutes are indicated by PD. With each registered time update the expected OR closing time is altered leading to its shift in the figure.

Figure 7.6 illustrates that primarily the duration of the first surgery was significantly underestimated. However, through updates of the schedule, the expected OR closing time gradually aligns with the actual OR closing time, eventually falling within a 30-minute range as the day progresses.

Long Surgery Followed by Shorter Interventions

The DSS demonstrates good performance in predicting the closing time of ORs where surgeries with longer planned durations precede those with shorter durations in the program. This phenomenon is attributed to the data structure, where most uncertainty accumulates in the initial long surgery, which has relatively few data points for updating during its progress. Consequently, scheduling longer surgeries first allows for better anticipation of whether shorter surgeries will fit into the program by day's end. Especially, when the long surgery ends earlier than expected.

Figure 7.7 showcases three scenarios where longer surgeries are followed by shorter ones on the day of surgery. Following the conclusion of the longer surgery, the expected OR closing time is updated to align more closely with the actual closing time.

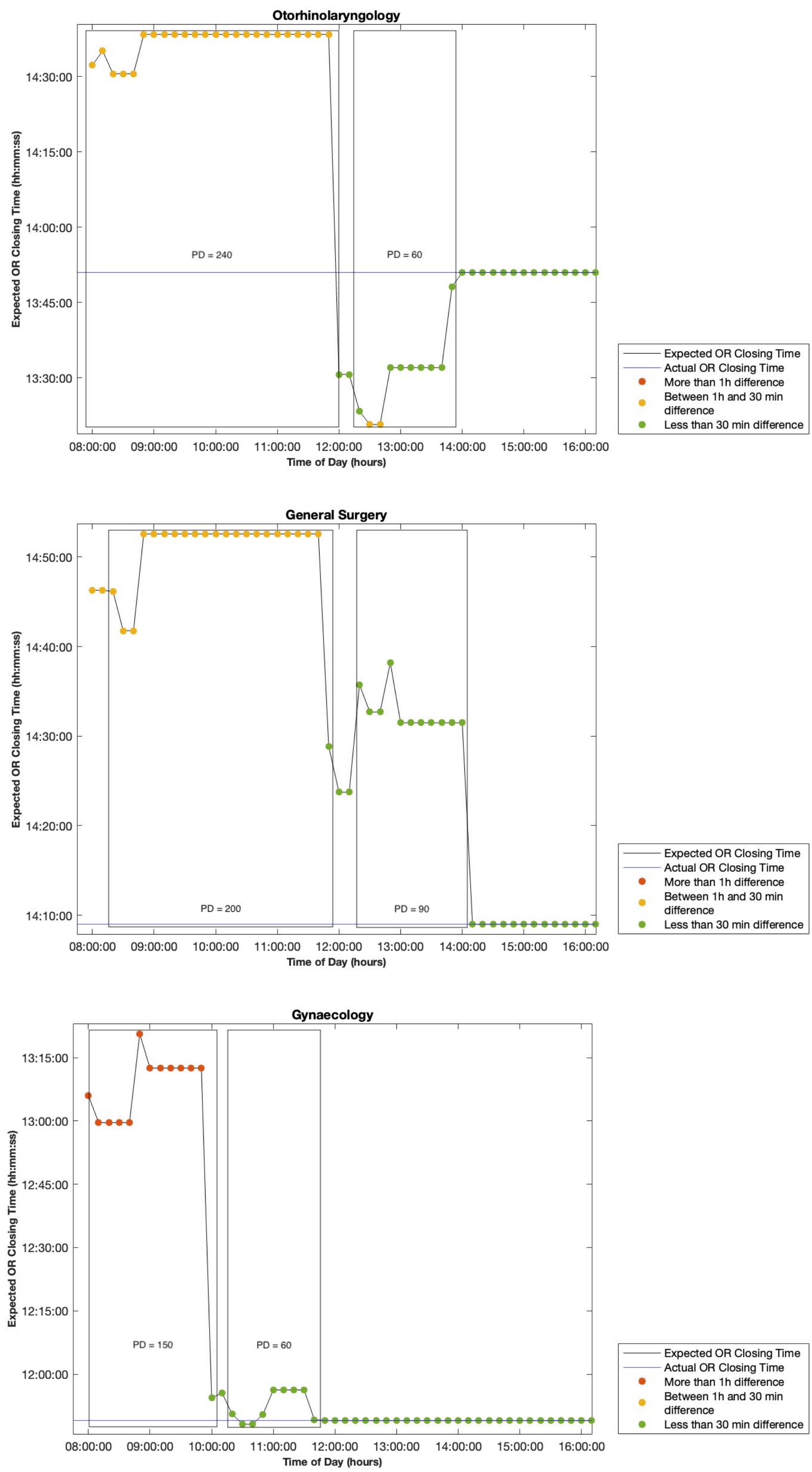


Figure 7.7: Expected OR closing time of three ORs with programs filled with surgery with a large planned duration followed by a surgery with a short planned duration. Blocks represent the gross OR duration of the surgeries and their planned duration in minutes is indicated by PD. With each registered time update the expected OR closing time is altered leading to its shift in the figure.

Bad Prediction OR Closing Time

In some cases, the DSS struggled to approximate the actual OR closing time, particularly when surgeries with substantial planned durations were scheduled later in the day.

Short Surgeries Followed by Long Interventions

The data suggests that poorer predictions of OR closing time are often observed in ORs where one or multiple short surgeries precede a long intervention scheduled later in the day. This discrepancy can be attributed to the significant uncertainty associated with the long intervention, as data updates are less frequent throughout its duration due to its extended net. surgical time. Figure 7.8 illustrates three scenarios where this scheduling pattern was observed and highlights the divergence between the expected OR closing time and the actual closing time over the course of the day.

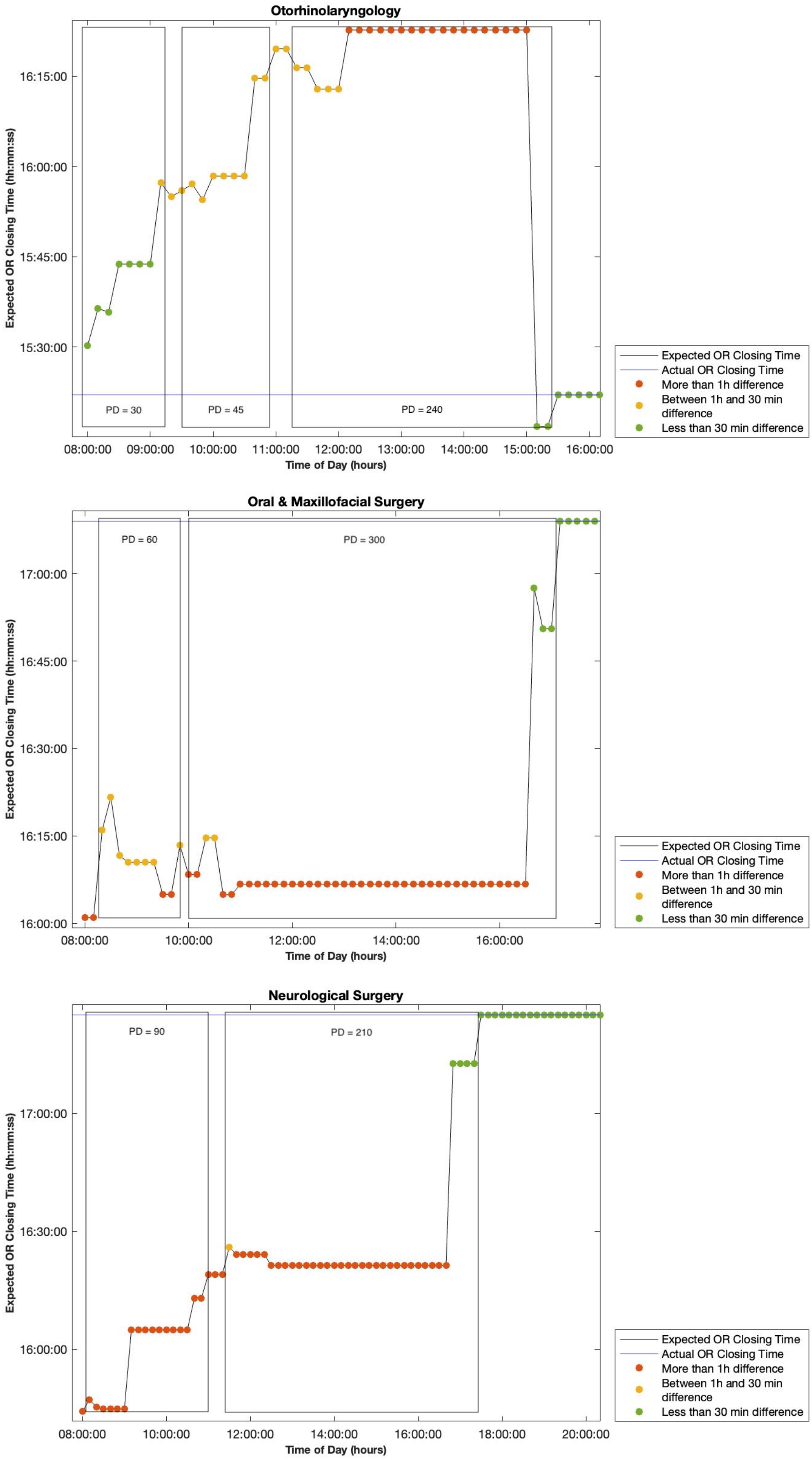


Figure 7.8: Expected OR closing time of three ORs with programs filled with surgery with a short planned duration followed by a surgery with a large planned duration. Blocks represent the gross OR duration of the surgeries and their planned duration in minutes is indicated by PD. With each registered time update the expected OR closing time is altered leading to its shift in the figure.

7.4. Preliminary Conclusions

The updated concept for the decision support system underwent adjustments to align with available hospital data from the database created in part 3 of this thesis. The structure and availability of this data significantly influence the shape and capabilities of the decision support system and contribute to the removal of optimization features. The revised concept provides an overview of the schedule's progress and updates it based on real-time information throughout the day.

Analysis revealed that the revised concept demonstrated a notable ability to accurately predict overtime, although the identified optimal intervention window did not consistently perform as expected across additional dates. Consequently, the current utility of the DSS appears more geared towards real-time tracking of the schedule.

OR closing time approximations varied depending on data characteristics and programming of initial schedules. Optimal conditions for accurate OR closing time predictions were observed in scenarios with surgeries featuring appropriately sized, often short, planned durations and ample data points for updates throughout the day. The system's OR closing time approximation is anticipated to benefit from the increased availability of intermediate data points, particularly for surgeries with longer planned durations.

8 Discussion

The goal of this thesis was to design a universally applicable decision support system for the OR coordinator in Dutch UMCs, helping them make optimal scheduling decisions throughout the day. The system uses readily available hospital data, ensuring that OR staff can access and evaluate the decision support system without significant complications.

To achieve this goal, the OR policy document was examined. Using this document and feedback from validation interviews, a process flowchart is developed which outlines the steps involved in OR coordination on the day of surgery when an uncertainty factor is introduced. While this flowchart has not yet been validated in other UMCs, it is mainly based on statements of the OR policy document classified as similar to ensure application to other UMCs. This flowchart can help the OR coordination team explain their response to uncertainty on the day of surgery and can serve as a basic guide for those outside their role to understand the process. Since it describes the OR coordinator's workflow, and workflow mapping is a critical aspect for implementing technologies in hospitals [Schoville and Titler, 2020], this flowchart is a valuable tool that can be used as a template for further development of decision support models.

In addition to the flowchart, the stakeholder analysis offers valuable insights into the real-world environment in which a decision support system will operate. The stakeholder maps shed light on the constant need for information exchange and collaboration between stakeholders in making changes to the schedule. Subsequently, it underlines the importance of allowing other stakeholders to extract information from the decision support system, as this will be required to communicate schedule progression and to discuss adding new cases. This means that the system must be accessible to others, and cannot not just be supplied to the OR coordinator.

Using elements from the OR policy document and the flowchart, a decision support system was developed to visualize the changing schedule throughout the day and to offer alternative scheduling options when enhanced OR performance is anticipated. The evaluation of this proposed decision support system with OR staff showed that its ability to provide an overview of the schedule was regarded as a significant improvement over the current system. While it might seem trivial to add a legend to the schedule, existing systems do not have this feature. Instead, OR coordinators must go through multiple clicks to understand which color represents which part of the surgery, in this process, they are diverted from the main schedule in the electronic patient record system interface. This lack of central information and reduced ease of use may contribute to why the current schedule overview feature in the electronic patient record system is underused [Lee and See, 2004, Gagnon et al., 2016, Safi et al., 2018]. Interestingly, the planning specialist claimed he knew what the colors meant because he was part of the team that designed the electronic patient record system. This illustrates that those with a deeper familiarity with the system can use it more effectively and integrate it into their workflow [Gagnon et al., 2016, Safi et al., 2018]. Therefore, it's crucial to design a system that is intuitive for users who were not involved in its creation.

A key benefit of the decision support system, as designed in part 1 of this thesis, is that it gives the OR coordinator administrative control over scheduling changes on the day of surgery. This allows them to view and assess different scheduling scenarios in real-time, considering their impact on OR performance, and select the best option for the situation. However, it's crucial to remember that any change in the OR schedule also requires an update to the electronic patient record system. Through stakeholder mapping, it has become clear that the OR secretariat is currently responsible for administrative tasks. Since the proposed decision support system transfers some of these tasks to the OR coordinator, this necessitates a further examination of workflow pathways and work processes to ensure that the integration of the decision support system with the electronic patient record system is seamless [Schoville and Titler, 2020].

An additional benefit of the interactive visualization within the decision support system is that OR coordinators no longer have to make calls to the OR to check how much time is left for a surgery. This reduces interruptions, which are known to cause delays and increase the risk of errors [Bretonnier et al., 2020]. However, for this benefit to be realized, it's critical to facilitate more intermediate time registrations during surgery, especially for longer surgeries.

