BSC THESIS INDUSTRIAL ENGINEERING AND MANAGEMENT

ASSESING THE EFFICIENCY OF A LARGE UNIVERSITY HOSPITAL'S OPERATING ROOM PLANNING

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PREFACE

Dear reader,
I am delighted to present this thesis paper, which symbolizes a special event for my academic career. I have been working on this research for the past two modules of my bachelor's degree of Industrial Engineering and Management in the University of Twente. Moreover, during my experience of this research, there were sometimes I was not sure of whether I would be able to successfully conduct it by myself, as it was something I have not done before. However, the journey taught me that with hard work, consistency and application of the knowledge learned during the 3 years of studying for this degree, it was possible. This was one of the first times in the program, were no schedules or deadlines were available and the research progress depended exclusively on the student.

The completion of this thesis would not be possible without the contribution of multiple individuals that helped throughout the conduction of the research. Even though, I found the freedom of no deadlines challenging to plan my time and distribute tasks of my thesis, with the support of my university as well as company supervisors, any challenges experienced were dealt with. As a result, I would like to sincerely thank Hospital X and the company supervisor for providing me with all the hospital operating room data thus giving me the opportunity to conduct my thesis research in their organization and get insights into the interesting industry of healthcare. Special thanks to my university first supervisor Dr. Sebastian Rachuba, and second supervisor Dr. Daniela Guericke, for being there for me by guiding me through my decisions as well as providing useful advice, were needed. Finally, I would like to thank my friends and family, for providing me with emotional support when I was stressed, and constantly encouraging me to push my limits and become the best version of myself. Their daily messages and wishes boosted my motivation and made the research conduction procedure easier for me.

Thank you to everyone that supported me and contributed to the completion of this thesis.

Angelos Fyntikis
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July 2024.

MANAGEMENT SUMMARY

This thesis was conducted at Hospital X, a German academic hospital. Additional information regarding the company will not be mentioned for confidentiality reasons.

INTRODUCTION

Hospital X is a leading academic institution in the healthcare industry, known for its high-quality care in a variety of medical disciplines. Offering a wide range of operating rooms along with highly experienced professionals and state-of-art technology, the hospital can assist nearly all medical services, ranging from state-of-the-art inpatient, preventive as well as ambulatory medical care (confidential). The hospital has implemented a planning method for the daily distribution of the operating rooms among different specialties, depending on the scheduled operations. With regards to the high volume of surgeries performed daily, the hospital would like to assess the efficiency of the planning method currently used, to identify weaknesses and strengths and improve resource utilization.

OPERATING ROOM ASSESSMENT IN HEALTHCARE

In this research, the importance of operating room planning method efficiency assessment, is highlighted. Through a comprehensive assessment, a certain hospital can better utilize resource allocation and increase patient satisfaction, by realizing the efficiency of the planning strategy implemented and discovering areas for improvement. Even though several key performance indicators have been discovered and connected with operational efficiency in operating rooms, their generalizability is limited, given the unique data available in every hospital and the various data collection techniques used. Some of the identified KPI's in the literature review require a large set of valid data in order to produce reliable outcomes. Due to the difficult accessibility or even availability of such data in healthcare institutions, gathering large volumes of valid data is a time-consuming process (Ubiali et al., 2021).

Following the lack of established frameworks in the industry, hospitals are in need to develop an assessment framework to address the efficiency of the planning method used and allow continuous improvement as well as targeted adjustments. According to literature review if no assessment framework to evaluate the planning method is developed, several implications including insufficient resource utilization, reduced patient satisfaction and overall operating room performance can come up (Şeyda Gür & Eren, 2018). As a result, the development of a specialized framework to assess the efficiency in the schedule approach used is essential. This assessment will allow healthcare institutions to develop an efficient strategy that reduces uncertainty effects and increases overall OR performance.

METHODS

The research approach consists of a comprehensive qualitative as well as quantitative approach. Vital information regarding operating rooms and the planning assessment, performance indicators in the industry, potential implications as well as benchmark values used to improve efficiency, were discussed. Moreover, a context analysis was conducted using hospital records provided, followed by a data analysis of the available dataset regarding performance of activities in the operating rooms. The available operational data were filtered and screened using Excel, to determine the exclusion and inclusion criteria. Missing datapoints that reduced the reliability of the study were excluded. Six feasible metrics for analysis given the variables recorded in the data available as well as OR Key Performance Indicators identified, were chosen for the study, using the available dataset, including

operational activity monitoring, provided by the company. Utilization, throughput, makespan, average waiting time, average anaesthesia preparation time and average surgery duration, of operations in the hospital, were analysed from the dataset provided. The data analysis results were used to compare the respective benchmarks of efficient operating room performance metrics in the industry defined. Using the context analysis and the outcomes of the comparison of the metrics measured the planning strategy efficiency of hospital X could therefore be evaluated. Finally, using the literature review, the results of the study and the inefficiencies identified in the planning process, conclusions were made about the efficiency of it. Additional KPI's were recommended to promote and support performance improvements based on the challenges experienced.

OUTCOMES

The study produced key findings regarding the efficiency of the operating room planning approach. The data analysis results, when compared to the benchmarks identified, pinpointed aspects in need for improvement that could increase the efficiency of hospital X's scheduling approach. Moreover, using the context analysis, the identified deviations in the metrics were associated with the implemented planning strategy and its efficiency was evaluated. A relationship between the OR planning strategy and the values of the metrics achieved was discovered. The data analysis resulted in the following metric performances as well as standard deviation and was compared to the benchmarks shown:

KPI	Average Calculation	Standard Deviation	Benchmark
Total OR Utilization	65.62%	17.49	75-85%
Average Anaesthesia Preparation Time/patient	33.24 minutes	26.58	15-40 minutes
Average Patient WT/patient	92.05 minutes	55.9	30 minutes
Makespan/day	9.71 hours	63.03	8 hours
Surgery Duration Time/patient	47.4 minutes	36.3	30-70 minutes
Throughput/day	91.21 total operations	4.22 per OR	120 operations

Table 1: Data analysis KPI measurements

CONCLUSION

In conclusion, throughout this research the efficiency of the planning strategy implemented by hospital X is assessed. From the study conducted several factors that decrease efficiency in the current approach implemented were identified. Moreover, the final assessment, determined operational efficiency in the hospital but also identified inefficiencies in the patient flow and patient preparation aspects of the planning. Moreover, high standard deviations for most of the KPIs measured indicated inconsistency in the planning approach and schedule execution, which is caused by the different type of operations performed at the hospital daily. Considerable high waiting times were measured and addressed the inefficiency of patient flow. On the other hand, average surgery time and throughput measurements, determined the operational efficiency with values close or within the benchmark ranges identified. Finally, key performance indicators and actions specialized in providing greater insights to the causes of the challenges experienced, were identified for the assessment framework recommendations.

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1.INTRODUCTION

This research is conducted with an external organization, Hospital X. In this chapter, the hospital, the challenges experienced as well as the design of the research will be discussed in sections 1.1, 1.2, 1.5 respectively.

1.1 ABOUT THE HOSPITAL

X academic hospital, is a tertiary care provider as well as one of the largest healthcare institutions in Germany, aiming to offer the best patient treatment. With its high-quality care, combining technology and "state-of-the-art" care as well as remarkably high skilled and experienced professionals, the hospital provides patients with the best care available based on their needs. With over 2.500 employees and 50.000 patients every year, the hospital offers a variety of services, including inpatient, preventive as well as ambulatory medical care (Confidential). The hospital's acute clinics, offer the entire range of medical services throughout Germany, whereas private clinics focus on combining medical expertise with comfort and high-quality service, offering a "hotel-like atmosphere" (*Confidential*).

Moreover, multiple head physicians are put in charge of their respective departments at the university, which explains the close connection of research efforts and medical practices. The most fundamental strength of Hospital X is the "conservative and surgical treatment of cardiac disorders" offering operating rooms for surgical specialties to numerous locations around the hospital (confidential).

To ensure an organized utilization of the operating rooms, the hospital utilizes a weekly schedule including specific time slots available for each specialty. As one of the largest healthcare institutions in the region, X would like to assess the efficiency of the planning strategy implemented.

1.2 RESEARCH MOTIVATION

Operating Rooms (OR) are considered a major cost as well as revenue stream for hospitals in healthcare (Pappada et al., 2022). From literature review, ORs cover a significant percentage of hospital expenses and more than 40% of its total revenues (Schoenfelder et al., 2021).

The operating room is a complicated and at times uncertain environment with several factors that result in inefficiency (Lee et al., 2019, p. 1). Unpredictability plays a huge role in OR complexity. Patient as well as hospital-oriented effects, such as insurance type, can influence the execution of OR schedule and therefore the overall performance of OR (Meyers et al., 2024, p. 119) Having that in mind, an efficient OR planning strategy can reduce the operating costs and improve the utilization of OR.