The suggested alternative schedules provided by the decision support system are well received by OR staff. They report that these alternatives can serve as a backup during discussions with surgeons, potentially reducing the burden of decision-making [Stepaniak et al., 2009, Riley and Manias, 2006]. Given this context, it's crucial for the data driving these decisions and visualizations to be reliable and easy to interpret. However, OR staff noted in validation interviews that the data available on the day of surgery is often inaccurate or incomplete. If the decision support system relies on the same data, its effectiveness could be compromised. To address this issue, leadership should focus on establishing clear work processes and encouraging a culture of accurate data registration [Schoville and Titler, 2020]. Additionally, collaboration on data registration standardization should be sought with electronic patient record system producers. Though it will improve quality of data, it remains questionable whether this will be sufficient to solve the data gap as high complex less frequent surgeries occur often. Therefore, I propose to explore methods to fill data gaps using historical data. As long as hospitals cannot ensure completely accurate data, a balance must be struck in which relying on less specific data to enhance the OR's performance might prove useful.

Analysis of data from 2023 revealed and confirmed that information which can be extracted from electronic patient record systems and used by OR personnel is often disorganized and incomplete. There exist large variations in naming conventions of procedures of the same type, which requires standardization to be able to determine average procedure duration. By streamlining the registration process, the aim is to ensure that OR workers can use and analyze the data without needing external systems or domain experts for interpretation. The issue of messy data appears to be common in other health information systems as well. Research by Epstein and Dexter [2018] indicated that linking the anesthesia information management system with the operating room management system and other external databases was crucial for assessing data quality and ensuring that the data pulled for studies was reliable. It seems that this is a widespread issue which transcends just electronic patient record systems. Consequently, data registration standards need to be addressed moving forward.

Furthermore, analysis showed that registered planned durations are generally good indicators of net. surgical times, with a slight overestimation on average. Thus, the key to reducing overtime is to adjust the time margins surrounding these surgical durations. van Veen-Berkx et al. [2014] established a 1.33 margin that can be used to calculate the gross OR duration for a procedure. However, the study also suggested that the specific margin might vary among university medical centers and across surgical specialties [van Veen-Berkx et al., 2014]. Data analysis in this thesis indeed demonstrate that for the LUMC, different margins are more suitable. Yet, these factors are not currently reflected in the hospital's scheduling procedures, indicating a significant potential for reducing overtime.

Additionally, the paper by van Veen-Berkx et al. [2014] focused on surgeon-controlled time and anesthesia-controlled time, without accounting for turnover time—the time needed to prepare the OR for a new patient. Despite this, it seems that LUMC has interpreted the 1.33 factor as covering the entire day of surgery, overlooking the need for additional buffers due to turnovers. This discrepancy highlights a recurring issue noted in previous research [Samudra et al., 2016, Van Veen-Berkx et al., 2016, Harris and Claudio, 2022]: research findings are not always implemented as intended to improve OR scheduling. The reasons behind this misinterpretation remain unclear, warranting further investigation to identify the facilitators and barriers to successful research application in practice.

Nevertheless, neither alternative margins nor historical data at the procedure level can completely account for the uncertainty in surgical procedures and approximate the duration with high accuracy. Although considerable research is being conducted to predict case duration, with more precise results thanks to additional data characteristics and the use of machine learning [Bartek et al., 2019, Zhao et al., 2019], these are still predictions, which means they cannot fully account for all uncertainties that can occur during surgery [Guédon et al., 2016, Zhao et al., 2019, Bartek et al., 2019]. As a result, continuous monitoring is proposed as a valuable tool to track schedule progression throughout the day. This approach can enable the OR coordinator to make timely decisions that improve performance, reduce overtime, and ensure patient care.

As detailed durations for surgical cases could not be determined using the available data, this meant reevaluating the decision support system and removing the feature that offered alternative schedules. Instead, a focus was applied on ensuring continuous monitoring by updating the schedule at intermediate time points throughout the day, using data from our historical duration database.

Since the aim is to reduce overtime, the system's ability to indicate which ORs are likely to run into overtime and its approximation of OR closing times are crucial performance metrics. Interestingly, the average overtime prediction for days that had not been manually adjusted was better than for days where the data was adjusted. A potential reason could be that the initial OR programs on days where the data was left unaltered — meaning surgeries were not transferred to other ORs — were well-constructed from the beginning. The schedules aligned well with the day's planned activities, suggesting that the schedule's predictability was already strong on days when no changes were required. This might be because the schedules on those days included surgeries that were frequently performed, with planned durations that aligned well with actual outcomes, leading to accurate gross OR duration calculations and subsequent good estimations of overtime.

OR closing time of ORs containing surgeries with durations that closely matched those in the database were estimated more accurately than those with larger deviations. This was more often observed in ORs with multiple short surgeries. The basic structure of the schedules also played a significant role in either aiding or hindering the ability of the decision support system to predict OR closing time. The decision support system better predicted the closing time of ORs with multiple short surgeries. This can be attributed to the more frequent updates in schedules of ORs with shorter surgeries, leading to a higher density of data and leaving less space for uncertainty to build up. The high density of data and smaller deviations in the durations of shorter surgeries also explain why the closing time of ORs containing shorter surgeries following a longer surgery saw significant improvement in accuracy once the longer surgery was completed.

It's worth noting that even though the schedule updates might not always reflect accurate ending times or resemble actual procedure durations due to data limitations, an OR coordinator's decision making could still improve using a system like this. The schedule's visualization offers much more information than just ending times, and this extra context might provide OR coordinators with the insights needed to make informed decisions, even if the decision support system sometimes indicates inaccurate information. It has been shown that OR nurses possess exceptional knowledge about their colleagues' work speed and problem-solving abilities. This knowledge subsequently enables them to manage time in the operating room effectively [Riley and Manias, 2006, Allen, 2018]. This same knowledge likely exists among OR coordinators. During interviews, two coordinators mentioned, though not explicitly, that this implicit knowledge is currently underutilized when constructing schedules. This invisible knowledge deserves further exploration to fully understand its role and impact on OR scheduling and decision support systems.

To implement the current concept for the Decision Support System 2.0, it is crucial to acquire additional data to fill the gaps currently addressed by multiplication factors, thereby enhancing schedule reliability. This can be achieved by adding more data from previous years to the historical durations database. Once this is done, the introduction of the decision support system should be gradual. Initially, it should be used alongside existing methods for schedule decision-making to assess whether the system can help decision-makers make better or earlier decisions than current processes allow. During this pilot phase, it is also crucial to assess which parts of the available data are underperforming to consider targeted actions for improvement.

It is anticipated that organizational culture might pose a barrier to implementing the decision support system. Therefore, it's essential to keep all stakeholders informed and demonstrate the system's benefits compared to the current practices [Schoville and Titler, 2020]. It's also crucial to emphasize that the decision support system is not intended to be a management tool for penalizing surgeons or OR coordinators. Instead, it's designed to aid decision-making without removing the decision-maker from the process.

8.1. Limitations

The study and its outcomes are subject to several limitations that warrant consideration. First of all, the categorization of statements as similarity or difference was done by one researcher based on subjective interpretation of supporting research, statement meaning, and testimonies from professionals. Reducing this subjectivity of the researcher through control by other researchers would reinforce the argument. Another notable limitation is the lack of validation of the process flowchart and decision support system design in other UMCs. Although efforts were made to ensure generalizability, the absence of validation in other UMCs poses a constraint on the study's applicability beyond the original setting. While the flowchart was discussed with the project manager of the benchmarking initiative, her expertise and knowledge on OR coordination within various Dutch UMCs, albeit valuable, does not substitute for validation by OR coordinators or coordination teams, which could provide more comprehensive insights.

The data used for testing and designing the decision support system originated from only one university medical center, introducing potential biases and limiting the system's adaptability to other UMCs. Variations in structure of data that can be extracted from the electronic patient record systems among UMCs may necessitate adjustments to the MATLAB script. Though these are expected to be small due to the uniform data structures established by the OR Benchmarking initiative, it does require extra steps for implementation. Additionally, differences in surgical planning practices among UMCs, particularly regarding reliance on historical surgery durations, may render certain aspects of the proposed support system less effective in alternative settings. However, the dataset containing these durations can serve as input for the decision support system. It will be necessary to investigate whether the average duration of intermediate time registrations leading up to the end of surgery are available, to ensure that the schedule can be updated throughout the day when it is implemented in other university medical centers (UMCs).

Lastly, the analysis of the decision support system's performance was hindered by the scarcity of data, with only nine days suitable for analysis of which three days required no manual data manipulation. This limited dataset may not fully capture the system's efficacy under diverse circumstances, potentially compromising the robustness of the study's findings. Furthermore, the ability of the decision support system to predict overtime and closing time is largely influenced by the accuracy of the registered planned duration in initial schedules. In case of incorrect estimation of planned duration, the decision support system is unable to accurately determine overtime and OR closing time. Though on average planned duration are good indications of surgical time, reliance on planned duration for procedure time estimation will have to be reduced moving forward to improve the performance of the decision support system.

Even though the hospital data wasn't as clean as one might have hoped, it does reflect the reality of the data one has to work with to create a system that is useful for an operating room coordinator. This provided valuable insights into the state of hospital data, suggesting that its imperfections need to be anticipated to make it work in a decision support system.

8.2. Recommendations Hospital Data

Though the decision support system 2.0 created in this thesis could potentially be applied in hospitals in with slight adjustments. There are some general recommendation for hospital data to enable further development of a decision support system that can reach higher accuracy rates in overtime and OR closing time prediction.

8.2.1. Short Term Recommendations

Short term recommendations for improvement in decision support system accuracy can be reached through adherence to set scheduling rules and data registration standardization.
At present, the OR policy document stipulates that surgeries with shorter durations should be scheduled towards the end of the program (see statement 34, Appendix A). As demonstrated in section 7.3.5, the DSS shows improved performance in approximating OR closing times for surgeries with shorter durations, especially when they follow procedures with longer durations (i.e. are scheduled at the end of the day). Adhering to this scheduling rule enhances the DSS's effectiveness and increases its value in scenarios requiring (re)allocation of procedures on the day of surgery.

Secondly, I propose enhancing registration standardization for surgical procedures by adopting unified naming conventions. While this may not be feasible for highly specialized procedures with low frequency, it is achievable for the majority of surgeries. Standardization streamlines data utilization within the hospital, benefiting not only the decision support system but also reporting processes, eliminating the need for external assistance. Moreover, standardizing procedures can enhance the DSS's accuracy in the short term by enabling more precise estimations of gross OR durations and intermediate remaining case durations for each procedure.

8.2.2. Long Term Recommendations

In the long term, it is important that attention is payed to data standardization and structure but also to increase intermediate data points to further develop the decision support system toward an optimization which can present real-time scheduling alternatives using hospital data.

By improving standardization of data registration more detailed insights at the procedure level can be yielded. Improved data quality translates to better system design and performance. Especially, for optimization or prediction models to have a positive impact, accurate and detailed data is essential. Moreover, to enhance the accuracy of determining surgery ending times throughout the day, procedures with longer durations should incorporate intermediate data points for the net. surgical time interval. Some existing systems are already automatically tracking surgery progress for certain procedures [Padoy et al., 2008, Guédon et al., 2016, Guzmán-García et al., 2022]. Though the scalability of these systems will require significant efforts, they could prove beneficial to achieving the goal of automatically determining intermediate data points in the surgery process for updating the schedule progress in combination with the decision support system.

8.3. Future Research

To advance the decision support model towards its full potential, including schedule optimization, several steps in future research must be undertaken. A suggested 4-step plan outlines the process. Firstly, verifying the accuracy of the decision-making flowchart and assessing the reception of the optimization options mock-up in other UMCs is crucial. Expanding the analysis of Part 4 of this thesis to encompass additional data from other UMCs and more detailed procedural duration data would further enhance understanding of whether the decision support system can effectively assist OR Coordinators in reducing overtime and minimizing cancellations.

If the flowcharts and mock-ups receive positive feedback and the decision support system is determined to be sufficiently beneficial, the next stage involves developing and validating a prediction model for procedure durations using data from multiple medical centers. Ideally, this prediction model should incorporate input from additional intermediate stages of the surgery process to enhance accuracy, particularly for procedures with longer durations. Subsequently, an optimization model that generates multiple suggestions for alternative schedules based on available basic schedule information can be constructed and needs validation. Finally, if the optimization model demonstrates satisfactory performance, additional functionalities, such as equipment and assisting OR staff capacity, can be incorporated into the model for further optimization to improve its alternative scheduling suggestions.

9 Conclusion

Despite the prevailing notion that hospital systems should be created in and tailored to local contexts, the policy analysis of this thesis reveals more similarities than differences in OR policies across UMCs. Given that the process flowchart and concept decision support system were primarily informed by policy statements reflecting resemblance, it suggests their general applicability across Dutch UMCs. Although validation of both outputs in other UMCs is required, using OR policy documents to identify flexible design factors, can contribute to widespread application of the decision support system to OR environments of other UMCs.

Drawing from operating room policy, the workflow of an OR coordinator was reconstructed in a process flowchart to address schedule management when uncertainty factors were encountered on the day of surgery. Only minor adjustments to the flowchart to ensure alignment with real-world practices were required after validation. This flowchart served as a foundational template for designing a decision support system, which was well-received by OR coordinators and addressed critical information gaps. Consequently, leveraging functionalities extracted from OR policy offers a promising approach for creating a system fitting to the needs of an OR coordinator.

Stakeholder analysis revealed continuous interactions and collaboration between stakeholders on the day of surgery. This underscored the necessity for flexibility in system design and the ongoing need for user input to adjust schedules. In the creation of a decision support system for the OR coordinator it is key to recognize that the information conveyed by it must be accessible to other stakeholders to facilitate collaboration.

Current hospital data hinder use of data on detailed procedure level across specialties due to naming variability, and inconsistent additional characteristics. To address this, clever use of available data is required to be able to generate information that can be utilized by a decision support system to help OR coordinators improve the OR complex's performance. Analysis suggests that the current generalized approaches for creating reliable schedules may not be optimal, advocating for a slightly more specialized approach tailored to each surgical specialty and procedure's registered planned duration. While historical data alone may lead to discrepancies between expected and actual duration of interventions due to various uncertainties, continuous tracking of the OR schedule and updating it with intermediate time registrations is proposed as a solution for better real-time insight into schedule progression.

Analysis of such a system revealed an ability to predict overtime with relative high accuracy. Nonetheless, the identified optimal intervention window for predicting potential overtime didn't consistently perform as expected across additional dates, further indicating that the decision support system may be more useful for real-time tracking of the schedule throughout a day. Based on data characteristics and programming of initial schedules, the systems ability to predict OR closing time varied largely. Accurate predictions are observed in ORs with surgeries of appropriate estimates of planned durations and/or ample data points. More intermediate data points, especially for surgery with longer duration, could enhance the performance of the decision support system with regard to closing time prediction.

In conclusion, the OR policy document provides valuable insights into the functionalities required for an effective decision support system for daily OR schedule management. By analyzing both differences and commonalities in policies across centers, it becomes possible to identify areas where the design of the decision support system can be adapted for use in multiple centers. Moreover, the structure and availability of data significantly influence the input and output of the decision support system and subsequently the quality of scheduling decisions based on the system. To enhance the performance of such systems in the future, efforts should be focused on standardizing input data and introducing intermediate data points, particularly for surgeries with longer durations.

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Appendix A

A.1. OR Policy Analysis Statements

Table A.1 contains all statements pertaining to the daily management of the OR schedule from the OR policy document. The table includes reference number, page number of statement, dutch statement, english translation, label, catergory and additional explanation for category.

Table A.1: Statements extracted from OR policy document of the LUMC including reference number, page numbers, english translation, label, category and explanation of category.

Ref. Nr.	Page Nr.	Statement	Translation	Label	Category	Explanation Category
1	4	Dagelijkse OK coordinatie is in handen van het regieteam	The OR Coordination Team is responsible for the daily coordination of the OR	Background	Difference	The paper of Stepaniak et al. [2009] mentions a single OR Coordinator who is responsible for daily coordination
2	4	Binnen de OK wordt er gewerkt met de volgende Clusters; - Cluster 1: Urologie, Orthopedie, Heelkunde, en Verloskunde - Cluster 2: KNO, Gyneacologie, Plastische Chirurgie, Kaakchirurgie, Oogheelkunde, en Neurochirurgie - Cluster 3: Cardiothoracale Chirurgie en Cardiologie	In the OR Center surgical specialties are clustered; - Cluster 1: Urology, Orthopaedics, General Surgery and Obstetrics - Cluster 2: ENT, Gyneacology, Plastic Surgery, Dental Surgery, Opthalmology and Neurosurgery - Cluster 3: Cardiothoracic Surgery and Cardiology	Background	Difference	Hospitals can have different clusters of surgical specialties
3	6	Het gehele operatieteam is bij opstart van de eerste operatie, gedurende bedrijfstijd (8:00-16:00), om 8:00 in de operatiekamer aanwezig	At the start of the first operation of the day (during business hours 8:00-16:00), the complete operating team is present in the OR at 8:00	Background	Similarity	Although starting times of the ORs can differ between hospitals the basic principle of the whole team being present at the start of the day is common practice
4	12	Fysieke capaciteit; - 20 OKs, - 1 babyopvangkamer (2 werkstations) - 1 hulpverrichtingen kamer - 6 Kinderverkoever bedden - 7 Holding bedden - 6 PACU bedden (5 actief) - 14 Verkoever bedden - 1 Orgaantransplantatiekamer	Physical capacity OR Center; - 20 ORs, - 1 baby nursery (2 workstations) - 1 relief operations room - 6 Childrens recovery beds - 7 Holding beds - 6 PACU beds (5 active) - 14 Recovery beds - 1 Organtransplantation room	Input	Difference	Dutch UMC's all report different number of ORs on their patient information websites. Additionally, there may also be times when ORs are under construction or unavailable for another reason which reduces their capacity

Table A.1 continued from previous page

Ref. Nr.	Page Nr.	Statement	Translation	Label	Category	Explanation Category
5	12	Bedrijfstijd is van 8:00 tot 16:00 (= 1 sessie). Met uitzondering van de eerste dinsdag van de maand (8:30 tot 16:00)	Business hours start at 8:00 and end at 16:00 (= 1 session). Except for the first Tuesday of the month (8:30-16:00)	Input	Similarity	ORs can have a difference in opening hours depending on the day of the week. Nonetheless, Dutch UMCs have similar business hours van Veen-Berkx et al. [2016]
6	12	OK-sessierooster is beschikbaar in HiX	OR schedule is available in HiX	Input	Similarity	Though not all hospitals work with HiX de Bruyn et al. [2024], an OR schedule is available in every hospital in a central online environment
7	12	Anesthesieteams hebben veel taken ook buiten de OK. Daarom kan de regie-anesthesioloog besluiten om minder OKs te bezetten dan beschikbaar vanwege andere werkzaamheden	Anesthesiateams have responsibilities outside the OR Complex. Therefore, the OR Coordinator can decide to use less OR capacity because of need for anesthesiologist in other locations	Background	Similarity	Anesthesiologists are not endlessly available and also have to work in other places in the hospital Dexter et al. [2007a]
8	12	Verlengde bedrijfstijd; enkele medische specialismen hebben afspraken voor verlengde bedrijfstijd (werk na 16:00). Het is mogelijk om voor specifieke operaties verlengde bedrijfstijd aan te vragen.	Extended business hours; some medical specialists are allowed to work beyond 16:00. It is possible to request prolonged business hours for certain interventions.	Background	Similarity	For some surgeries, regular hours are to short to finish the procedure in time. In this case prolonged hours can be requested for certain interventions. The use of this policy in other Dutch UMC's is also mentioned in a paper by Van Veen-Berkx et al. [2016]
9	12	Buitenlocaties waar anesthesiemedewerkers werken; verkoever, SEH, verloskamer en interventiekamers	Other locations where anesthesiology staff is needed; recovery, delivery room, the ER and intervention rooms	Background	Similarity	Locations where anesthesiology staff is needed are similar for all hospitals [Dexter et al., 2007b]
10	13	Minder OKs op aangeven specialisme & in schoolvakanties. OK-sessierooster wordt daarop aangepast	Specialisms can indicate the need for less ORs. During school holidays there are also less ORs utilized. The OR-session schedule is adjusted as such	Background	Similarity	Using less OR space when less surgical staff members are available is common practice in all hospitals

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Ref. Nr.	Page Nr.	Statement	Translation	Label	Category	Explanation Category
11	13	Indien ingeschat wordt dat een OK niet sluit voor 16:00. Kan de laatst geplande OK als ProMemorie (PM) worden geplanned	In case of the possibility of an OR not closing before 16:00, the latest planned surgery in the OR can be planned ProMemorie (PM)	Guideline	Difference	The ProMemorie regulation is specific to the LUMC
12	13	Op de dag zelf wordt tussen 13:00 en 14:00 overleg gepleegd over de doorgang van ProMemorie geroosterde ingrepen	Between 13:00 and 14:00 the OR Coordination Team deliberates if the planned PM can be pursued	Background	Difference	All PM related statements are specific to the LUMC
13	13	PMs worden binnen het eigen specialisme programma gerealiseerd	PMs are executed in the program of the surgical specialty it is assigned to	Guideline	Difference	All PM related statements are specific to the LUMC
14	13	Indien er ruimte ontstaat op een andere OK gaat een categorie B(S2) of C(S3) spoed operatie voor op een PM-operatie	In case there is an open slot in another OR an urgency classes B(S2) and C(S3) have priority over the PM-labeled surgery	Guideline	Difference	All PM related statements are specific to the LUMC
15	13	Decentrale planning: ieder specialisme is zelf verantwoordelijk voor planning van patienten. Met behulp van historische OK-tijd per operateur per ingreep	Decentral planning: every surgical specialty is responsible for planning patients, using the historical duration per surgeon per surgical intervention	Background	Difference	"In other hospitals there is a central planning office" - Project manager Benchmark OK. Additionally, not all hospitals use historical times to plan surgery, some use time estimations provided by surgeons [Eijkemans et al., 2010]
16	14	Indicenteel OK- en anesthesiefaciliteiten gebruik wordt afgestemd met het regie-team	Indicental use of the OR and anesthesiological facilities needs to be tuned in with the OR Coordination Team	Background	Similarity	It is trivial that the people responsible for OR coordination are also the ones that oversee incidental use

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Ref. Nr.	Page Nr.	Statement	Translation	Label	Category	Explanation Category
17	15	Hix Geregistreerde tijden; - Briefing = Start Anesthesie - Patient OK - Inleiding tijd = Einde inductie - Start Anesthesie - Chirurgische Voorbereiding = Start Ingreep - Eind Inductie - Snijtijd = Einde Ingreep - Start ingreep - Uitleidings tijd = Einde Anesthesie - Einde Ingreep - Anesthesie tijd = Uitleiding tijd - Inleiding tijd - Turnover time = Patient OK - Vertrek OK - Bruto operatie duur = Vertrek OK - Patient OK - Holding tijd (max 1 uur) = Patient OK - Op Holding	HiX Registrered times; - Briefing = Start Anesthesia - Patient in OR - Induction time = End Induction - Start Anesthesia - Surgical preparation = Start Surgery - End Induction - Surgical time = End Surgery - Start Surgery - Emergence time = End Anesthesia - End Surgery - Anesthesia controlled time = Emergence time - Induction time - Turnover time = Patient in OR - Departure OR - Gross surgical duration = Departure OR - Patient in OR - Holding time (max 1 hrs) = Patient in OR - Patient at Holding	Time Calculation	Similarity	"These times are recorded by alln UMCs in the Netherlands. They have been established through the collaborative OR Benchmarking project" - Projectmanager Benchmark OK. Calculation of these times is described in a paper by van Houdenhoven [2006]
18	16, 39	HiX Tijdenregistratie momenten - Besteld - Op holding - Patient op OK - Stopmoment 5b = Briefing - Start Anesthesie - Eind Inductie - Start Chirurgische Voorbereiding - Start Ingreep - Einde Ingreep - Eerste postoperatieve Temperatuur - Einde Anesthesie - Vertrek OK	HiX Registration moments - Patient Ordered - Patient at Holding - Patient in OR - Stopmoment 5b = Briefing - Start Anesthesia - End Induction - Start Surgical Preparation - Start Surgery - End Surgery - First Postop. Temperature - End Anesthesia - Departure OR	Time Stamp	Similarity	Registrations moments are uniform for all UMCs in the Netherlands as these are connected to the previously described time recordings [van Houdenhoven, 2006]. Nonetheless, the LUMC considers two extra time recordings for logging information, those are 'Patient Ordered' and 'First Postop. Temperature measurement'

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Ref. Nr.	Page Nr.	Statement	Translation	Label	Category	Explanation Category
19	17	Primaire doel van regie-team = Geplande operaties doorgang te laten vinden & optimaal gebruik spoedcapaciteit	Goal of the OR Coordination Team = Oversee proceedings of planned surgeries & optimal use of emergency capacity	Background	Similarity	OR coordination in other hospitals might only be performed by a single OR coordinator, though tasks and objective are similar [Stepaniak et al., 2009]
20	17	Indien patient volgens reguliere procedure al op het OK-centrum (Holding) is, wordt de operatie niet afgezegd	Surgery will not be cancelled if the patient has already arrived at the OR Complex (in Holding)	Cancellation	Similarity	Preferably a patient is not cancelled once he has been transported to the Holding area, as this greatly distresses patients, hospitals aim to avoid this cancellation scenario [Scheenstra et al., 2022]
21	17	Afzegging mogelijk als patient op Holding is indien; - Acuut capaciteits gebrek (door calamiteit) - Besteld door chirurg tegen wil regieteam - Onverwachte uitloop operatieduur van daarvoor geplande patient	Cancellation of surgery of a patient in holding can be done in the following cases; - Immediate capacity problems (due to calamity) - If the patient was ordered by the surgeon without approval, or against the will of, the OR Coordination Team - Unexpected delay in surgery duration of the previously planned patient	Cancellation	Similarity	In case of unexpected events or miscommunication a patient in the holding area sometimes has to be cancelled
22	17	Patienten kunnen afgezegd worden door het regieteam of door het specialisme	Patients can be cancelled by the OR Coordination Team or by the surgical specialty	Background	Similarity	For all hospitals holds that the OR coordinator but also a medical specialist can cancel a surgery
23	17	De medisch coordinator is bevoegt beslissingen te nemen over de planning in overleg met dagcoordinatoren en specialismen. Hierbij wordt gestuurd op bedrijfstijden en rekening gehouden met (buiten)locaties	The OR Coordinator is qualified to make decisions about the planning in consult with daytime coordinators and surgical specialties. They keep business hours and other locations in mind	Background	Similarity	Each OR coordinator has the same task. Making sure the OR finishes on time while keeping capacity in mind

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Ref. Nr.	Page Nr.	Statement	Translation	Label	Category	Explanation Category
24	17	Regieteam tijdens bedrijfstijd (8-16u) bestaat uit; - Medisch coordinator = regie-anesthesioloog - dagcoordinator operatieassistenten (OA) - dagcoordinator anesthesiemedewerkers (AM) - dagcoordinator holding, PACU, verkoever	The regie-team during business hours consists of; - OR Coordinator - daytime coordinator OR assistents (OA) - daytime coordinator anesthesiologists (AM) - daytime coordinator holding, PACU and recovery	Background	Difference	In the paper of Stepaniak et al. [2009] there is mention of a single OR coordinator whom is responsible for daily coordination, whereas in the LUMC there is a team responsible for coordination
25	18	Bij onverwachte uitloop van geplande operatieduur, zal een patient van dat programma herplant moeten worden	In case of unexpected delays in planned surgery duration, a patient of the pending program will need to be rescheduled	Delay	Similarity	Unexpected delays running into overtime are an often seen cause for cancellation or rescheduling in hospitals [Dimitriadis et al., 2013]
26	18	In overleg kan de geplande operatie door in een andere onverwacht vrijgekomen OK-sessie, bij uitloop van een voorgaande operatie	A surgery that needs to be rescheduled due to unexpected delays in previous cases, can be scheduled in another timeslot that has been freed up	Delay	Similarity	Unexpected delays running into overtime are an often seen cause for cancellation or rescheduling in hospitals [Dimitriadis et al., 2013]
27	18	De laatste ingreep in verlengde bedrijfstijd moet voor 15:30 gestart zijn (bedrijfstijd aangevraagd door specialisme na 16:00)	The last surgery in prolonged business hours needs to be started before 15:30 (prolonged business hours are extra hours after 16:00 requested by the surgical specialty)	Guideline	Difference	Depending on the OR policy of a hospital requesting prolonged business hours might be arranged differently, as well as the start time limit
28	18	Operatie gegevens van Spoed worden in HiX gezet door de medisch specialist waarbij de spoed hoort. Alvorens de volgende gegevens bij de regie-anesthesioloog bekend zijn - urgentie klasse (A(S1), B(S2), C(S3) of D(S4)) - geplande ingreep	Surgery information of the emergency is entered in HiX by the medical specialist. The medical specialist declares the urgency class (A(S1), B(S2), C(S3) or D(S4)) and the planned intervention to the OR Coordinator	Emergency	Similarity	All Dutch hospitals make use of urgency classes which are declared by a medical specialist (Nederlandse Vereninging voor Heelkunde, 2018). The urgency classes are used together with information on the planned intervention to find a suitable place in the schedule