More specifically, in Germany due to the continuous technological developments and socio-economic demands in the past decades, the need for hospitals and operating room organizations to adapt and satisfy patient's needs has been growing. As a result, a planning strategy that takes into account the most important factors inside an OR should be implemented to ensure that uncertainty effects are minimized, and patient satisfaction is ensured.

In section 3.2 of the literature review, the assessment of the planning strategy implemented, is essential for hospitals to identify potential factors limiting OR performance and reducing the impact of uncertainty. With monitoring the performance of OR, assessing the planning strategy used by a hospital becomes possible, allowing the continuous adjustment of the schedule to improve efficiency

in OR. On the other hand, the lack of scheduling assessment prevents the identification and continuous improvement of the OR planning strategy, increasing uncertainty.

Because of the variety of metrics used to track OR performance, "assessing the impact of suggested approaches are complex" (Schouten et al., 2023). However as discussed in 3.2, further analysing the planning strategy used by a hospital, can help assess the efficiency of the generated OR schedule as well as understand the variability of certain factors.

Hospital X's strategy used to form the schedule of operating rooms, is currently not being assessed, preventing the identification of factors enhancing inefficiency effects and improvement actions. The purpose of this research is to fill this gap, through a precise assessment of the Hospital X's OR planning strategy. Having that in mind, the analysis of the practices used, can generate valuable insights regarding the efficiency of the strategy and pinpoint improvement settings.

In conclusion, the research methodology of this thesis paper, can be adopted to help hospitals dealing with similar limitations and contribute to the optimization of overall OR performance in healthcare, by identifying inefficient aspects in the planning strategy implemented. The results of this research are also intended to form an assessment framework for hospital OR planning method, allowing the realization of the planning strategy's efficiency and development of efficient OR utilization and patient treatment schedules in healthcare.

1.3 ACTION PROBLEM

The lack of OR planning performance monitoring, leading to the inability to develop a planning strategy assessment and determine whether the implemented strategy, resulting in hospital X's surgery schedule is efficient or not, is addressed in the following action problem:

"The hospital institution is not aware of the OR scheduling performance of the planning strategy implemented, and is hence, unable to identify inefficiencies as well as opportunities for improvement."

The operating room planning strategy used by Hospital X, might have potential issues and inefficiencies enhancing uncertainty effects in the OR. However, the identification and realization of the specific roots of these inefficiencies as well as their influence on the overall OR performance cannot be clearly identified. The lack of OR performance monitoring and therefore assessment framework development by the hospital, makes the planning strategy's efficiency evaluation impossible. As a result, the action problem was established to address this gap and raise awareness on comprehensively assessing the current planning strategy used, analyzing available data, and identifying critical elements that may be preventing scheduling efficiency.

1.4 PROBLEM CLUSTER- CORE PROBLEM

Following the explanation of the research motivation and the action problem, this chapter gives insights into the causes and impacts of the problem identified. The Problem cluster below, in Figure 1, identifies the core problem this research will focus on.

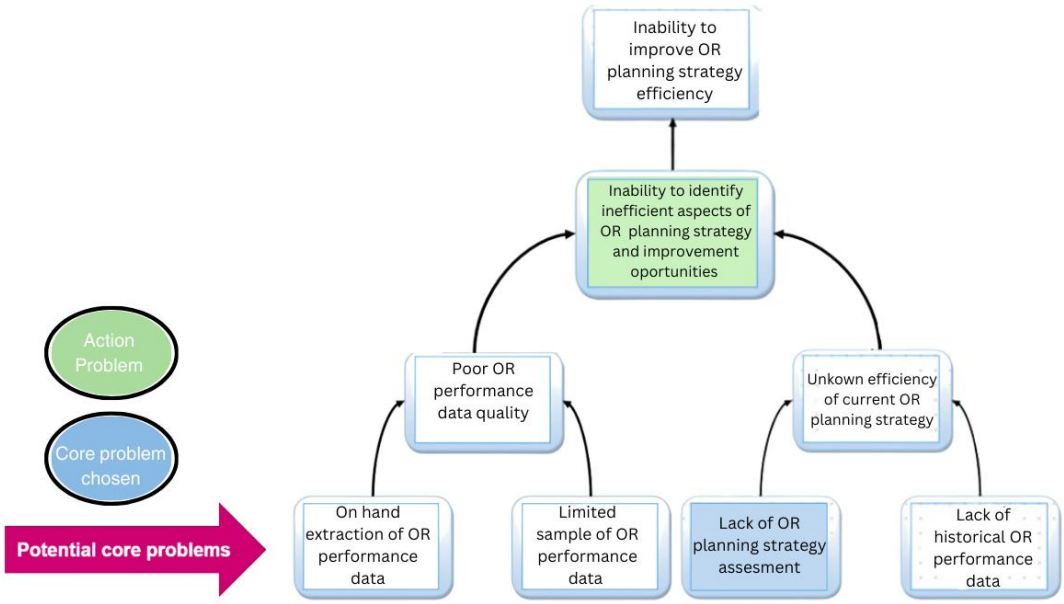

Figure 1: Problem Cluster

Highlighting the inability to quantifying inefficiencies on the current OR planning strategy used by the hospital as well as pinpointing potential ways to improve, the problem cluster helps the visualization of the potential core problems, the core problem chosen as well as the action problem of this research as discussed in section 1.3. Setting the core problem as lack of OR planning strategy assessment in the hospital, this research will concentrate on generating knowledge about why scheduling assessment is essential for the performance of a hospital's OR.

Looking into the representation of the current situation on the Problem Cluster, multiple factors, preventing the identification of inefficient aspects as well as improvement opportunities of the OR planning strategy, can be shown. For instance, on-hand extraction of data, limited sample of OR performance data, lack of OR planning strategy assessment and lack of historical OR performance data, all play a crucial role in triggering the action problem. However, the lack of OR planning strategy assessment was chosen as the most important and influential problem. Moreover, the OR performance data used on this paper, is extracted on-hand from an IT software system, which is used by the hospital for patient management. As a result, the sample size as well as the quality of the data is limited.

Furthermore, even though it is known that operating rooms face a lot of uncertainty, due to the multiple stakeholders involved throughout their operations, factors increasing uncertainty impact in the hospital's OR, can be identified, and addressed, given a proper assessment of the planning strategy. In conclusion, the efficiency improvement of the OR planning strategy implemented by Hospital X, can become possible, with identification of inefficient aspects of the planning.

1.5 RESEARCH DESIGN

In this chapter, the main research question, related sub-questions as well as the activities that must be caried out to answer the main research question, will be analyzed. It is essential to identify the important knowledge gaps that must be dealt with, for the proper conduction of this research. In sub-section 1.5.2, research questions that will help with the solution of the main research question and their research design, will be analysed.

1.5.1 Main research question

From the problem description, problem-cluster as well as core problem described, the following main research question was identified:

How can Hospital X's operating room scheduling efficiency be assessed?

1.5.2 SUB RESEARCH QUESTIONS/DESIGN

To help with the solution of the research question, sub-questions were generated, to enrich, and support the research. The problem can be explored with more precision, by dividing the main research question into multiple, closely related secondary ones.

Sub Questions:

1. What are the most important key performance indicators that should be taken into account by a hospital, in order to minimize uncertainty and arrange OR scheduling efficiently?

Understanding the key factors considered by a hospital when organizing operating room scheduling is especially important for tackling the main research question of "assessing Hospital X's OR scheduling efficiency". Moreover, by investigating these factors, significant insights into the complexity of OR scheduling and most important factors considered, will be generated. This sub-research question dives into the main factors that influence the OR scheduling process of a hospital, providing a thorough review of the most important and common metrics considered in OR planning strategy, in order to make the final schedule. Using the generated information, potential variables that could be analysed to indicate OR performance and realize the efficiency of the hospitals OR planning strategy, using the operational data provided by the company will be identified.

2. How should stochastic parameters in the operating rooms be represented in the scheduling?

Since the operating room performance of hospitals is influenced by stochasticity, generating knowledge about the representation of such parameters in the OR planning strategy is crucial for assessing Hospital X's scheduling efficiency. This information can allow and assist hospital X with the accurate implementation of stochastic parameters in OR planning strategy, leading to the ability of improving the OR scheduling efficiency. Moreover, this sub research question will also help identify and analyse stochastic factors included in the OR, along with the consequences their representation on the planning strategy has. Finally, the implications that come with the lack of representation of stochastic parameters in the OR schedule will be highlighted.