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Ref. Nr.	Page Nr.	Statement	Translation	Label	Category	Explanation Category
29	18, 21	Urgentieklasse; - A(S1): Acuut, moet direct maar uiterlijk binnen 1 uur op tafel - B(S2): Spoed, binnen dagdeel (uiterlijk 8 uur) op tafel - C(S3): Semispoed, binnen een dag (24 uur) op tafel. Bij voorkeur overdag en op een programma van het "eigen" specialisme - D(S4): Semi-electief, tussen morgen en een paar dagen (24-72 uur) op eigen programma plannen. Wordt niet buiten bedrijfstijd gepland	Urgency class; - A(S1): Needs to be operated on within 1 hour - B(S2): Needs to be operated on within the day (8 hours max) - C(S3): Needs to be operated on within 24 hours. Preferably planned during business hours, and in the program of the related surgical specialty - D(S4): Needs to be operated on within a couple of days (between 24 and 72 hours). Is planned in the program of the related surgical specialty in regular business hours	Emergency	Similarity	These urgency classes are universally used in Dutch hospitals. The guideline that outlines these urgency classes was created by Nederlandse Vereniging voor Heelkunde (2018)
30	19	AS1 klasse wordt eerste vrije OK in gebruik genomen (ook bij niet passend specialisme)	Urgency class AS1 is scheduled in the first available OR (also when the OR is occupied by a different surgical specialty)	Emergency	Similarity	Based on the urgency classification guideline from the Nederlandse Vereniging voor Heelkunde (2018) the highest urgency class needs to be admitted to the OR as soon as possible
31	19	Eventueel onderbroken specialisme bij planning spoed, in overleg met het onderbroken specialisme voor herplanning patient	When emergency surgeries are planned in ORs where the program is interrupted. The specialty and OR Coordination Team deliberate when to reschedule pending patients	Emergency	Similarity	The need for rescheduling after an emergency surgery has bumped other patients in the schedule is universally applicable
32	19	Spoed OKs (Acute tijd) in principe alleen voor spoedeisende ingrepen, mag vanaf geweken worden bij niet te plannen elective of semi-elective OF dreigende uitloop	Dedicated emergency ORs are for Emergency cases only. However, in case of impending overtime or not to be planned elective or semi-electives the deviation from this policy are allowed	Guideline	Difference	In the paper by van Riet et al. (2015) a description is given of the different policies that can be used by hospitals to deal with incoming emergency surgeries

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Ref. Nr.	Page Nr.	Statement	Translation	Label	Category	Explanation Category
33	20	Bij iedere geplande patient is het operatie aanvraagformulier ingevuld en beschikbaar in HiX. Deze bevat; - Naam Hoofd Operateur - Behandelcode - Verrichtingencode(s) - Prioriteit - Anesthesietechniek - Ligging - Geplande duur = netto snijtijd (max 360 min) - Speciale aandachtspunten/ benodigdheden - Speciale materialen/apparatuur - Radiologie/C-boog - Post-operatieve bestemming	For every planned patient a surgery application form is filled out and available in HiX. This form consists of; - Name Head Surgeon - Treatment code - Operation code(s) - Priority - Anesthesia technique - Positioning - Planned duration = net. surgical time (max 360 min) - Special points of attention/supplies - Special materials/equipment - Radiology/C-arch - Post-operative destination	Input	Similarity	At least for all UMCs that use HiX this information is accurate. Other UMC's that use other applications will perhaps wield a slightly different format, though contain similar relevant components
34	20	Plan regel: Operaties van relatief korte duur aan het einde van het programma	Surgeries with short expected duration are planned at the end of the day	Guideline	Difference	Other researchers have suggested scheduling procedures of short duration at the start of the schedule [Lebowitz, 2003], [Marjamaa et al., 2008]. This alternative guideline can be applicable to other hospitals
35	37	Benutting berekening = Bruto OK duur (elective of extra ingreep)/ Totale toegekende sessietijd	Utilization calculation = Gross OR duration (elective or extra surgeries)/ Total assigned session time	Performance Metric	Similarity	"Benchmarking OK initiative has made agreements on calculation of this performance metric for comparing the UMCs" - Projectmanager Benchmark OK.
36	37	Uit de NFU Benchmark OK is een norm van 85% benutting ontstaan	Utilization Benchmark OK NFU norm = 85%	Performance Norm	Similarity	This norm has been established previously by van Veen-Berkx et al. [2015] and is adopted by the NFU

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Ref. Nr.	Page Nr.	Statement	Translation	Label	Category	Explanation Category
37	37	De aan een specialisme toegekende sessie (uren in het OK-sessierooster) is in principe voor elective of extra ingrepen (geregistreerd met N of X)	The hours allocated to a surgical specialty (in the OR-session schedule) is reserved for elective or extra interventions (registered in HiX with N or X)	Background	Similarity	Most hospitals work with a block schedule in which OR hours are allocated to surgical specialties in which they can perform surgeries [Levine and Dunn, 2015], [Zhu et al., 2019]. These hours are used to plan elective and semi-elective patients
38	38	Totale OK tijd berekening = Bruto OK duur vs. Geplande Duur	Total OR time calculation = Gross OR duration vs. Planned duration	Performance Metric	Similarity	"The Benchmarking OK initiative has made agreements on calculation of this performance metric to be able to compare performance among UMCs" - Projectmanager Benchmark OK
39	38	Benchmark OK NFU norm Totale OK tijd = 133%	Benchmark OK NFU norm total OR time = 133%	Performance Norm	Similarity	This norm has been established previously by van Veen-Berkx et al. [2014] and is adopted by the NFU
40	38	In een ideale situatie is de Netto Snijtijd gelijk aan de Geplande duur. Berekening Acceptabele afwijking = Geplande Duur vs. Netto Snijtijd	In an ideal scenario the net. surgical time is equal to the planned duration. Calculation of acceptable time diversion = Planned Duration vs. Net. Surgical time	Performance Metric	Similarity	All UMC are able to calculate net. surgical time and register planned duration in construction of the schedule [van Houdenhoven, 2006]. Thus calculation of acceptable surgical time diversion is possible for all UMCs
41	38	Acceptabele afwijking NFU norm = 90%/110%	Acceptable time diversion NFU norm = 90%/110%	Performance Norm	Similarity	This norm has not been established by the Benchmarking OK initiative. Nonetheless, it can be used for performance improvement of the OR

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Ref. Nr.	Page Nr.	Statement	Translation	Label	Category	Explanation Category
42	39	Alle Stopmomenten moeten worden geregistreerd in het Patientdossier	All so called "Stopmoments" need to be registered in the electronic patient record	Time Stamp	Similarity	The guideline 'Perioperatief Traject' is active in all Dutch hospitals and is developed by Nederlandse Vereniging voor Anesthesiologie (2020), it describes the purpose and use of "Stopmoments" in the perioperative process

B

Appendix B

This appendix provides a link to the mock-up version of the concept decision support system referenced in section 4.3.3. Additionally, it includes a process flowchart outlining the functionality of the DSS and the interactions a user would have with it. The link to the mock-up can be found in section B.1, while the flowchart is presented in section B.2.

B.1. Link to Mock-up

The mock-up of the decision support system has been developed using Figma. In the mock-up a user has several options to click through the mock-up and see the abilities that have been integrated into the design of the concept decision support system.

https://www.figma.com/proto/vXFB80NEttlfU4VKg0IiUF/Scheduling-Tool?type=design&node-id=475-11729&t=W2lHkRrNMF9bxq7e-1&scaling=min-zoom&page-id=25%3A6201mode=design

B.2. DSS Flowchart

The flowchart depicted in Figure B.1 illustrates the decision support system's operation and outlines the steps leading to the internal optimization process. Blue elements within the flowchart correspond to recurring components from the initial decision-making process flowchart based on the OR policy analysis (section 4.3.2). Additionally, this flowchart highlights the added functionality of manual rescheduling in the event of unsuitable suggestions during the optimization process.

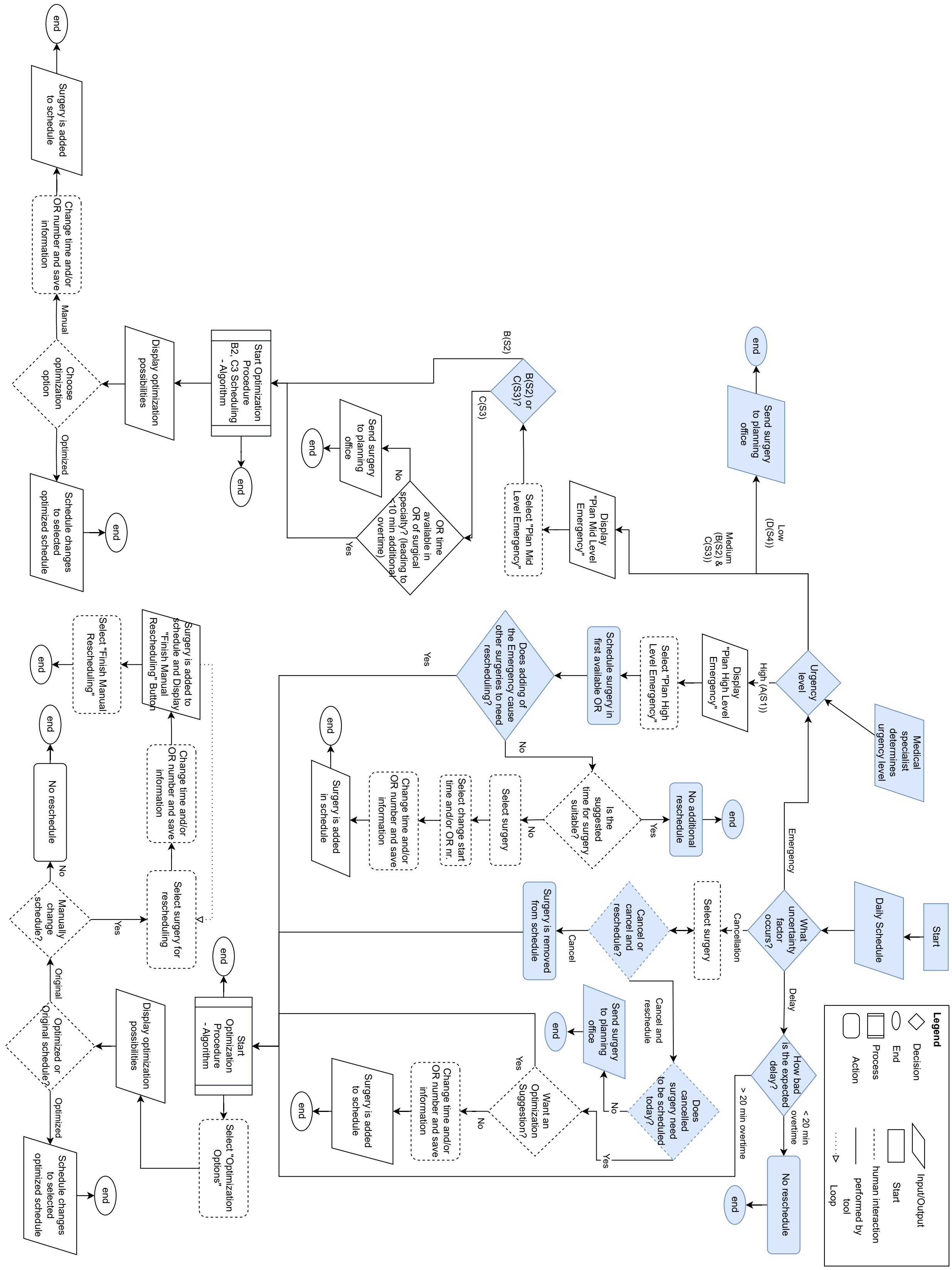

Figure B.1: Flowchart illustrates the process flow within the concept DSS. Recurring elements from the decision-making process flowchart are highlighted in blue, while steps in the DSS requiring user interaction are depicted with elements enclosed by dotted lines

C

Appendix C

C.1. Historical Duration Database

This appendix contains data on the historical duration of averages calculated based on the timestamps acquired in HiX. For each surgical specialty the durations have been sorted.