3. What is the relationship between planned surgery time and actual surgery time in OR?

The relationship between planned vs actual surgery time in operating rooms, can determine the deviation between the planned schedule finalization and the actual execution of it. Getting insights into the difference between planed and actual surgery time as well as the meaning behind this

deviation, this sub-question will highlight the importance of this relationship in operating rooms and help understand what a standard relationship of an efficient OR schedule should look like.

4. What are some implications of potential mismatches in OR scheduling? How could those be prevented?

This question is focused on generating information around the most common and potentially disturbing implications of operating room scheduling in hospitals. Moreover, this knowledge can help with understanding the impact of potential mismatches of OR scheduling on the implemented planning strategy's efficiency and therefore the overall OR performance. In that way, the consequences of common implications in OR will be highlighted and brought to light. Hospital X can therefore realize the importance of identifying factors influencing the execution of operating room scheduling and how addressing such factors in OR planning can influence the impact of uncertainty in OR.

5. How can performance be measured in OR? What performance metrics benchmarks can be found around the industry?

This sub-research question can help determine how the performance of OR is measured. Benchmark of OR performance metrics that can help with the comparison and therefore evaluation of OR performance, can be discovered, to address the efficiency and impact the planning method implemented has on the overall OR performance.

Theoretical Framework Research Design

In the following research design, based on the theoretical framework the sub-research questions aim to generate, knowledge will be gained in order to assist in the thorough assessment of the hospital's operating room planning strategy efficiency. Moreover, through the sub-research questions identified, the research design of the theoretical framework, focuses into identifying and highlighting the importance of reflecting the stochasticity of key factors into hospital operating rooms. To start, general knowledge about OR and their assessment will be gained. Moreover, the most common KPIs and their stochasticity representation into OR planning will be discovered. For instance, this design will establish a foundation for determining the most crucial factors for consideration in OR planning. The continuous improvement to achieve scheduling efficiency, will be ensured using this foundation.

The method used by the hospital to make the OR plan, including all variables, stakeholders and equipment taken into account will be further analysed and understood. Moreover, using all the previously discussed information as well as knowledge which will be generated, the current situation of the hospital's planning strategy will be compared to the benchmarks identified around the healthcare industry. This assessment will as a result allow this research to recommend certain actions based on the analysis and comparison done, to the company, which could improve OR planning strategy efficiency if implemented. In conclusion this research design of the theoretical framework was developed to help answer the main research question, through smaller closely related ones, by explaining their use and activities included for the generation of reliable and valuable for the company outcomes.

1.5.3 RESEARCH SCOPE

This sub-chapter analyses the scope and addresses any limitations or boundaries for the conduction of this research.

Operating room operations is one of the main reasons Hospital X is known for. However, due to the lack of assessment of the current planning strategy implemented, the quality of the data extracted from the company's operation system regarding operations activity information, is not ensured. This dataset extracted on-hand for a period of 1 month and is only used for the conduction of this research. Moreover, the data provided have reduced reliability, due to missing values of patient arrivals as well as operation activity start and end times. This fact has an impact on the analysis of the current OR planning method's efficiency. Considering the inadequate quality of the available dataset about certain variables and demographics of operations throughout the hospital, the conclusion's reliability cannot be ensured.

As standardized values for efficient metrics of the key performance indicators identified, do not exist for all KPI's, certain assumptions regarding efficient values were made. Even though making assumptions of performance metrics benchmark values, can decrease reliability of the analysis, a more specialized comparison based on the hospital's context was made. For example, instead of considering unestablished benchmarks achieved by efficient operating room hospitals in the industry, which can be misleading, objectives and restrictions of the planning strategy, were used to develop reasonable benchmark values or range, were none was found. As a result, the generalizability of the analysis is decreased, following the identification of a more targeted benchmark comparison values.

Having in mind that an assessment about a specific hospital's operating room planning strategy implemented will be conducted, the generalizability of the outcomes of this research is limited. Because this assessment is focused on the efficiency of the OR planning strategy of Hospital X, including the planning strategy implemented, stakeholders involved, and process used to finalize the schedule, the recommendations and conclusions of this research are specialized in Hospital X's situation and have therefore limited generalizability. However, the procedure, knowledge and insights generated throughout the analysis of the hospital's situation can be generalized as an integrated theoretical framework about operating room planning strategy and implications formed around it.

Considering the limitations discussed, the validity and reliability of the research is influenced. The credibility of the research is restricted by the inadequate quality and availability of data recorded by the company discussed, resulting in incomplete and illogical monitored patient activity times. Although, the limitations discussed can affect the reliability and validity of my research findings, they can also promote improvement, increasing awareness around data quality as well as reliability, since this is not an uncommon problem in the healthcare industry generally.

This research assesses the efficiency of the operating room schedule implemented by Hospital X, generates knowledge and insights regarding operating room planning, analyses the OR performance the planning strategy implemented results to and provides institutional recommendations for the improvement of its efficiency. By understanding the impact that lack of planning assessment can have on the overall performance of operating rooms, this research aims to raise awareness in the industry and promote efficient operating room allocation and planning. Moreover, through the literature review a framework of the most crucial factors, key performance indicators and implications that should be taken into account when deciding on the OR planning strategy for operating room activities will be gained. After analysing the current planning strategy hospital X implemented, the literature review will be used to assess OR performance of the hospital and make conclusions. This includes, identifying factors in the schedule conduction that suggest inefficiency, realizing potential KPI's not

considered. Finally, based on the comparison done, certain actions or strategy improvements will be recommended to the company, to utilize OR more efficiently.

2. CONTEXT ANALYSIS

A context analysis will be performed to provide valuable insights with regards to the planning strategy and finalization of schedule for hospital X. Moreover, getting insights into the stakeholders involved, stakeholders responsible for the formulation of it and description of the planning approach used, will help assess its efficiency and identify points of weaknesses and strengths in the schedule. then the literature review of chapter 3 and the study results of chapter 5, inefficient aspects of the planning strategy and recommendations for improvement will then be given to the hospital to guide the adjustment or change of the schedule and increase planning as well as overall OR efficiency.

2.1 HOSPITAL X PLANNING STRATEGY AND SCHEDULE FINALIZATION

In this section, the stakeholders involved in the planning strategy, their role in the operating rooms as well as the analysed process of the schedule formulization and execution of Hospital X, is described.

2.1.1 Stakeholders involved in the process.

The operating room planning process of the hospital, involves multiple stakeholders that all play a crucial role in the final efficiency of the resulted schedule and therefore the performance of the hospital's OR. More specifically, four different main stakeholders participate in the process. The anaesthesia department, nursing department, surgeon department and the operating room coordinating team. As described by the operating room coordinator, the person responsible for approving and finalizing the OR schedule of the hospital, all departments involved in the operating room processes, consist of a head physician (OA), responsible for the planning estimations of his/her specialty. Moreover, the head physician of each department is required to input the estimated values for scheduled operations in an IT system used by the hospital, where the operating rooms schedule is finally integrated and finalized.

2.1.2 Stakeholders responsible for schedule finalization

The coordinator of the operating rooms of the hospital, together with his team, inspect the values estimated by the head physicians for each department. The operating rooms are therefore allocated based on the scheduled operations and available OR rooms. However, not all operating rooms are suitable for all types of operations. For instance, a urologic type of surgery can only be performed in the Urology specialty rooms, where the required equipment and resources are available. Additionally, certain types of operations might require radiation protection or specified conditions that can only be met in specific specialized operating rooms. Having all these details in mind, the operating room coordinator should review the entries of the head physicians of all departments in the IT software system, allocate operating rooms according to the planned operations and finalize the schedule for all departments as well as operating rooms.

2.1.3 Operating Room planning strategy used.

After describing the stakeholders as well as the main coordinator, involved in the planning strategy of the operating rooms of the hospital, the actual process from the start of estimations to finalization of

the schedule will be described. The finalization of the schedule is done in an IT software used around the industry for conducting OR planning and an 8 hour OR available time daily is considered.

The planning strategy used by the hospital, is based mainly on estimations of professionals regarding the average duration needed for a specific activity to be completed, based on their experience. Every day, the availability of intensive care beds is checked. Operations that require intensive care, are cancelled for the day, in the instances where no intensive care beds are available in the hospital.

When it comes to emergency patients, the hospital is integrating cases into the OR schedule generated, according to the urgency of the situation. For instance, a life-threatening emergency case, will be scheduled in the next available operating room. However, in the case of urgent but not life-threatening emergency health conditions, an operation is planned later that day in the next available timeslot. On the other hand, less dangerous emergency situations are scheduled for operation as soon as possible without affecting the schedule, after the completion of the daily planned operations.

Operating room schedule in hospital X, can be generated for daily or weekly periods. All three groups of professionals involved in the process put together daily and weekly plans. However, all head physicians are required to submit the surgery schedule as well as estimations of operation durations of the next day, in the IT software system, before 1:00 PM of the previous day of the surgery. This restriction assures there is enough time available for the coordinator to integrate all surgery schedules for each operating room and allocate the available rooms accordingly. In that way, early cancellations of patients can be replaced, and delays are prevented. Moreover, after 1:00 PM of the previous day of a certain operation, the schedule is locked in the system and becomes non-editable for head physicians and only the coordinator can make changes. However, serious operations that require extra specified resources and capacity, are scheduled, and registered in the system in advance. Finally, after the schedule is locked and all operations and activities of the upcoming day are transferred in the software system, the OR coordinator, and the management team of the hospital, finalize the schedule. They are responsible for allocating the operating rooms available to a respective specialty, for the estimated period needed for all activities included in a given operation. In addition, patients that have undergone the same type of surgery multiple times, or experience critical health conditions, are accounted and given an extra available time in the planning, for unexpected outcomes to be considered and delt with.

The allocation of staff in the hospital is also distributed among different stakeholders. Anaesthesia nurses determine the number of staff needed for the anaesthesia department for a given day. Moreover, the nursing staff needed is decided by the OR management team. The OR management team of the OR coordinator is also responsible for inspecting the proper function of technological medical devices available in the hospital, such as X-ray machines and laparoscopic towers as well as providing feedback to the coordinator, for the implementation of changes to prevent implications.

The flow diagram in Figure 2. was made to help visualize the planning strategy implemented by the Hospital X.

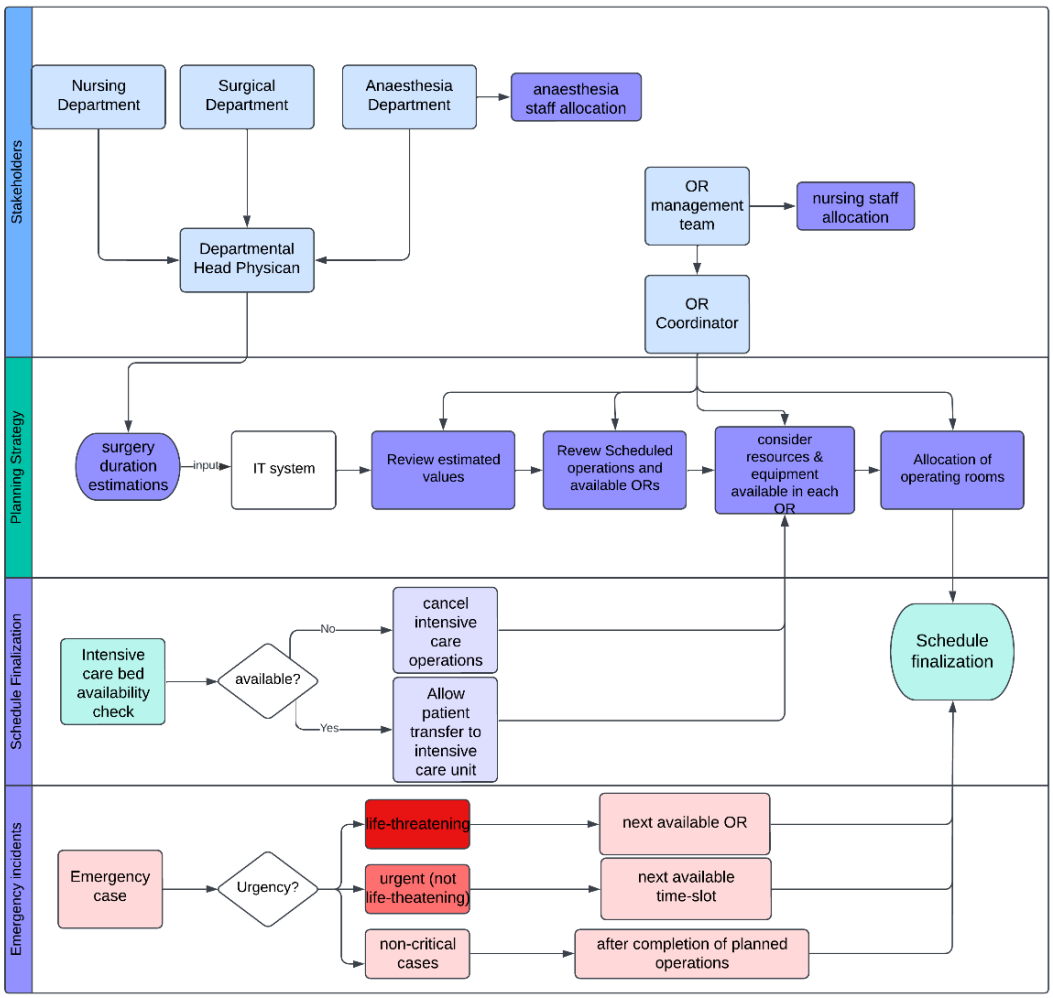

Figure 2: Hospital X OR planning strategy Flow diagram.

3. OPERATING ROOM PLANNING IN HEALTHCARE

This chapter focuses on the analysis of operating rooms and more specifically their utilization planning. Through this literature review, the sub-research questions including, the importance of OR planning assessment as well as the identification of key performance indicators (KPI's) and implications as well as benchmarks found in operating room scheduling, will be investigated.

3.1 OR PLANNING

For large hospital institutions, operating rooms are the main source of revenue as well as costs (Gaon et al., 2023). More specifically, around 40% of hospital expenses are based on operating rooms and their workflow (Schoenfelder et al., 2021). Operating room scheduling is critical for hospitals in order to efficiently utilize resources and increase revenue while maintaining high patient satisfaction and reducing costs (Cardoen et al., 2010).

OR planning consists of multiple aspects. The main aspects included are, patient preparation, operational planning, scheduling as well as communication and coordination of departments. For instance, patient preparation, refers to the preoperative medical checks and all activities included in the preparation of patients to undergo surgery (Krupka & Sandberg, 2006). Operational planning, is associated with resource allocation, including staff level planning and equipment as well as supply utilization (Marjamaa et al., 2008). The scheduling aspect of OR planning, involves the prediction of surgery durations, and therefore the allocation of timeslots for different operating specialties in operating rooms (Rothstein & Raval, 2018). Last but not least, communication and collaboration are both associated with the relationship and coordination of all staff as well as specialties involved and performing in operating rooms (Sandbaek et al., 2010).

Efficient operating room planning and scheduling allows hospitals to facilitate operations while reducing operational defects and improve overall patient care quality. JV Divatia & Ranganathan (2015) said that the efficiency of OR utilization, is determined by "event scheduling", "staff allocation", "available equipment", "time required for anaesthetic preparation and induction", "surgery performance", "anaesthesia recovery", "OR preparation for the next patient" and other resources. The lack of standard definitions for various OR planning strategies, inconsistencies in methods used for calculating utilization across studies, the lack of validation of these metrics as performance indicators, as well as the inability to generalize results from one institution to another, has made it is difficult to establish common criteria for all ORs in the industry. These factors, differ significantly according to the number of patients, hospital type, surgery type, and anesthesia (JV Divatia & Ranganathan, 2015).

Inefficient OR planning, can lead to operational cancellations and higher patient waiting times. An efficient operating room generates a high surgical turnover, along with fewer postoperative challenges, improved patient-centred outcomes, and higher patient satisfaction (JV Divatia & Ranganathan, 2015). Addressing uncertain factors in the implementation of the planning is therefore important. Such variables include unpredictability in patient attendance, non-elective patient scheduling, as well as integrating facilities outside of the operating room in the planning (Cardoen et al., 2010).

Van Ackere (1994) addressed scheduling as multi-person issue. The alignment of the schedule with respect to the objectives is by itself not sufficient for achieving an efficient planning process. The stakeholders involved need to pay close attention and precisely follow the schedule in order for its proper execution. Failing to comply with the schedule, increases inefficiency as well as uncertainty effects on operating rooms, leading to limited overall performance, regardless the optimality of the schedule. Finally, an optimal operating room schedule does not refer to a perfect planned and executed schedule (Van Ackere, 1994). However, an optimal OR schedule, considers trade-offs

between certain criteria, focuses on the personalized situation of a hospital and objectives formed to improve performance and limit uncertainty effects. More specifically, Van Ackee (1994) claims that "an optimal schedule, is denoted as the schedule that optimizes the scheduler's objective".

3.1.1 Diverse Perspectives on Efficiency in OR planning

When evaluating efficiency in operating room planning, different targeted strategies have been developed, on different areas of OR performance optimization (Schouten et al., 2023). These strategies, demonstrate a specific unique definition of efficiency and focus of OR optimization for different institutions.