C.1.1. General Surgery - CHI

Table C.1: Average remaining duration in minutes per time registration in surgery until OR Departure registration for General Surgery

Planned Duration (min)	Average Gross OR Duration (min)	Average Duration from Start Anesthesia to OR Departure (min)	Average Duration from Start Surgical Preparations to OR Departure (min)	Average Duration from Start Surgery to OR Departure (min)	Average Duration from End Surgery to OR Departure (min)	Average Duration from End Anesthesia to OR Departure (min)	Nr. of Data Points
20	45.62	36.54	29.38	25.39	3.54	1.85	13
30	59.23	51.14	41.59	34.38	8.34	1.58	115
45	72.05	63.68	53.08	43.94	9.12	2.42	158
60	92.00	85.88	71.28	60.04	11.82	1.73	197
75	113	102.18	88.09	75.77	7.18	2.14	22
90	136.74	128.69	113.18	99.49	10.42	2.39	231
100	148.47	138	122.06	110.24	10.35	1.59	17
120	162.94	153.42	137.47	122.02	12.39	1.97	175
150	207.24	195.79	179.24	164	13.16	2.48	114
180	230.53	220.95	203.05	187.81	11.22	1.17	179
210	286.17	273.51	254.40	234.44	14.83	1.98	82
240	284.12	257.05	248.20	228.95	12.83	2.24	41
270	358.80	347.23	322.68	306.91	12.95	3.38	56
300	334.85	322.08	297.77	282.77	18.23	2.6	13
360	435.69	423.14	398.69	378.38	18.55	7.41	29

Table C.2: Multiplication factors to obtain average remaining duration for clustered planned durations per registered timestamp until the OR Departure for General Surgery

Planned Duration (min)	Multiplication Factor for Gross OR Duration	Multiplication Factor for Start Anesthesia to OR Departure	Multiplication Factor for Start Surgical Preparations to OR Departure	Multiplication Factor for Start Surgery to OR Departure	Multiplication Factor for End Surgery to OR Departure	Multiplication Factor for End Anesthesia to OR Departure	Nr. of Data Points
Short Duration (t < 90 min)	1.70	1.51	1.25	1.05	0.22	0.05	535
Medium Duration (t ≥ 90 min, t ≤ 180 min)	1.39	1.32	1.18	1.06	0.09	0.02	734
Long Duration (t > 180 min)	1.27	1.21	1.14	1.06	0.06	0.01	242

C.1.2. Cardiothoracic Surgery - CTC

Table C.3: Average remaining duration in minutes per time registration in surgery until OR Departure registration for Cardiothoracic Surgery

Planned Duration (min)	Average Gross OR Duration (min)	Average Duration from Start Anesthesia to OR Departure (min)	Average Duration from Start Surgical Preparations to OR Departure (min)	Average Duration from Start Surgery to OR Departure (min)	Average Duration from End Surgery to OR Departure (min)	Average Duration from End Anesthesia to OR Departure (min)	Nr. of Data Points
60	88	79.56	66.31	57	13.19	6.13	16
90	107.90	101.50	85.90	73.60	10.50	3.70	10
120	169.76	156.12	130.12	114	13.06	4.18	17
170	195.26	183.04	156.37	133.52	12.59	3.52	27
180	238.45	228	195.93	172.02	12.41	4.45	124
200	291.40	283.19	251.53	232.97	13.56	5.24	70
220	313.85	305	274.77	259.69	11.54	7.46	13
240	312.94	303.88	270.10	248.81	12.88	3.16	606
300	440.04	425.68	384.71	357.86	13.82	5.07	28
360	456.11	446.31	411.02	382.85	11.81	4.50	48

Table C.4: Multiplication factors to obtain average remaining duration for clustered planned durations per registered timestamp until the OR Departure for Cardiothoracic Surgery

Planned Duration (min)	Multiplication Factor for Gross OR Duration	Multiplication Factor for Start Anesthesia to OR Departure	Multiplication Factor for Start Surgical Preparations to OR Departure	Multiplication Factor for Start Surgery to OR Departure	Multiplication Factor for End Surgery to OR Departure	Multiplication Factor for End Anesthesia to OR Departure	Nr. of Data Points
Short Duration (t < 90 min)	1.65	1.49	1.22	1.02	0.22	0.10	31
Medium Duration (t ≥ 90 min, t ≤ 180 min)	1.30	1.23	1.05	0.92	0.08	0.03	184
Long Duration (t > 180 min)	1.32	1.29	1.15	1.06	0.05	0.01	722

C.1.3. Gynaecology - GYN

Table C.5: Average remaining duration in minutes per time registration in surgery until OR Departure registration for Gynaecology

Planned Duration (min)	Average Gross OR Duration (min)	Average Duration from Start Anesthesia to OR Departure (min)	Average Duration from Start Surgical Preparations to OR Departure (min)	Average Duration from Start Surgery to OR Departure (min)	Average Duration from End Surgery to OR Departure (min)	Average Duration from End Anesthesia to OR Departure (min)	Nr. of Data Points
30	54.47	45.76	37.02	31.18	8.31	2.82	45
45	65	57.06	47.11	37.20	6.66	1.78	80
60	93.55	79.14	68.48	58.26	9.21	1.86	42
75	119.42	108.08	95.75	82.58	9.75	0.83	12
90	111.72	102.39	90.61	76.44	9.17	2.28	18
120	173.61	164.21	147.75	133.08	9.39	2	76
150	197.51	184.04	165.10	150.97	8.83	1.76	72
180	235.57	224.02	202.19	185.55	11.68	3	47
210	282.30	268	248.40	227.90	6.30	2.20	10
240	314.05	298.24	269.95	248.95	8.71	2.91	21
360	394.35	377.06	341.47	315.76	17.12	4.29	17

Table C.6: Multiplication factors to obtain average remaining duration for clustered planned durations per registered timestamp until the OR Departure for Gyneacology

Planned Duration (min)	Multiplication Factor for Gross OR Duration	Multiplication Factor for Start Anesthesia to OR Departure	Multiplication Factor for Start Surgical Preparations to OR Departure	Multiplication Factor for Start Surgery to OR Departure	Multiplication Factor for End Surgery to OR Departure	Multiplication Factor for End Anesthesia to OR Departure	Nr. of Data Points
Short Duration ($t < 90$ min)	1.58	1.39	1.36	1.19	0.44	0.31	183
Medium Duration ($t \geq 90$ min, $t \leq 180$ min)	1.35	1.27	1.14	1.03	0.07	0.02	216
Long Duration ($t > 180$ min)	1.24	1.18	1.07	0.99	0.04	0.01	54

C.1.4. Hematology - HEM

Since there are too little data points for Hematology interventions in the OR, Hematology only consists of a table in which multiplication factors have been calculated per time incidence until the OR Departure.

Table C.7: Multiplication factors to obtain average remaining duration for clustered planned durations per registered timestamp until the OR Departure for Hematology

Planned Duration (min)	Multiplication Factor for Gross OR Duration	Multiplication Factor for Start Anesthesia to OR Departure	Multiplication Factor for Start Surgical Preparations to OR Departure	Multiplication Factor for Start Surgery to OR Departure	Multiplication Factor for End Surgery to OR Departure	Multiplication Factor for End Anesthesia to OR Departure	Nr. of Data Points
Short Duration (t < 90 min)							
Medium Duration (t > 90 min, t < 180 min)	0.96	0.75	0.64	0.51	0.10	0.03	5
Long Duration (t > 180 min)							

C.1.5. Oral & Maxillofacial Surgery - KAA

Table C.8: Average remaining duration in minutes per time registration in surgery until OR Departure registration for Oral & Maxillofacial Surgery

Planned Duration (min)	Average Gross OR Duration (min)	Average Duration from Start Anesthesia to OR Departure (min)	Average Duration from Start Surgical Preparations to OR Departure (min)	Average Duration from Start Surgery to OR Departure (min)	Average Duration from End Surgery to OR Departure (min)	Average Duration from End Anesthesia to OR Departure (min)	Nr. of Data Points
30	71.90	63.70	50.90	41.90	15.60	2.80	10
60	97.60	88.26	72.24	62.07	11.60	1.67	42
90	130.13	120.02	105.63	93.67	9	1.46	48
120	165.61	153.63	140.66	127.54	11.49	1.20	41

Table C.9: Multiplication factors to obtain average remaining duration for clustered planned durations per registered timestamp until the OR Departure for Oral & Maxillofacial Surgery

Planned Duration (min)	Multiplication Factor for Gross OR Duration	Multiplication Factor for Start Anesthesia to OR Departure	Multiplication Factor for Start Surgical Preparations to OR Departure	Multiplication Factor for Start Surgery to OR Departure	Multiplication Factor for End Surgery to OR Departure	Multiplication Factor for End Anesthesia to OR Departure	Nr. of Data Points
Short Duration (t < 90 min)	1.89	1.69	1.38	1.16	0.27	0.04	62
Medium Duration (t ≥ 90 min, t ≤ 180 min)	1.41	1.30	1.17	1.05	0.10	0.02	99
Long Duration (t > 180 min)	1.23	1.19	1.11	1.02	0.06	0.01	13

C.1.6. Respiratory Medicine - KLZ

Since there are too little data points for Respiratory Medicine interventions in the OR, Respiratory Medicine only consists of a table in which multiplication factors have been calculated per time incidence until the OR Departure.

Table C.10: Multiplication factors to obtain average remaining duration for clustered planned durations per registered timestamp until the OR Departure for Respiratory Medicine

Planned Duration (min)	Multiplication Factor for Gross OR Duration	Multiplication Factor for Start Anesthesia to OR Departure	Multiplication Factor for Start Surgical Preparations to OR Departure	Multiplication Factor for Start Surgery to OR Departure	Multiplication Factor for End Surgery to OR Departure	Multiplication Factor for End Anesthesia to OR Departure	Nr. of Data Points
Short Duration (t < 90 min)	1.24	1.13	0.88	0.81	0.39	0.06	6
Medium Duration (t ≥ 90 min, t ≤ 180 min)	1.08	1.06	0.91	0.89	0.27	0.03	3
Long Duration (t > 180 min)							

C.1.7. Otorhinolaryngology - KNO

Table C.11: Average remaining duration in minutes per time registration in surgery until OR Departure registration for Otorhinolaryngology

Planned Duration (min)	Average Gross OR Duration (min)	Average Duration from Start Anesthesia to OR Departure (min)	Average Duration from Start Surgical Preparations to OR Departure (min)	Average Duration from Start Surgery to OR Departure (min)	Average Duration from End Surgery to OR Departure (min)	Average Duration from End Anesthesia to OR Departure (min)	Nr. of Data Points
30	55.25	47.42	38.76	34.81	10.28	2.03	67
45	62.40	53.49	43.89	39.80	11.06	2.17	35
60	75.71	66.34	55.75	49.05	7.19	1.89	151
75	96.30	90.10	77.20	73.80	11.20	2.70	10
90	123.57	112.99	102.15	89.90	11.50	1.68	68
120	146	135.51	119.50	108.86	11.86	3.20	70
150	171.09	159.74	143.50	131.68	9.91	2.03	34
180	238.25	227.43	212.99	188.90	11.67	1.92	142
210	261.26	249.95	235.53	211.16	14.16	2.21	19
240	308.58	296.42	281.86	257.69	11.75	2.47	36
360	444.60	433.04	411.32	373.08	36.12	2.08	25
480	553.70	540.70	505.80	456.30	10.50	2.90	10

Table C.12: Multiplication factors to obtain average remaining duration for clustered planned durations per registered timestamp until the OR Departure for Otorhinolaryngology

Planned Duration (min)	Multiplication Factor for Gross OR Duration	Multiplication Factor for Start Anesthesia to OR Departure	Multiplication Factor for Start Surgical Preparations to OR Departure	Multiplication Factor for Start Surgery to OR Departure	Multiplication Factor for End Surgery to OR Departure	Multiplication Factor for End Anesthesia to OR Departure	Nr. of Data Points
Short Duration (t < 90 min)	1.43	1.25	1.03	0.92	0.20	0.01	226
Medium Duration (t ≥ 90 min, t ≤ 180 min)	1.29	1.21	1.11	0.99	0.09	0.02	319
Long Duration (t > 180 min)	1.26	1.22	1.15	1.05	0.06	0.01	113

C.1.8. Neurological Surgery - NCH

Table C.13: Average remaining duration in minutes per time registration in surgery until OR Departure registration for Neurological Surgery

Planned Duration (min)	Average Gross OR Duration (min)	Average Duration from Start Anesthesia to OR Departure (min)	Average Duration from Start Surgical Preparations to OR Departure (min)	Average Duration from Start Surgery to OR Departure (min)	Average Duration from End Surgery to OR Departure (min)	Average Duration from End Anesthesia to OR Departure (min)	Nr. of Data Points
60	129.07	117.70	102.15	79.22	10	1.22	27
75	172.92	161.50	140.25	105.75	16.17	4.42	12
90	145.21	135.31	119.83	98.94	13.94	3.21	48
120	159.78	149.79	135.12	115.25	13.66	1.65	134
150	201.43	189.49	173.04	151.68	18.79	1.74	47
180	245.76	232.73	215.38	187.44	14.13	2	55
210	304	291.10	270.63	238.30	22.60	2.60	30
240	321.35	311.35	286.73	254.69	17.75	2.10	51
300	441.24	427.76	403.97	362.03	22.07	1.07	29
360	467.80	456.74	426.22	384.82	22.01	3.32	74
480	589.50	576.57	549.36	500.07	26.50	5.71	14
720	665.32	656	630.47	597.21	23.26	1.63	19

Table C.14: Multiplication factors to obtain average remaining duration for clustered planned durations per registered timestamp until the OR Departure for Neurological Surgery

Planned Duration (min)	Multiplication Factor for Gross OR Duration	Multiplication Factor for Start Anesthesia to OR Departure	Multiplication Factor for Start Surgical Preparations to OR Departure	Multiplication Factor for Start Surgery to OR Departure	Multiplication Factor for End Surgery to OR Departure	Multiplication Factor for End Anesthesia to OR Departure	Nr. of Data Points
Short Duration (t < 90 min)	2.54	2.30	1.98	1.56	0.31	0.10	55
Medium Duration (t ≥ 90 min, t ≤ 180 min)	1.39	1.31	1.18	1.01	0.12	0.02	292
Long Duration (t > 180 min)	1.31	1.27	1.18	1.07	0.07	0.01	239

C.1.9. Ophthalmology - OOG

Table C.15: Average remaining duration in minutes per time registration in surgery until OR Departure registration for Ophthalmology

Planned Duration (min)	Average Gross OR Duration (min)	Average Duration from Start Anesthesia to OR Departure (min)	Average Duration from Start Surgical Preparations to OR Departure (min)	Average Duration from Start Surgery to OR Departure (min)	Average Duration from End Surgery to OR Departure (min)	Average Duration from End Anesthesia to OR Departure (min)	Nr. of Data Points
30	50.89	44.48	36.31	31.57	8.52	1.43	54
45	62.92	55.58	46.27	39.87	10.89	1.29	84
60	76.24	69.24	59.33	53.85	10.58	1.28	310
75	75.57	68.07	58.70	53.03	9.74	0.91	89
90	114.81	105.58	92.48	86	9.19	1.10	31

Table C.16: Multiplication factors to obtain average remaining duration for clustered planned durations per registered timestamp until the OR Departure for Ophthalmology

Planned Duration (min)	Multiplication Factor for Gross OR Duration	Multiplication Factor for Start Anesthesia to OR Departure	Multiplication Factor for Start Surgical Preparations to OR Departure	Multiplication Factor for Start Surgery to OR Departure	Multiplication Factor for End Surgery to OR Departure	Multiplication Factor for End Anesthesia to OR Departure	Nr. of Data Points
Short Duration ($t < 90$ min)	1.29	1.15	0.98	0.87	0.19	0.02	558
Medium Duration ($t \geq 90$ min, $t \leq 180$ min)	1.19	1.10	0.98	0.90	0.09	0.02	54
Long Duration ($t > 180$ min)							