The research study by Bellini et al. (2019), emphasized the use of accurate scheduling and utilization of resources to eliminate waste. Bellini et al. underlined the importance of Machine Learning (ML) in improving the OR scheduling accuracy and resource allocation. He revealed that ML can precisely estimate surgical case durations, allowing for greater scheduling accuracy and less resource waste. For example, Bellini found that, ML systems such as Random Forest is able to recognize surgeries with a high cancellation probability, allowing for preventive interventions to reduce cancellations. While this method maximizes OR use with the accurate estimation of case durations and therefore planned schedule execution, it also has a significant financial effect by eliminating inefficiencies and improving overall OR performance (Bellini et al., 2019).

Sandbaek et al. (2014) aims to increase throughput and utilization while reducing overtime and waiting times, without the need of extra resources. He emphasizes increasing operating room efficiency with an alternative resource allocation approach. This is achieved by categorizing patient urgency and implementing an OR reservation system. Switching from a mixed to a dedicated resource model (considering both emergency and regular patients when determining capacity and allocating patients to ORs), they increased throughput as well as OR utilization while decreasing overtime and waiting times. This study was carried out at a tertiary referral hospital and revealed significant benefits from scheduling elective surgery during the day and efficiently implementing non-elective cases. More specifically, reduced cancellations, resulting in higher resource use without extra expenses, was noticed.

Furthermore, efficiency is also measured using metrics like procedural fees, utilization times, and turnover times. Tanaka et al. (2012) developed metrics for OR planning strategy efficiency that take into account variations in hospital size and staff, which makes them acceptable for cross-institutional comparison. Using administrative data from 224 Japanese hospitals, they ran several regression models to generate predicted values for indicators including the number of operations, operational fees, total utilization time as well as the overall cost per OR per month. Moreover, these adjusted indicators were proven to help uncover inefficiencies more accurately than unadjusted measurements. Through this study, improved and continuous high-quality healthcare systems are promoted with the use of the suggested indicators (Tanaka et al., 2012).

Rothstein & Raval (2018) underline the importance of implementing Lean and Six Sigma methods to improve OR efficiency. They concentrate on process mapping and extensive analysis of each stage of the patient preparation journey, from pre-operative activities to post-operative discharge. Off-hours surgery, same-day cancellation rates, first-case start-time accuracy, OR utilization and unscheduled delays, case duration accuracy, turnover time as well as the excess staffing costs are the key metrics examined. These metrics were obtained through tracking frequency, identifying causes of cancelations, and categorizing them, comparing scheduled with actual operation durations, calculating utilization rates and comparing chosen staff member levels to the actual usage. These indicators, through this research, were proven to assist in identifying inefficiencies and optimizing OR operations,

resulting in reduced expenses, greater patient safety, and increased satisfaction for both patients and staff (Rothstein & Raval, 2018).

Summarizing, there are different opinions on how to balance cost-effectiveness with patient safety and quality of care, depending on the optimization aspect of the planning strategy chosen, as discussed. As a result, quantifying efficiency for research purposes is critical for accurately evaluating OR performance. The various efficiency perspectives and focuses highlight the need for a thorough understanding of efficiency indicators adapted to the objectives of the research/assessment.

3.2 OR PLANNING ASSESSMENT

According to Krupka & Sandberg (2006) operating room management departments' main goal is to eliminate wasted time so that more operations can be completed within regular business hours and staff and patients have a better experience. In that way, the overall OR performance of the hospital improves.

Schouten et al. (2023) emphasize the importance and dependency of OR planning assessment on hospital operating room performance. More specifically, the significance of a systematic approach to connect different metrics across all aspects of OR performance is underlined. Monitoring indicators focuses in understanding how various components are related to and influence the overall OR performance, ensuring that assessment and optimization efforts are both effective and accurate.
As a result, monitoring OR performance, is essential for a hospital's implemented planning strategy assessment. Helpful for finding inefficiencies and opportunities for improvement, the continuous assessment of OR performance and therefore OR planning strategy assessment, is crucial for adjusting and improving OR planning strategies implemented, based on the hospital's goals. Moreover, operational data make the assessment of OR performance possible, by providing insightful data into the execution of the planning strategy and are therefore very important for the assessment of OR planning strategies. However, the lack of adequate assessment of OR performance and therefore OR planning, can result in a variety of problems, such as patient flow limitations, insufficient resource utilization, reduced staff satisfaction, and overall decreased financial performance for the hospital (Şeyda Gür & Eren, 2018).

The evaluation of the efficiency of operating rooms planning, is concerning a lot of institutions in the healthcare industry, as a clear standardized assessment framework has not been established yet, despite the use of multiple methods by different institutions (Neumann et al., 2020).

Preoperative care efficiency, according to Krupka & Sandberg (2006), involves improving patient preparation, such as early medical checks and efficient scheduling, to reduce delays and cancellations. Moreover, it has proven incredibly challenging to increase perioperative efficiency sufficiently enough to consistently increase operations during regular hours (Krupka & Sandberg, 2006). The time that must be saved to achieve such effect is significant, as the majority of surgeries can only save just a few minutes per case. On the other hand, research has challenged the fundamental norms for turning over operating rooms. By significantly lowering nonproductive time while improving operating room efficiency, it was shown that the number of surgeries on a given day, could be increased (Krupka & Sandberg, 2006).
As stated by Rothstein & Raval (2018), operational efficiency is assessed using a detailed data analysis. Key performance indicators, such as the number of operations performed per OR per month, total OR utilization time as well as operational costs per OR, help evaluate the productivity and financial performance of OR. These measurements assist hospitals in detecting inefficiencies and make targeted improvements in the operational aspect of OR. Additionally, scheduling, patient flow, and cooperation between departments are also important elements related to operational efficiency.

The described improvements, however, are not possible without the proper assessment of the operating room planning efficiency, including both assessment of the patient preparation as well as the operational processes involved in ORs.

In conclusion, the assessment of efficiency in operating room planning, can be done in plenty of ways as mentioned in section 3.2. The institutions involved, should make important decisions in terms of what should be considered to measure performance, which aspects of OR planning should be prioritized to assess the efficiency of the planning strategy. Depending on the data availability, data quality, intended insights and the scale of the institution, as well as the assessment's aims, a different approach can be used to track down performance and determine efficiency as implied by the institution.

3.3 KPI'S IN OR PLANNING

A variety of performance indicators have been developed with the pass of the years in the industry to quantify efficiency (Aljaffary et al., 2023). The most common and widely used approach to measure performance developed, is the implementation of a dashboard for a chosen set of performance indicators, for operation monitoring. The results of the monitored metrics can therefore help assess the planning efficiency.

Despite the fact that, dashboards may allow the in-depth understanding of factors influencing efficiency in the OR, the implementation of them require very large volumes of data regarding performance indicators. As the number of performance indicators considered increases, the actions and data required for their proper assessment increases, respectively. This data is usually not easily accessible or even available for healthcare institutions and the proper collection and consideration of them, would describe a very time-consuming process (Ubiali et al., 2021). The combination of multiple performance indicators with the challenging required data collection, make the implementation of a dashboard to monitor operations a long-term process that not every institution is committed to trust and follow in order to assess their OR planning strategy.

Benefits of OR planning as discussed in section 3.1, include an overall increased financial performance for the hospital's OR as well as better customer satisfaction. Considering the number of different approaches used to measure performance in operating rooms, there is no standardized KPI's defined in the industry. However, during multiple assessments throughout the years, some commonly used key performance indicators that contribute to efficient OR planning have been identified (Cardoen et al., 2010, pp. 923-925)

A standardized method including eight performance indicators, was developed by Macario (2006), in order to provide a standardized scoring system method for hospitals to evaluate performance and assess OR efficiency, without the need for collection. The scoring system was developed according to the literature of the study conducted by Macario, and the available data of OR software systems.

Macario emphasizes the significance of the following metrics in monitoring different aspects of OR performance, highlighting the importance of data-driven techniques to identify inefficiencies and make improvements in the OR planning strategy. This method focused on gathering data that are available in the OR data systems, identified through the hundreds of OR management journals published, and do not require any additional data collection. The metrics included were, excess staffing costs, OR start-time lateness per day, case cancellation rate, Post-Anaesthesia Care Unit (PACU) admission delays, contribution margin, turnover times, prediction bias as well as prolonged turnover, the percentage of turnovers over 1 hour long. Moreover, PACU admission delays, refers to the

percentage of workdays with at least one delay in the Post-Anaesthesia Care Unit admission, and turnover times refer to the average setup and cleanup turnover times for all operations. Prediction bias is the bias in the estimation of operation durations every 8h of OR use and OR start-time lateness, is the average lateness of operation start times during a day. The described performance indicators are said to improve operating room efficiency and function as a simple scoring system to assess it (Macario, 2006, pp. 237-239). Scoring from 0-2 for the standardized ranges of the eight performance indicators found, the efficiency of hospital OR planning was determined according to the final score achieved. For instance, poor OR planning strategies were determined to score 0-5 points and efficient ones would score between 13-16 points.

On the other hand, Cardoen et al. also defined eight crucial performance measures that can evaluate OR efficiency, improve it and reduce costs while enhancing patient satisfaction. “Waiting time, throughput, utilization, levelling, makespan, patient deferrals, financial measure and preferences” were the metrics identified and highlighted during the research (Cardoen et al., 2010, p. 923).

Large waiting lists are a common issue in healthcare and surgeons are considered an expensive resource. As a result, reducing the patient waiting times of OR means reducing costs for the hospital which is crucial and essential. The development of models to optimize planning and minimize waiting times, justifies the use of this KPI. Throughput is also connected to patient waiting times as increasing the number of patients treated during a day, reduces waiting times. Moreover, utilization is also a particularly important factor in OR, as the lack of efficient usage can increase operating costs. The preferences, key performance indicator, takes into account the requests of patients and stuff for better care and satisfaction, where financial measures are used to highlight efficient resource allocation in order to improve financial outcomes. Makespan, refers to the time between the entrance of the first patient and the completion of the last patient’s recovery process. This metric’s minimization can balance the schedule execution (Cardoen et al., 2010, p. 923). Finally, levelling involves the OR resource capacity management to prevent overutilization, lower the chances of capacity issues, , caused on by unexpected situations and guarantee smooth flow of operations, for a hospital. Patient deferrals measure the number of cancelations from shortage of resources. Moreover, comparing those values to benchmarks of the industry and the objective of the hospital, inefficiencies of the planning strategy will be addressed. Implementing these KPI’s to the OR planning strategy, the OR schedule efficiency can be improved while lowering costs and improving total resource utilization. Finally, this approach and selection of KPI’s for OR planning assessment proved to help hospital's operating room schedule accuracy and effectiveness.

Moreover, anaesthesia preparation time, was also determined as a crucial metric for operating rooms (Schad et al., 2023). The process of anaesthesia induction is done parallel to the operations scheduled. This preparation period is calculated from the beginning of anesthesia admission, until the point at which the patient is completely unconscious and prepared for surgery. Furthermore, emergence from anesthesia, the process of a patient recovering from anesthesia post-operation is monitored, starting from the end of the operation, and ending when the patient returns to consciousness and is ready to be transferred to recovery (Schad et al., 2023). On this research the values achieved by operating rooms that lack an OR planning strategy assessment on anaesthesia preparation time, was compared to hospitals evaluating the impact of anaesthesia preparation time on the workflow and performance of the OR, to determine efficiency or not. Influencing the waiting times and operation start time of patients, reducing anaesthesia preparation time, will result in a higher number of surgeries completed for a given day (throughput). As a result, efficiently utilizing this performance metric, is crucial to minimize delays and improve overall efficiency in the planning method of a hospital.

In conclusion, the previously mentioned KPI's have been connected with efficiency in operating rooms. However, while these key performance indicators have been proven by Macario (2006), Cardoen et al. (2010), Schad et al. (2023), to be generally beneficial in some hospital operating room context, their consequences are not known for every hospital's specific situation. As a result, when assessing operating rooms planning efficiency, looking for the main factors and decision that influence performance in the hospital's specific context and developing KPI's based on the operational data available as mentioned in section 3.2, is crucial.

3.4 REPRESENTATION OF STOCHASTIC PARAMETERS IN "OR" PLANNING

Operations management techniques have been developed to deal with stochasticity and reduce its impact. Simulation tools like Monte-Carlo and discrete-event simulation are extremely useful for performing scenario analysis and assessing the effects of various scheduling regulations on OR usage and patient flow. On the other hand, stochastic strategies provide a more adaptable and comprehensive analysis of complex, uncertain situations. Stochastic strategies, consequently, result into greater tolerance and efficiency of operating room schedules that directly consider every factor and unpredictability during the planning (Cardoen et al., 2010, pp. 928-929).

The uncertainty of operating rooms and their scheduling is analysed in sections 3.1, 3.2. Incorporating stochastic characteristics into operating room planning is critical for preventing the uncertainty impact that come with surgical procedures. For instance, hospitals can improve the accuracy of their planning approach and minimize the impact of uncertainty by taking into consideration the stochasticity of factors such as, unpredictable patient arrivals and variable procedure durations (Cardoen et al., 2010). Such factors should be considered during the implementation of an operating room planning strategy, in order to reduce uncertainty effects. The lack of reflection of stochastic parameters on planning, however, can lead to a more unpredictable operation room environment, where uncertainty effects are not limited or controlled.

Two of the most common types of uncertainty in operating rooms in the industry are arrival uncertainty and duration uncertainty (Cardoen et al., 2010, p. 928). Arrival uncertainty refers to the unpredictability in patient arrivals, whereas duration uncertainty refers to the variation between planned and actual operation time. The lack of actual stochastic parameter implementation in the industry's operating room planning approaches, makes the resulting schedules challenging to operationalize by OR coordinators, and therefore limits their improvement. The main reason hospital OR managers fail to optimize/operationalize the scheduling process, lies around the high variability of surgery durations (Guerriero & Guido, 2011).

Research in the industry has demonstrated that when encountering and dealing with uncertainty in operating rooms, healthcare institutions assume a specific level of uncertainty (Cardoen et al., 2010, p. 928). For example, researchers typically analyse the available data regarding operating rooms and utilize it as input for estimations, assuming some level of variability. This assumption shifts the focus of the approach to reducing the overall uncertainty of the OR system. However, not investigating the individual unpredictability or describing the relationships of individual uncertainties that form the overall uncertainty, makes this approach unreliable and untrustworthy. As a result, the total uncertainty should be investigated and analysed properly, by taking into account the unpredictability coming from individuals contributing to the system's overall unpredictability. For example, estimating the duration of a certain operation based on a sample of patients undergone the same surgery as well as the average time needed to complete the surgery, should not be the objective and is not taking stochasticity into account. However, hospitals should focus on ensuring the reliability and validity of

the given sample set, in order to prevent misleading information and make relevant and more accurate estimations.

In conclusion, using an operating room planning approach or a planning approach where stochastic characteristics are reflected into the schedule, provides the basis for managing the unpredictability that arises, thus reducing negative effects. As stochasticity is a significant part of operating rooms and can be found in many processes involved, addressing it when forming the schedule should be a priority objective for hospitals. Reflecting stochastic parameters into OR planning can improve planning efficiency, by allowing greater estimation accuracy and reduce consequences.

3.5 RELATIONSHIP OF PLANNED VS ACTUAL SURGERY TIME IN "OR"

Plenty of studies have been conducted on OR efficiency and the way accurate operation scheduling influences OR efficiency (Wang & Dexter, 2022). Hospital operating room utilization can be improved, with a precise planning method. Moreover, accurate operation estimations during the scheduling process are also said to improve the overall efficiency of OR (Riahi et al., 2023).

Usually, operating room schedules in hospitals are said to be based on simple estimation methods, including operation duration predictions. These approaches are described, using the average values of the historical data of certain operations to estimate their duration. Sometimes the schedule is even implemented based only on the surgeon's duration estimations (Riahi et al., 2023, p. 2). Although, such estimation approaches can form an easy and not time-consuming process to develop the OR schedule, taking into account the uncertainty in operation durations, the unreliability of such estimations make the execution of the schedule very challenging.

Three types of models have been discussed by Riahi et al. (2023, p. 2) to deal with operation duration uncertainty. The first type of model estimates the operation procedure duration exclusively, without considering the total operation time, the time between the patient's retrieval and release. However, some limitations can be identified, following those models. For instance, the surgery duration estimation by itself does not consider the total operation duration. Total operation duration includes anaesthesia induction duration as well as patient recovery time. Moreover, such factors are not included in the professional estimations, made by the surgeons, and therefore decrease the reliability of this model category. The second type of models, shift the focus from operation procedure estimations to estimations on just a selected number of subspecialties. In that way, the operating room coordinators are utilizing the rooms and forming the schedule, using a wider range of specialties. While this model's estimation does not prove to produce reliable outcomes, the uncertainty consequences on operating room performance increases. Furthermore, the third category of models uses factors not available before the conduction of the operation to make estimations. For instance, these factors include, the operation order, operation start time as well as the cancelation status of previous surgeries. The effectiveness of this model is also limited with the use of the discussed variables. Even though information about the variables can be found in historical data on the hospital's OR system, the use of them is impossible when making the model, since they are not yet recorded. As a result, this model will not increase the accuracy of duration estimations.