C.1.10. Orthopaedics - ORT

Table C.17: Average remaining duration in minutes per time registration in surgery until OR Departure registration for Orthopaedics

Planned Duration (min)	Average Gross OR Duration (min)	Average Duration from Start Anesthesia to OR Departure (min)	Average Duration from Start Surgical Preparations to OR Departure (min)	Average Duration from Start Surgery to OR Departure (min)	Average Duration from End Surgery to OR Departure (min)	Average Duration from End Anesthesia to OR Departure (min)	Nr. of Data Points
30	80.97	54.66	44.84	36.94	12.53	1.69	32
45	74.16	65.32	56.32	46.08	7.71	1.18	38
60	89.91	85.41	71.53	60.52	8.70	1.41	64
75	105.37	101.47	86.32	70.89	7.05	1.68	19
90	133.90	123.67	111.13	95.68	9.63	1.88	60
100	148.06	138.65	126.12	107.41	5.88	2.18	17
120	166.75	156.07	142.23	124.86	9.05	2.29	103
150	198.95	187.90	172.02	152.52	10.09	2.05	44
180	227.61	215.44	198.78	177.46	12.44	3.76	41
240	313	299.64	279.82	255.27	15.73	5.91	11

Table C.18: Multiplication factors to obtain average remaining duration for clustered planned durations per registered timestamp until the OR Departure for Orthopaedics

Planned Duration (min)	Multiplication Factor for Gross OR Duration	Multiplication Factor for Start Anesthesia to OR Departure	Multiplication Factor for Start Surgical Preparations to OR Departure	Multiplication Factor for Start Surgery to OR Departure	Multiplication Factor for End Surgery to OR Departure	Multiplication Factor for End Anesthesia to OR Departure	Nr. of Data Points
Short Duration (t < 90 min)	1.77	1.50	1.26	1.05	0.21	0.03	168
Medium Duration (t ≥ 90 min, t ≤ 180 min)	1.38	1.29	1.17	1.02	0.08	0.02	284
Long Duration (t > 180 min)	1.44	1.38	1.30	1.20	0.06	0.02	29

C.1.11. Plastic Surgery - PLA

Table C.19: Average remaining duration in minutes per time registration in surgery until OR Departure registration for Plastic Surgery

Planned Duration (min)	Average Gross OR Duration (min)	Average Duration from Start Anesthesia to OR Departure (min)	Average Duration from Start Surgical Preparations to OR Departure (min)	Average Duration from Start Surgery to OR Departure (min)	Average Duration from End Surgery to OR Departure (min)	Average Duration from End Anesthesia to OR Departure (min)	Nr. of Data Points
45	93.734	70	60.78	48.61	7.30	2	32
60	94.81	84.10	70.81	60.86	8.33	0.95	38
90	108.82	96.10	83.55	72.36	9.18	2.09	64
360	416.53	404.27	381	346	12.67	5	19

Table C.20: Multiplication factors to obtain average remaining duration for clustered planned durations per registered timestamp until the OR Departure for Plastic Surgery

Planned Duration (min)	Multiplication Factor for Gross OR Duration	Multiplication Factor for Start Anesthesia to OR Departure	Multiplication Factor for Start Surgical Preparations to OR Departure	Multiplication Factor for Start Surgery to OR Departure	Multiplication Factor for End Surgery to OR Departure	Multiplication Factor for End Anesthesia to OR Departure	Nr. of Data Points
Short Duration (t < 90 min)	1.84	1.52	1.30	1.09	0.16	0.03	62
Medium Duration (t ≥ 90 min, t ≤ 180 min)	1.22	1.10	0.98	0.86	0.08	0.02	24
Long Duration (t > 180 min)	1.21	1.18	1.11	1.02	0.04	0.01	21

C.1.12. Radiotherapy - RTH

Since there are too little data point for Radiotherapy interventions in the OR, Radiotherapy only consist of a table in which multiplication factors have been calculated per time incidence until the OR Departure.

Table C.21: Multiplication factors to obtain average remaining duration for clustered planned durations per registered timestamp until the OR Departure for Radiotherapy

Planned Duration (min)	Multiplication Factor for Gross OR Duration	Multiplication Factor for Start Anesthesia to OR Departure	Multiplication Factor for Start Surgical Preparations to OR Departure	Multiplication Factor for Start Surgery to OR Departure	Multiplication Factor for End Surgery to OR Departure	Multiplication Factor for End Anesthesia to OR Departure	Nr. of Data Points
Short Duration ($t < 90$ min)	1.18	1.01	0.86	0.72	0.16	0.02	62
Medium Duration ($t \geq 90$ min, $t \leq 180$ min)							
Long Duration ($t > 180$ min)							

C.1.13. Urology - URO

Table C.22: Average remaining duration in minutes per time registration in surgery until OR Departure registration for Urology

Planned Duration (min)	Average Gross OR Duration (min)	Average Duration from Start Anesthesia to OR Departure (min)	Average Duration from Start Surgical Preparations to OR Departure (min)	Average Duration from Start Surgery to OR Departure (min)	Average Duration from End Surgery to OR Departure (min)	Average Duration from End Anesthesia to OR Departure (min)	Nr. of Data Points
30	61.78	52.41	42.50	33.77	6.31	2.34	90
45	71.33	63.50	52.42	44.75	4	2.67	12
60	78.59	68.88	57.59	46.82	6.76	2.18	17
120	174.75	163.39	150.14	133.67	10.64	0.22	36
150	203.26	193.26	177.68	157.32	12.29	0.16	38
180	220.78	206.33	188.22	172.61	13.28	1.06	18
360	412.55	399.65	379.20	359.75	12.10	3.35	20

Table C.23: Multiplication factors to obtain average remaining duration for clustered planned durations per registered timestamp until the OR Departure for Urology

Planned Duration (min)	Multiplication Factor for Gross OR Duration	Multiplication Factor for Start Anesthesia to OR Departure	Multiplication Factor for Start Surgical Preparations to OR Departure	Multiplication Factor for Start Surgery to OR Departure	Multiplication Factor for End Surgery to OR Departure	Multiplication Factor for End Anesthesia to OR Departure	Nr. of Data Points
Short Duration ($t < 90$ min)	1.88	1.61	1.32	1.06	0.18	0.07	124
Medium Duration ($t \geq 90$ min, $t \leq 180$ min)	1.36	1.27	1.19	1.03	0.09	0.01	106
Long Duration ($t > 180$ min)	1.18	1.09	1.02	0.96	0.04	0.01	41

C.1.14. Obstetrics - VRV

Table C.24: Average remaining duration in minutes per time registration in surgery until OR Departure registration for Obstetrics

Planned Duration (min)	Average Gross OR Duration (min)	Average Duration from Start Anesthesia to OR Departure (min)	Average Duration from Start Surgical Preparations to OR Departure (min)	Average Duration from Start Surgery to OR Departure (min)	Average Duration from End Surgery to OR Departure (min)	Average Duration from End Anesthesia to OR Departure (min)	Nr. of Data Points
30	51.24	45.41	37.53	32.58	7.29	1.59	17
45	73.57	64.06	55.35	49.33	4.37	2.55	51
60	80.02	71.25	59.99	53.48	6.66	2.60	111

Table C.25: Multiplication factors to obtain average remaining duration for clustered planned durations per registered timestamp until the OR Departure for Obstetrics

Planned Duration (min)	Multiplication Factor for Gross OR Duration	Multiplication Factor for Start Anesthesia to OR Departure	Multiplication Factor for Start Surgical Preparations to OR Departure	Multiplication Factor for Start Surgery to OR Departure	Multiplication Factor for End Surgery to OR Departure	Multiplication Factor for End Anesthesia to OR Departure	Nr. of Data Points
Short Duration ($t < 90$ min)	1.45	1.28	1.08	0.96	0.12	0.05	199
Medium Duration ($t \geq 90$ min, $t \leq 180$ min)	1.14	1.04	0.88	0.82	0.07	0.02	11
Long Duration ($t > 180$ min)							

D

Appendix D

This appendix contains the MATLAB scripts that were used to generate the historical database, and update the schedule using this data throughout the day of surgery.

D.1. MATLAB Script - Historical Database

The following script can be used to obtain durations of procedures per planned duration per surgical specialty generated from a dataset containing all completed procedures in 2023.

```
%% Input Data
T = readtable("/Users/sannesmid/Documents/BME THESIS/OK data/OK RAW 2023.
    xlsx");
Tori = T; % All surgical procedures from 2023
%Tleeg = T(1,:); % check
Spoed = T(1,:); % All emergency surgical procedures from 2023

%% Clean input data
% Remove and Separate data from Emergency surgeries
for i = height(T):-1:1
    if T.Prioriteit(i) == "S1" | T.Prioriteit(i) == "S2" | T.Prioriteit(i)
         == "S3" | T.Prioriteit(i) == "S4"
        Spoed = [Spoed;T(i,:)];
        T(i,:) = [];
    end
end
Spoed(1,:) = [];
%}

% Remove all procedures that were performed in external locations (not OR)
OperatieKamerCode = unique(T.OperatieKamerCode);
NietOK = find(T.OperatieKamerCode=="");
NietOK = [NietOK;find(T.OperatieKamerCode=="OK19")];
NietOK = [NietOK;find(T.OperatieKamerCode=="OKHV")];
NietOK = [NietOK;find(T.OperatieKamerCode=="OKS")];
NietOK = [NietOK;find(T.OperatieKamerCode=="SP")];
NietOK = [NietOK;find(T.OperatieKamerCode=="XANE")];
NietOK = [NietOK;find(T.OperatieKamerCode=="XBL1")];
NietOK = [NietOK;find(T.OperatieKamerCode=="XBL2")];
NietOK = [NietOK;find(T.OperatieKamerCode=="XBL3")];
NietOK = [NietOK;find(T.OperatieKamerCode=="XBL4")];
NietOK = [NietOK;find(T.OperatieKamerCode=="XBL5")];
NietOK = [NietOK;find(T.OperatieKamerCode=="XBL6")];
```

```matlab
NietOK = [NietOK;find(T.OperatieKamerCode=="XBL7")];
NietOK = [NietOK;find(T.OperatieKamerCode=="XBL8")];
NietOK = [NietOK;find(T.OperatieKamerCode=="XBL9")];
NietOK = [NietOK;find(T.OperatieKamerCode=="XINT")];
NietOK = [NietOK;find(T.OperatieKamerCode=="XMDL")];
NietOK = [NietOK;find(T.OperatieKamerCode=="XMRI")];
NietOK = [NietOK;find(T.OperatieKamerCode=="XRAD")];
NietOK = sort(NietOK);

OKs = T;
OKs(NietOK,:) = [];

NietOK = T(NietOK,:);

% Remove procedures with Timestamp recording = 0 or Planned Duration (Geplannde Duur) = 0,1 of ""
BadData = find(OKs.GeplandeDuur==1);
OKs(BadData,:) = [];
BadData = find(OKs.GeplandeDuur==0);
OKs(BadData,:) = [];
BadData = find(OKs.EindeOperatie==0);
OKs(BadData,:) = [];
BadData = find(OKs.OpOK==0);
OKs(BadData,:) = [];
BadData = find(OKs.StartInleiding==0);
OKs(BadData,:) = [];
BadData = find(OKs.StartChiVoorb==0);
OKs(BadData,:) = [];
BadData = find(OKs.StartSnijder==0);
OKs(BadData,:) = [];
BadData = find(OKs.EindeSnijder==0);
OKs(BadData,:) = [];
BadData = find(OKs.EindeUitleiding==0);
OKs(BadData,:) = [];

%% Prepare historical database with Geplande Duur per Specialism
Specialismen = unique(OKs.Spe);

% Perparation of multiplication factors
for i = 1:length(Specialismen)
    SS{i} = OKs(find(contains(OKs.Spe,Specialismen(i))),:);
    % find index of segmented categories
    IndexL{i} = find(SS{i}.GeplandeDuur<90);    % less than 90 minute = L or Low
    IndexM{i} = find(SS{i}.GeplandeDuur>=90&SS{i}.GeplandeDuur<=180); % 90 min until 180 min = M or Middle
    IndexH{i} = find(SS{i}.GeplandeDuur>180); % More than 180 min = H or High

    % Record durations of timestamps until OR Departure for segmented categories
    TimestampsOKDuurL{i} = table(SS{i}.Spe(IndexL{i}),SS{i}.GeplandeDuur(IndexL{i}),SS{i}.EindeOperatie(IndexL{i},:)-SS{i}.OpOK(IndexL{i},:),(SS{i}.EindeOperatie(IndexL{i},:)-SS{i}.StartInleiding(IndexL{i},:)),(SS{i}.EindeOperatie(IndexL{i},:)-SS{i}.StartChiVoorb(IndexL{i},:)),(SS{i}.EindeOperatie(IndexL{i},:)-SS{i}.StartSnijder(IndexL{
```

```
i},:)),(SS{i}.EindeOperatie(IndexL{i},:)-SS{i}.EindeSnijder(IndexL{i},:)),(SS{i}.EindeOperatie(IndexL{i},:)-SS{i}.EindeUitleiding(IndexL{i},:)),'VariableNames',{'Specialism','GD','BrutoOKDuur','vanafStartInl','vanafStartChiV','vanafStartSnij','vanafEindSnij','vanafEindUitl'});
    TimestampsOKDuurM{i} = table(SS{i}.Spe(IndexM{i}),SS{i}.GeplandeDuur(IndexM{i}),SS{i}.EindeOperatie(IndexM{i},:)-SS{i}.OpOK(IndexM{i},:),(SS{i}.EindeOperatie(IndexM{i},:)-SS{i}.StartInleiding(IndexM{i},:)),(SS{i}.EindeOperatie(IndexM{i},:)-SS{i}.StartChiVoorb(IndexM{i},:)),(SS{i}.EindeOperatie(IndexM{i},:)-SS{i}.StartSnijder(IndexM{i},:)),(SS{i}.EindeOperatie(IndexM{i},:)-SS{i}.EindeSnijder(IndexM{i},:)),(SS{i}.EindeOperatie(IndexM{i},:)-SS{i}.EindeUitleiding(IndexM{i},:)),'VariableNames',{'Specialism','GD','BrutoOKDuur','vanafStartInl','vanafStartChiV','vanafStartSnij','vanafEindSnij','vanafEindUitl'});
    TimestampsOKDuurH{i} = table(SS{i}.Spe(IndexH{i}),SS{i}.GeplandeDuur(IndexH{i}),SS{i}.EindeOperatie(IndexH{i},:)-SS{i}.OpOK(IndexH{i},:),(SS{i}.EindeOperatie(IndexH{i},:)-SS{i}.StartInleiding(IndexH{i},:)),(SS{i}.EindeOperatie(IndexH{i},:)-SS{i}.StartChiVoorb(IndexH{i},:)),(SS{i}.EindeOperatie(IndexH{i},:)-SS{i}.StartSnijder(IndexH{i},:)),(SS{i}.EindeOperatie(IndexH{i},:)-SS{i}.EindeSnijder(IndexH{i},:)),(SS{i}.EindeOperatie(IndexH{i},:)-SS{i}.EindeUitleiding(IndexH{i},:)),'VariableNames',{'Specialism','GD','BrutoOKDuur','vanafStartInl','vanafStartChiV','vanafStartSnij','vanafEindSnij','vanafEindUitl'});

    % Calculate Multiplication factors for segmented categories per timestamp until OR Departure
    TimestampsvsGD{i}(1,:) = table(Specialismen(i),string('BrutoOK'),mean(TimestampsOKDuurL{i}.BrutoOKDuur./TimestampsOKDuurL{i}.GD),mean(TimestampsOKDuurM{i}.BrutoOKDuur./TimestampsOKDuurM{i}.GD),mean(TimestampsOKDuurH{i}.BrutoOKDuur./TimestampsOKDuurH{i}.GD),'VariableNames',{'Specialism','Timestamp','Low','Middle','High',}); % Bruto OK Duur
    TimestampsvsGD{i}(2,:) = table(Specialismen(i),string('vanafStartInleiding'),mean(TimestampsOKDuurL{i}.vanafStartInl./TimestampsOKDuurL{i}.GD),mean(TimestampsOKDuurM{i}.vanafStartInl./TimestampsOKDuurM{i}.GD),mean(TimestampsOKDuurH{i}.vanafStartInl./TimestampsOKDuurH{i}.GD),'VariableNames',{'Specialism','Timestamp','Low','Middle','High'}); % Start Inleiding
    TimestampsvsGD{i}(3,:) = table(Specialismen(i),string('vanafStartChiVoorb'),mean(TimestampsOKDuurL{i}.vanafStartChiV./TimestampsOKDuurL{i}.GD),mean(TimestampsOKDuurM{i}.vanafStartChiV./TimestampsOKDuurM{i}.GD),mean(TimestampsOKDuurH{i}.vanafStartChiV./TimestampsOKDuurH{i}.GD),'VariableNames',{'Specialism','Timestamp','Low','Middle','High'});  % Start Chirurgische Voorbereiding
    TimestampsvsGD{i}(4,:) = table(Specialismen(i),string('vanafStartSnij'),mean(TimestampsOKDuurL{i}.vanafStartSnij./TimestampsOKDuurL{i}.GD),mean(TimestampsOKDuurM{i}.vanafStartSnij./TimestampsOKDuurM{i}.GD),mean(TimestampsOKDuurH{i}.vanafStartSnij./TimestampsOKDuurH{i}.GD),'VariableNames',{'Specialism','Timestamp','Low','Middle','High'}); % vanaf Start Snij
    TimestampsvsGD{i}(5,:) = table(Specialismen(i),string('vanafEindSnij'),mean(TimestampsOKDuurL{i}.vanafEindSnij./TimestampsOKDuurL{i}.GD),mean(TimestampsOKDuurM{i}.vanafEindSnij./TimestampsOKDuurM{i}.GD),mean(TimestampsOKDuurH{i}.vanafEindSnij./TimestampsOKDuurH{i}.GD),'
```

```
        VariableNames',{'Specialism','Timestamp','Low','Middle','High'}); %
         vanaf Eind Snij
    TimestampsvsGD{i}(6,:) = table(Specialismen(i),string('vanafEindUitl')
        ,mean(TimestampsOKDuurL{i}.vanafEindUitl./TimestampsOKDuurL{i}.GD),
        mean(TimestampsOKDuurM{i}.vanafEindUitl./TimestampsOKDuurM{i}.GD),
        mean(TimestampsOKDuurH{i}.vanafEindUitl./TimestampsOKDuurH{i}.GD),'
        VariableNames',{'Specialism','Timestamp','Low','Middle','High'}); %
         vanaf Eind Uitleiding
    TimestampsvsGD{i}(7,:) = table(Specialismen(i),string('Count'),height(
        TimestampsOKDuurL{i}),height(TimestampsOKDuurM{i}),height(
        TimestampsOKDuurH{i}),'VariableNames',{'Specialism','Timestamp','
        Low','Middle','High'});

    % Calculate Historical Database for Surgeries with more than 10
        procedures with same planned duration per specialism
    ii = 0;
    zz = unique(SS{i}.GeplandeDuur);
        for j = 1:length(zz)
            ind = find(zz(j)==SS{i}.GeplandeDuur);
            if length(ind) >= 10 %only calculate averages if >10
                procedures with same planned durations
            ii = ii + 1;
            VerwachteDuur_vanaf_OpOK{i}(ii,:) = table(zz(j),mean(SS{i}.
                EindeOperatie(ind)-SS{i}.OpOK(ind)),length(ind),'
                VariableNames',{'GD','VerwachteDuurAvg','Count'});
            VerwachteDuur_vanaf_StartInl{i}(ii,:) = table(zz(j),mean(SS{i
                }.EindeOperatie(ind)-SS{i}.StartInleiding(ind)),length(ind)
                ,'VariableNames',{'GD','VerwachteDuurAvg','Count'});
            VerwachteDuur_vanaf_StartChiVoor{i}(ii,:) = table(zz(j),mean(
                SS{i}.EindeOperatie(ind)-SS{i}.StartChiVoorb(ind)),length(
                ind),'VariableNames',{'GD','VerwachteDuurAvg','Count'});
            VerwachteDuur_vanaf_StartSnij{i}(ii,:) = table(zz(j),mean(SS{i
                }.EindeOperatie(ind)-SS{i}.StartSnijder(ind)),length(ind),'
                VariableNames',{'GD','VerwachteDuurAvg','Count'});
            VerwachteDuur_vanaf_EindSnij{i}(ii,:) = table(zz(j),mean(SS{i
                }.EindeOperatie(ind)-SS{i}.EindeSnijder(ind)),length(ind),'
                VariableNames',{'GD','VerwachteDuurAvg','Count'});
            VerwachteDuur_vanaf_EindUitl{i}(ii,:) = table(zz(j),mean(SS{i
                }.EindeOperatie(ind)-SS{i}.EindeUitleiding(ind)),length(ind
                ),'VariableNames',{'GD','VerwachteDuurAvg','Count'});
            end
        end
end
```