Accurately predicting the duration of a surgical procedure is crucial for keeping an effective and well-executed operating room schedule. There planned and actual operation time has no significant difference and patient waiting times are reduced. A surgeons' estimation of a duration of a certain activity, can be influenced by several factors (Laskin et al., 2013). Moreover, when the number of patients on a given day is not considerable, the operation time can be overestimated by surgeons, while others may underestimate the time needed for extra cases. As a result, the accurate estimation

from surgeons is not always feasible, if the professional has not conducted this type of surgery for a considerable number of times and therefore is unable to produce logical durations. This can also be the case for overly complex operations.

3.6 IMPLICATIONS OF MISMATCHES IN OPERATING ROOM SCHEDULING

In a major hospital, a variety of departments are collaborating in order to schedule operating room procedures, each with unique objectives and restrictions (Gaon et al., 2023). This task as described in the previous sections, includes the distribution of operating rooms and planning of all daily operations in each room. It is obvious, that the resulted schedule has to comply with both the most crucial constraints such as "allocation of anaesthetics" as well as the "soft" ones like "urgency and complexity of operations" (Gaon et al., 2023, p. 1).

Scheduling inaccuracies can have certain consequences that disrupt the schedule implementation and possibly, outcomes for patients (Posnick, 2022, pp. 420-421). According to Posnick (2022), upcoming surgical deadlines require precise scheduling and failing to meet these due dates can lead to operational unpredictability and sometimes "chaos".

Potential mismatches in the OR schedule, can result in low utilization, inefficient resource allocation, therefore affecting the finances of the hospital (Gaon et al., 2023). However, it has been proved that OR planning inefficiency is connected to patient safety and satisfaction as well (Eshghali et al, 2023). Mismatches in OR scheduling can lead to longer waiting times and imply inadequate quality of care of the respective hospital. This can result to patient's increased stress or even lead to influenced operation outcomes (Gaon et al., 2023, pp. 1-3). Together with the high uncertainty that comes with the surgical program on operating rooms, the significant "downstream" of ward beds as well as intensive care resources can also be noticed (Schoenfelder et al., 2021, p. 2).

Patient-oriented factors are closely related to scheduling efficiency as well (Meyers et al., 2024). Patient-centred information, such as insurance type as well as health status and type of anaesthesia are known to have an impact on schedule inefficiencies and therefore cause surgical delays (Meyers et al., 2024, p. 119). Meyers et al., discovered a relationship between the race of a patient and surgical delays, influencing the overall operating room scheduling efficiency and execution. For instance, after analysis it was discovered that African American race as well as people that own a public insurance, increased the odds of having a delay in the schedule, whereas using a cardiovascular instead of general anaesthesia decreases such odds (Meyers et al., 2024, p. 119). Overall, errors or inefficiencies in hospital OR scheduling can have significant repercussions for the hospital's greater efficiency and certain strategies should be implemented to resolve this situation.

As discussed, the most common implications that can come up following an inefficient operating room planning method, are, increasing costs and inefficient utilization of resources. The consequences of such implications result, into higher waiting times, high cancelation rate as well as increased pressure, frustration and anxiety on the patients and staff that can affect operational outcomes (Negash et al., 2022). These types of problems are most commonly said to be affecting small developing countries, where there are no resources available to meet operational needs. However, any country that is experiencing issues with unmet operational needs can also encounter such implications.

Negash et al. (2022), conducted a study to assess operating room utilization in Ethiopia, where no assessment system was developed. This study lasted 3 months and the efficiency of eight different operating rooms, was assessed, using various performance indicators. For instance, surgical cases start and end time, room turnover time as well as operation cancellations and the reason behind them, were used to address the efficiency of those rooms. The study included 933 operations, where 246

were cancelled, resulting in a cancelation rate of 35.8%. The high cancelation rate was caused by limited facilities and resources, unprepared patients and limited operating room time of 7,7 percent, 7,7 percent, and 8,7 percent, respectively. Moreover, the last case completion time was underestimated 20.6% of the times and overestimated 47.9% of those cases. Turnover times were also delayed 34.5% of the time, with 42.7% underutilization and 14.6% overutilization of operating rooms. Finally, the total utilization of the 933-operation sample, spanned between 10% and 175%.

The significant cancellation rate, which was discovered during the assessment of eight operating rooms in Ethiopia, was mainly due to the delayed operation start times. Those delays therefore left limited time for preoperative patient preparation as well as caused additional lateness for the remaining patients of the day (Negash et al., 2022). Moreover, the very wide range of utilization, showed an inconsistent planning method with inaccurate estimations, leading to inefficient resource allocation and limited OR available time. Through this study, the effects of mismatches in operating rooms are highlighted, using a quantitative explanation while at the same time promoting quality improvements in the industry to prevent issues and increase efficiency in OR.

In conclusion, potential implications that can be caused by inefficient planning, both patient and hospital oriented were discussed alongside with their effects. Through the analysis of such consequences, the importance of enhanced patient assessment process flow, sufficient stuffing as well as execution of surgeries on the scheduled time is established. By focusing on eliminating the discussed domains of implications, hospitals can increase efficiency in their OR planning and achieve better overall OR performance and patient satisfaction. The research emphasizes the critical importance of accurate and efficient OR planning, by describing implications of mismatches in OR planning strategy and the impact on the overall OR performance. Furthermore, issues in scheduling, improper use of resources, as well as inefficiencies related to patients can have a negative effect on a hospital's OR performance and patient outcomes. Finally, it is possible to improve OR efficiency, lower expenses, and improve patient satisfaction by addressing such problems with scheduling accuracy as described in section 3.5, efficient resource allocation, and assessment procedures as described in section 3.2.

3.7 BENCHMARK VALUES OF “OR” KPI’S

OR planning benchmarking uses implemented KPI measurements to assess and improve OR performance of a hospital. According to Pedron et al. (2017), using effective benchmarking hospitals can evaluate their performance in comparison to industry norms, pinpoint inefficiencies, and apply targeted adjustments to improve operating room planning efficiency. A study was conducted by Pedron et al. (2017) to examine the effects of benchmarking application on OR efficiency in German hospitals. The study highlighted the significance of these benchmarks in determining the performance of hospitals OR and enhancing indicators such as raw utilization and first-case delay. Staiger et al. (2019) have reported that several studies have developed benchmarks for various KPIs in order to simplify cross-institutional comparisons and pinpoint areas that require improvement. Additionally, Wu et al. (2023) highlighted that benchmarking can be used as an efficient improvement strategy in operating rooms. By identifying and assessing the best performance results achievable, a useful standard for evaluating surgical performance can be used through benchmarking.

Establishing and maintaining benchmark values however is difficult due to the variability of medical facilities, demographics of patients, and operational types (Salluh et al., 2018). The lack of established benchmarks for many KPIs causes variations in measurements and evaluation among studies and organizations. Reliable benchmarking requires extensive and high-quality data, which can be challenging to collect regularly (Ubiali et al., 2021). Hospitals have to adapt benchmarks to their

particular objectives and continuously adjust them based on available operational data in order to continuously assess OR performance and therefore planning strategy efficiency (Neumann et al., 2020).

Raw utilization is considered efficient when between 75% and 85%, indicating efficient OR operating (Moshier, 2019). When it comes to surgery preparation time and waiting times, even though no established benchmark values can be found despite the high volume of operations conducted daily in medical institution operating rooms, average values of different types of operations including variable preparation as well as surgery durations exist. For instance, congenital cardiac surgery preparation times, a surgery that requires skilled experienced professionals and is considered a complicated and time-consuming operation with 239 minutes average operation time range from 38 to 66 minutes, indicating a surgical preparation efficiency standard (Brown et al., 2023). However, surgery preparation and duration differ significantly between complex, long-duration surgeries and less complicated, short-duration procedures.

For shorter-duration surgeries, preparation and duration periods are significantly lower. For example, cataract surgery, one of the most common treatments in the EU according to Eurostat (2024), has an average preparation time of 10 to 15 minutes, with the procedure itself lasting 10 to 20 minutes. Carpal tunnel release surgery, which normally takes 10 to 20 minutes to complete, includes short preparation and waiting times (Wood, 2023). Vasectomies, another type of short-duration surgery, often take 20-30 minutes to complete. The preparation time for a vasectomy is normally just a few minutes, reflecting the simplicity of the operation (Weiss & Paarz, 2020).

These shorter duration as well as longer procedures average measurements provide useful benchmarks for preparation and duration times, allowing for the establishment of appropriate lower and upper bounds on surgical efficiency. Considering the variability of benchmark development discussed by Salluh et al. (2018), hospitals can better measure their performance by taking into account complex as well as simple procedures, and establishing standards that reflect a wide range of surgical complexities and durations according to the hospital specializations.
Efficient hospitals aim for high throughput values every day to ensure a simplified OR schedule (Weiss & Paarz, 2020). Additionally, throughput benchmarks can vary depending on the type of procedure. For example, cataract procedures, which are relatively fast operations, can be performed numerous times during the day, resulting in better throughput. Complex surgeries, such as open-heart procedures, demand more time and resources, leading to reduced daily throughput (Schoenfelder et al., 2021). By taking these aspects into account, hospitals may establish a realistic and achievable throughput benchmark that will meet both medical care quality and operational efficiency objectives.