D.2. MATLAB Script - Schedule Update

The following code was used to obtain updated schedules. The script uses variables that were already defined in the previous section for generating schedules based on the historical database.

```
%% Schedule Input
BasicSchedule = readtable("/Users/sannesmid/Documents/BME THESIS/
    Excelfiles for Matlab/12-01 Begin.xlsx");
Result = readtable("/Users/sannesmid/Documents/BME THESIS/Excelfiles for
    Matlab/12-01 Eind.xlsx");

BasicSchedule.StartTijd = timeofday(datetime(BasicSchedule.StartTijd, '
```

```
ConvertFrom','excel', 'Format','HH:mm'));
BasicSchedule.EindtijdOK = timeofday(datetime(BasicSchedule.EindtijdOK, 'ConvertFrom','excel', 'Format','HH:mm'));
BasicSchedule.EindTijd = BasicSchedule.StartTijd+minutes(BasicSchedule.GeplandeDuur_min_);
Result.EindtijdOK = timeofday(datetime(Result.EindtijdOK,'ConvertFrom','excel','Format','HH:mm'));
Result.Cancelled = timeofday(datetime(Result.Cancelled,'ConvertFrom','excel','Format','HH:mm'));

% Adjusted Schedule based on Historical Data
AdjustedScheduleHistorySeg = BasicSchedule;
AdjustedScheduleHistorySeg = renamevars(AdjustedScheduleHistorySeg,["GeplandeDuur_min_"],["VerwachteDuur"]);
for i = 1:height(AdjustedScheduleHistorySeg)
    Spec_Index = find(contains(Specialismen,AdjustedScheduleHistorySeg.Specialisme(i)));
    if Spec_Index == 7 || ismember(BasicSchedule.GeplandeDuur_min_(i),VerwachteDuur_vanaf_OpOK{Spec_Index}.GD) == 0
        if BasicSchedule.GeplandeDuur_min_(i) < 90
        AdjustedScheduleHistorySeg.VerwachteDuur(i) = BasicSchedule.GeplandeDuur_min_(i)*TimestampsvsGD{Spec_Index}.Low(1);
        end
        if BasicSchedule.GeplandeDuur_min_(i) >= 90 && BasicSchedule.GeplandeDuur_min_(i) <= 180
        AdjustedScheduleHistorySeg.VerwachteDuur(i) = BasicSchedule.GeplandeDuur_min_(i)*TimestampsvsGD{Spec_Index}.Middle(1);
        end
        if BasicSchedule.GeplandeDuur_min_(i) > 180
        AdjustedScheduleHistorySeg.VerwachteDuur(i) = BasicSchedule.GeplandeDuur_min_(i)*TimestampsvsGD{Spec_Index}.High(1);
        end
    else
    Index_Value_Duur = find(BasicSchedule.GeplandeDuur_min_(i)==VerwachteDuur_vanaf_OpOK{Spec_Index}.GD);
    AdjustedScheduleHistorySeg.VerwachteDuur(i) = VerwachteDuur_vanaf_OpOK{Spec_Index}.VerwachteDuurAvg(Index_Value_Duur);
    end
end

uniekOK = unique(AdjustedScheduleHistorySeg.OK);
for j = 1:length(uniekOK)
    index = find(contains(AdjustedScheduleHistorySeg.OK,uniekOK(j)));
    AdjustedScheduleHistorySeg.EindTijd(index(1)) = AdjustedScheduleHistorySeg.StartTijd(index(1))+minutes(AdjustedScheduleHistorySeg.VerwachteDuur(index(1)));
        for ii = 2:length(index)
            AdjustedScheduleHistorySeg.StartTijd(index(ii)) = AdjustedScheduleHistorySeg.EindTijd(index(ii-1))+minutes(15);
            AdjustedScheduleHistorySeg.EindTijd(index(ii)) = AdjustedScheduleHistorySeg.StartTijd(index(ii))+minutes(AdjustedScheduleHistorySeg.VerwachteDuur(index(ii)));
        end
end
```

```
%% Transfer Results to Day Times
Result.Besteld = duration(minutes(Result.Besteld),'Format','hh:mm');
Result.OpHolding = duration(minutes(Result.OpHolding),'Format','hh:mm');
Result.OpOK = duration(minutes(Result.OpOK),'Format','hh:mm');
Result.StartInleiding = duration(minutes(Result.StartInleiding),'Format','hh:mm');
Result.StartChiVoorb = duration(minutes(Result.StartChiVoorb),'Format','hh:mm');
Result.StartSnij = duration(minutes(Result.StartSnij),'Format','hh:mm');
Result.EindSnij = duration(minutes(Result.EindSnij),'Format','hh:mm');
Result.EindUitleiding = duration(minutes(Result.EindUitleiding),'Format','hh:mm');
Result.EindOK = duration(minutes(Result.EindOK),'Format','hh:mm');
Result.OpVerkoever = duration(minutes(Result.OpVerkoever),'Format','hh:mm');

%% Current Time Stamp and Current Schedule
ScheduleUpdate = AdjustedScheduleHistorySeg;
Time = timeofday(datetime('08:00:00'));  %Change '00:00:00' to 'now' for current situation

%% Updating Schedule
% For Loop to obtain update of schedule every 10 minutes from 08:00:00 until 20:00:00
for i = 1:72 % 20:00
[DayScheduleUpdate,TotalOKsovertime_seg,totalminovertime_seg,OvertimeperOK_seg,TotalOKsna16_seg,TotminOvertimena16_seg,OKOTna16_seg,OKendinTime_seg] = ToDSUpdateSegment(BasicSchedule,Result,Time,ScheduleUpdate,VerwachteDuur_vanaf_StartInl,VerwachteDuur_vanaf_StartChiVoor,VerwachteDuur_vanaf_StartSnij,VerwachteDuur_vanaf_EindSnij,VerwachteDuur_vanaf_EindUitl,Specialismen,TimestampsvsGD); % Run function once, for updating the schedule one time! Shut off for-loop to do so
    DayScheduleUpate{i} = DayScheduleUpdate;
    Overtimeseg(i,:) = table(Time,TotalOKsovertime_seg,totalminovertime_seg,TotalOKsna16_seg,TotminOvertimena16_seg);
    OKsperTijdseg{i} = OvertimeperOK_seg;
    OKsperTijdna16seg{i} = OKOTna16_seg;
    OKendinTimeseg{i} = OKendinTime_seg;
    Time = Time+minutes(10);
end

%% Function Updating Schedules
function [Update,TotalOKsovertime,TotminOvertime,OKOT,TotalOKsna16,TotminOvertimena16,OKOTna16,OKendinTime] = ToDSUpdateSegment(Basic,Result,Time,Schedule,VerwachteDuur_vanaf_StartInl,VerwachteDuur_vanaf_StartChiVoor,VerwachteDuur_vanaf_StartSnij,VerwachteDuur_vanaf_EindSnij,VerwachteDuur_vanaf_EindUitl,Specialismen,TimestampsvsGD);

% Point of Process
PatientJourney(height(Schedule),:) = "Unknown";
Duur(height(Schedule),:) = 0;
GeplandeDuur = Basic.GeplandeDuur_min_;
Schedule = addvars(Schedule,PatientJourney);
Schedule = addvars(Schedule,Duur,'Before','VerwachteDuur');
```

```
Schedule = addvars(Schedule,GeplandeDuur,'Before','Duur');

% Cancellation
id = find(~isnan(Result.Cancelled));
for i = length(id):-1:1
    if Time > Result.Cancelled(id(i))
    Result(id(i),:) = [];
    Schedule(id(i),:) = [];
    end
end

% Adjustments Times - based on OpOK en EindOK
for i = 1:height(Schedule)
    Specials_index = find(contains(Specialismen,Schedule.Specialisme(i)));
    if Specials_index == 7 || ismember(Schedule.GeplandeDuur(i), VerwachteDuur_vanaf_StartInl{Specials_index}.GD) == 0
        if Result.OpOK(i) <= Time && Time < Result.StartInleiding(i)
            Schedule.PatientJourney(i) = "Op OK";
            Schedule.StartTijd(i) = Result.OpOK(i);
            Schedule.EindTijd(i) = Schedule.StartTijd(i)+minutes(Schedule.VerwachteDuur(i));
        end
        if Result.StartInleiding(i) <= Time && Time < Result.StartChiVoorb(i)
            Schedule.PatientJourney(i) = "Start Inleiding";
            Schedule.StartTijd(i) = Result.OpOK(i);
            Schedule.Duur(i) = minutes(Result.StartInleiding(i)-Result.OpOK(i));
            if Schedule.GeplandeDuur(i) < 90
            Schedule.VerwachteDuur(i) = Schedule.GeplandeDuur(i)*TimestampsvsGD{Specials_index}.Low(2);
            end
            if Schedule.GeplandeDuur(i) >= 90 && Schedule.GeplandeDuur(i) <= 180
            Schedule.VerwachteDuur(i) = Schedule.GeplandeDuur(i)*TimestampsvsGD{Specials_index}.Middle(2);
            end
            if Schedule.GeplandeDuur(i) > 180
            Schedule.VerwachteDuur(i) = Schedule.GeplandeDuur(i)*TimestampsvsGD{Specials_index}.High(2);
            end
            Schedule.EindTijd(i) = Schedule.StartTijd(i)+(Result.StartInleiding(i)-Result.OpOK(i))+minutes(Schedule.VerwachteDuur(i)); %
        end
        if Result.StartChiVoorb(i) <= Time && Time < Result.StartSnij(i)
            Schedule.PatientJourney(i) = "Start Chirugische Voorbereiding";
            Schedule.StartTijd(i) = Result.OpOK(i);
            Schedule.Duur(i) = minutes(Result.StartChiVoorb(i)-Result.OpOK(i));
            if Schedule.GeplandeDuur(i) < 90
            Schedule.VerwachteDuur(i) = Schedule.GeplandeDuur(i)*TimestampsvsGD{Specials_index}.Low(3);
            end
            if Schedule.GeplandeDuur(i) >= 90 && Schedule.GeplandeDuur(i)
```

```matlab
                <= 180
            Schedule.VerwachteDuur(i) = Schedule.GeplandeDuur(i)*TimestampsvsGD{Specials_index}.Middle(3);
            end
            if Schedule.GeplandeDuur(i) > 180
            Schedule.VerwachteDuur(i) = Schedule.GeplandeDuur(i)*TimestampsvsGD{Specials_index}.High(3);
            end
            Schedule.EindTijd(i) = Schedule.StartTijd(i)+(Result.StartChiVoorb(i)-Result.OpOK(i))+minutes(Schedule.VerwachteDuur(i)); %
        end
        if Result.StartSnij(i) <= Time && Time < Result.EindSnij(i)
            Schedule.PatientJourney(i) = "Start Snijder";
            Schedule.StartTijd(i) = Result.OpOK(i); % Aanpassen
            Schedule.Duur(i) = minutes(Result.StartSnij(i)-Result.OpOK(i));
            if Schedule.GeplandeDuur(i) < 90
            Schedule.VerwachteDuur(i) = Schedule.GeplandeDuur(i)*TimestampsvsGD{Specials_index}.Low(4);
            end
            if Schedule.GeplandeDuur(i) >= 90 && Schedule.GeplandeDuur(i) <= 180
            Schedule.VerwachteDuur(i) = Schedule.GeplandeDuur(i)*TimestampsvsGD{Specials_index}.Middle(4);
            end
            if Schedule.GeplandeDuur(i) > 180
            Schedule.VerwachteDuur(i) = Schedule.GeplandeDuur(i)*TimestampsvsGD{Specials_index}.High(4);
            end
            Schedule.EindTijd(i) = Schedule.StartTijd(i)+(Result.StartSnij(i)-Result.OpOK(i))+minutes(Schedule.VerwachteDuur(i)); %
        end
        if Result.EindSnij(i) <= Time && Time < Result.EindUitleiding(i)
            Schedule.PatientJourney(i) = "Einde Snijder";
            Schedule.StartTijd(i) = Result.OpOK(i); % Aanpassen
            Schedule.Duur(i) = minutes(Result.EindSnij(i)-Result.OpOK(i));
            if Schedule.GeplandeDuur(i) < 90
            Schedule.VerwachteDuur(i) = Schedule.GeplandeDuur(i)*TimestampsvsGD{Specials_index}.Low(5);
            end
            if Schedule.GeplandeDuur(i) >= 90 && Schedule.GeplandeDuur(i) <= 180
            Schedule.VerwachteDuur(i) = Schedule.GeplandeDuur(i)*TimestampsvsGD{Specials_index}.Middle(5);
            end
            if Schedule.GeplandeDuur(i) > 180
            Schedule.VerwachteDuur(i) = Schedule.GeplandeDuur(i)*TimestampsvsGD{Specials_index}.High(5);
            end
            Schedule.EindTijd(i) = Schedule.StartTijd(i)+(Result.EindSnij(i)-Result.OpOK(i))+minutes(Schedule.VerwachteDuur(i)); %
        end
        if Result.EindUitleiding(i) <= Time && Time < Result.EindOK(i)
            Schedule.PatientJourney(i) = "Eind Uitleiding";
            Schedule.StartTijd(i) = Result.OpOK(i); % Aanpassen
```

```
            Schedule.Duur(i) = minutes(Result.EindUitleiding(i)-Result.
                OpOK(i));
            if Schedule.GeplandeDuur(i) < 90
            Schedule.VerwachteDuur(i) = Schedule.GeplandeDuur(i)*
                TimestampsvsGD{Specials_index}.Low(6);
            end
            if Schedule.GeplandeDuur(i) >= 90 && Schedule.GeplandeDuur(i)
                <= 180
            Schedule.VerwachteDuur(i) = Schedule.GeplandeDuur(i)*
                TimestampsvsGD{Specials_index}.Middle(6);
            end
            if Schedule.GeplandeDuur(i) > 180
            Schedule.VerwachteDuur(i) = Schedule.GeplandeDuur(i)*
                TimestampsvsGD{Specials_index}.High(6);
            end
            Schedule.EindTijd(i) = Schedule.StartTijd(i)+(Result.
                EindUitleiding(i)-Result.OpOK(i))+minutes(Schedule.
                VerwachteDuur(i)); %
        end
        if Result.EindOK(i) <= Time
            Schedule.PatientJourney(i) = "Eind Operatie";
            Schedule.StartTijd(i) = Result.OpOK(i);
            Schedule.Duur(i) = minutes(Result.EindOK(i)-Result.OpOK(i));
            Schedule.VerwachteDuur(i) = 0;
            Schedule.EindTijd(i) = Result.EindOK(i);
        end
        if Time < Result.OpOK(i)
            index = find(contains(Result.OK,Result.OK(i)));
            if i == index(1)
                Schedule.EindTijd(i) = Schedule.StartTijd(i)+minutes(
                    Schedule.VerwachteDuur(i));
            else
                Schedule.StartTijd(i) = Schedule.EindTijd(i-1)+minutes(15)
                    ;
                Schedule.EindTijd(i) = Schedule.StartTijd(i)+minutes(
                    Schedule.VerwachteDuur(i));
            end
        end
    else
        Geplande_duur_index = find(VerwachteDuur_vanaf_StartInl{
            Specials_index}.GD==Schedule.GeplandeDuur(i));
        if Result.OpOK(i) <= Time && Time < Result.StartInleiding(i)
            Schedule.PatientJourney(i) = "Op OK";
            Schedule.StartTijd(i) = Result.OpOK(i);
            Schedule.EindTijd(i) = Schedule.StartTijd(i)+minutes(Schedule.
                VerwachteDuur(i));
        end
        if Result.StartInleiding(i) <= Time && Time < Result.StartChiVoorb
            (i)
            Schedule.PatientJourney(i) = "Start Inleiding";
            Schedule.StartTijd(i) = Result.OpOK(i);
            Schedule.Duur(i) = minutes(Result.StartInleiding(i)-Result.
                OpOK(i));
            Schedule.VerwachteDuur(i) = VerwachteDuur_vanaf_StartInl{
                Specials_index}.VerwachteDuurAvg(Geplande_duur_index);
            Schedule.EindTijd(i) = Schedule.StartTijd(i)+(Result.
```

```
                StartInleiding(i)-Result.OpOK(i))+minutes(Schedule.VerwachteDuur(i)); %
        end
        if Result.StartChiVoorb(i) <= Time && Time < Result.StartSnij(i)
            Schedule.PatientJourney(i) = "Start Chirugische Voorbereiding";
            Schedule.StartTijd(i) = Result.OpOK(i);
            Schedule.Duur(i) = minutes(Result.StartChiVoorb(i)-Result.OpOK(i));
            Schedule.VerwachteDuur(i) = VerwachteDuur_vanaf_StartChiVoor{Specials_index}.VerwachteDuurAvg(Geplande_duur_index);
            Schedule.EindTijd(i) = Schedule.StartTijd(i)+(Result.StartChiVoorb(i)-Result.OpOK(i))+minutes(Schedule.VerwachteDuur(i)); %
        end
        if Result.StartSnij(i) <= Time && Time < Result.EindSnij(i)
            Schedule.PatientJourney(i) = "Start Snijder";
            Schedule.StartTijd(i) = Result.OpOK(i);
            Schedule.Duur(i) = minutes(Result.StartSnij(i)-Result.OpOK(i));
            Schedule.VerwachteDuur(i) = VerwachteDuur_vanaf_StartSnij{Specials_index}.VerwachteDuurAvg(Geplande_duur_index);
            Schedule.EindTijd(i) = Schedule.StartTijd(i)+(Result.StartSnij(i)-Result.OpOK(i))+minutes(Schedule.VerwachteDuur(i)); %
        end
        if Result.EindSnij(i) <= Time && Time < Result.EindUitleiding(i)
            Schedule.PatientJourney(i) = "Einde Snijder";
            Schedule.StartTijd(i) = Result.OpOK(i);
            Schedule.Duur(i) = minutes(Result.EindSnij(i)-Result.OpOK(i));
            Schedule.VerwachteDuur(i) = VerwachteDuur_vanaf_EindSnij{Specials_index}.VerwachteDuurAvg(Geplande_duur_index);
            Schedule.EindTijd(i) = Schedule.StartTijd(i)+(Result.EindSnij(i)-Result.OpOK(i))+minutes(Schedule.VerwachteDuur(i)); %
        end
        if Result.EindUitleiding(i) <= Time && Time < Result.EindOK(i)
            Schedule.PatientJourney(i) = "Eind Uitleiding";
            Schedule.StartTijd(i) = Result.OpOK(i);
            Schedule.Duur(i) = minutes(Result.EindUitleiding(i)-Result.OpOK(i));
            Schedule.VerwachteDuur(i) = VerwachteDuur_vanaf_EindUitl{Specials_index}.VerwachteDuurAvg(Geplande_duur_index);
            Schedule.EindTijd(i) = Schedule.StartTijd(i)+(Result.EindUitleiding(i)-Result.OpOK(i))+minutes(Schedule.VerwachteDuur(i)); %
        end
        if Result.EindOK(i) <= Time
            Schedule.PatientJourney(i) = "Eind Operatie";
            Schedule.StartTijd(i) = Result.OpOK(i);
            Schedule.Duur(i) = minutes(Result.EindOK(i)-Result.OpOK(i));
            Schedule.VerwachteDuur(i) = 0;
            Schedule.EindTijd(i) = Result.EindOK(i);
        end
        if Time < Result.OpOK(i)
            index = find(contains(Result.OK,Result.OK(i)));
            if i == index(1)
                Schedule.EindTijd(i) = Schedule.StartTijd(i)+minutes(
```

```
                        Schedule.VerwachteDuur(i));
               else
               Schedule.StartTijd(i) = Schedule.EindTijd(i-1)+minutes(15);
               Schedule.EindTijd(i) = Schedule.StartTijd(i)+minutes(Schedule.
                   VerwachteDuur(i));
               end
          end
     end
end

Update = Schedule;

% Calculation Overtime
ind = find(Update.EindtijdOK < Update.EindTijd);
Tijd = zeros(length(ind),1)+Time;
OKOT = table(Update.OK(ind),Update.EindTijd(ind)-Update.EindtijdOK(ind),
    Tijd,'VariableNames',{'OK','Minutes','Nu'});
TotalOKsovertime = height(OKOT);
TotminOvertime = sum(OKOT.Minutes);
idex = find(timeofday(datetime('16:00:00')) <= Update.EindTijd);
Tijd = zeros(length(idex),1)+Time;
OKOTna16 = table(Update.OK(idex),Update.EindTijd(idex)-timeofday(datetime(
    '16:00:00')),Tijd,'VariableNames',{'OK','Minutes','Nu'});
TotalOKsna16 = height(OKOTna16);
TotminOvertimena16 = sum(OKOTna16.Minutes);

% Calculation Times ORs ending before 16:00
uni = unique(Update.OK);
j = 1;
for i = 1:length(uni)
     dex = find(contains(Update.OK,uni(i)));
     if Update.EindTijd(dex(end)) < timeofday(datetime('16:00:00'))
          dex1(j) = dex(end);
          j = j+1;
     end
end
Tijd = zeros(length(dex1),1)+Time;
OKendinTime = table(Update.OK(dex1),Update.EindTijd(dex1),timeofday(
    datetime('16:00:00'))-Update.EindTijd(dex1),Tijd,Result.EindOK(dex1),'
    VariableNames',{'OK','ExpectedEndT','MinutesLeft','Nu','RealEndTime'});

end
```