Efficient makespan is an important parameter for achieving OR planning efficiency as discussed in section 3.3. Makespan efficiency is achieved when the time between the first patient's admission and the final patient's discharge is minimized, enhancing the use of ORs and associated medical resources. Huang et al. (2018) discovered that minimizing waiting times and increasing the number of procedures performed every day, results in a more efficient makespan. The relationship of throughput and makespan was found to be proportional by Huang et al. (2018). This suggests that as throughput increases, the makespan of a hospital decreases, assuming optimal scheduling and resource allocation. However, there should be balance among increasing throughput and keeping a reasonable makespan. Overloading the OR schedule might lead to extended makespan and overtime hours, due to possible delays. As a result, hospitals must carefully establish benchmarks for these indicators to ensure they balance one another and contribute to optimal OR performance.

CHEN et al. (2010) provides benchmarks for physician waiting times (PWT), time between a patients arrival and operation start time, based on comprehensive data analysis. The study, examined almost 20,000 medical operations and discovered that an average PWT of 31.6 minutes was possible.

This standard was established through the use of a booking system and variable physician scheduling approach, which significantly reduced wait times. The findings of this large-scale study can provide a standard for establishing realistic and efficient waiting time targets in similar healthcare settings, taking into account the complexity and variety of operations performed in hospitals.

3.8 CONCLUSION

Throughout this literature review the importance of operating room planning is described. The information generated, pinpoints that OR planning strategy efficiency assessment is essential for continuously adapting to the industry requirements and improving overall operating room performance. However, the lack of established definition and the use of multiple ways used to quantify efficiency in OR planning, have made it challenging for every approach to fit in each hospital's context. As a result, based on the personalized situation of the hospital, efficiency and optimization focus of the planning strategy implemented, should be made to assess whether panning strategy is accomplishing the main objective. Moreover, maximizing resource usage, enhancing financial performance, and improving patient outcomes, are aspects associated with efficient OR planning for a hospital. Efficient OR planning considers a variety of criteria, including staff distribution, equipment accessibility as well as availability, and estimation accuracy, in order to reduce inefficiencies. As a result, assessing OR planning using key performance indicators and stochastic factors can help to reduce uncertainty effects while increasing scheduling accuracy. Moreover, monitoring performance and comparing the KPI measurements with respective benchmarks developed or defined according to the benchmark values found and institutional objectives, is very crucial for assessing OR planning strategy efficiency. Additionally, historical data are also very important for assessing efficiency, by comparing the historical performance measurements to the current OR performance, hospitals can determine whether the OR planning strategy implemented accomplished the objective of the hospital and is therefore efficient. With the combination of the multiple aspects of OR planning as well as OR planning assessment discussed throughout chapter 3, hospitals can use this literature as a useful insights on the different definitions of efficiency in OR and the variety of ways planning efficiency can be quantified and assessed in hospital operating rooms.

4. STUDY METHODOLOGY

Throughout this chapter, the methodology of solving the main research question will be described.

A methodological framework, including, the study design of this research, data collection and preparation method, analysis process to help answer the main research question will be described. Using the framework developed, the current operating room schedule process will be analysed, in order assess the efficiency of the OR planning approach, identify opportunities for improvement and produce organizational recommendations.

4.1 STUDY SETTINGS

This section will provide information about the available data and how it is related to the research goal.

4.1.1 Data description

Data Source

This study includes 1 dataset. This dataset consists of monitored data extracted by the hospital's IT operating room system, stored in an excel file. This data was extracted on hand, by the management department of the hospital, there operating steps as well as activities discussed in the data characteristics are monitored. The data was recorded for a period of 29 days in April 2024.

Data Characteristics

The provided dataset includes information about operating room process patient flow. Three different sheets of data are available, respectively, overview of operations, detailed operation data as well as day-by-day breakdown of operations are monitored by the hospitals OR system.

The first set of data summarizes the total number of patients that called for an appointment, arrived and went through anaesthesia as well as the number of operations that started and were completed for a 29-day period for each operating room. For instance Figure 3, shows the information given for twenty operating rooms available in the hospital.

Operating rooms	Number of patients on the counter	Number of patient retrievals (date)	Number of patient arrivals (date)	Number of anaesthesia releases (date)	Number of operations started (date)	Number of operations completed (date)
OR 1	609				521	519
OR 2	371				360	358
OR 3	159	39	78	67	150	148
OR 4	63	16	25	29	57	57
OR 5	95	42	54	57	85	82
OR 6	131	52	73	73	127	125
OR 7	159	14	14	14	158	156
OR 8	166	82	109	82	163	159
OR 9	63	13	24	24	63	62
OR 10	75	54	58	57	72	71
OR 11	129	93	101	95	126	125
OR 12	63	31	52	54	60	59
OR 13	103	43	55	77	101	97
OR 14	171	84	94	92	159	150
OR 15	2				2	2
OR 16	343	1	5	100	306	293
OR 17	64	29	42	43	60	59
OR 18	59	29	37	39	48	47
OR 19	28	12	19	21	28	28
OR 20	58	21	30	35	49	47
(blank)						
Grand Total	**2,912**	**655**	**870**	**959**	**2,696**	**2,645**

Figure 3: Overview of operations.

The detailed operational data worksheet contains information about the operating room, specialty performing the surgery, patient arrival, and anaesthesia release time as well as operation start and end times. This data is also provided for a period of 29 days during April of 2024 and included all operations conducted during that period with the previously mentioned metrics Figure 4.

OP-Date	OR	Specialty	Patient arrival (time)	Release from anesthesia (time)	Start of surgery (time)
4/28/2024	x	x	12:00:00 AM	12:00:00 AM	2:06:50 PM
			1:15:00 PM	1:35:00 PM	1:48:00 PM
			12:00:00 AM	12:00:00 AM	12:00:00 AM
			12:00:00 AM	12:00:00 AM	3:13:00 AM
			12:00:00 AM	12:00:00 AM	12:05:41 PM

OP-Date	OR	Specialty	Operation start (time)	End of surgery (time)
4/28/2024	x	x	2:06:50 PM	3:00:56 PM
			1:48:00 PM	2:56:33 PM
			12:00:00 AM	12:00:00 AM
			12:40:00 PM	12:55:25 PM
			12:05:41 PM	12:50:53 PM

Figure 4: Detailed Operational Data.

The third worksheet of data includes a breakdown of the operations shown in Figure 5**Error! Reference source not found.**, organized daily with additional data about the first operation start time and last operation completion time of a certain day. As shown in Figure 5, the arrival and anaesthesia release as well as surgery start time of patients undergoing the first operation of the given day for different departments and operating rooms is monitored. Additionally, information about the last operation of the day's completion time for different departments and operating rooms is also shown.**Error! Reference source not found.**

	4/22/2024			TTTT		KW 17
OP Room	1st Specialty	Patient Arrival (time)	Anaesthesia Release (time)	start of 1st operation (time)	Last Specialty	Last surgery end (time)
X	X				X	4:03:44 PM
		7:55:00 AM	8:16:00 AM	8:42:00 AM		2:10:00 PM
		7:16:23 AM	8:14:06 AM	8:50:12 AM		2:13:00 PM
		8:22:00 AM	8:40:00 AM	9:06:00 AM		1:42:00 PM
						3:25:00 PM
		7:34:08 AM	8:12:00 AM	8:28:51 AM		1:50:00 PM
		7:15:39 AM	8:15:00 AM	8:26:00 AM		4:18:29 PM
		7:40:00 AM	8:25:00 AM	8:37:27 AM		4:24:50 PM
				8:33:11 AM		2:37:00 PM
				8:46:00 AM		4:02:52 PM
						3:02:54 PM
				8:57:00 AM		
		8:01:00 AM	8:20:00 AM	8:50:48 AM		4:34:17 PM
		8:04:00 AM	8:20:00 AM	8:46:00 AM		3:26:00 PM
		7:27:21 AM	8:05:00 AM	8:34:00 AM		
						2:33:00 PM
				8:15:00 AM		3:40:09 PM
				8:15:59 AM		3:44:04 PM
				8:38:22 AM		1:14:27 PM
				8:26:00 AM		1:40:00 PM
		7:55:00 AM	8:20:00 AM	8:36:23 AM		
		7:30:00 AM	8:12:00 AM	8:28:00 AM		2:46:00 PM

Figure 5: Day-by-day breakdown of operations.

Operational Metrics Analysed

During the integration of the most commonly used key performance indicators of operating room scheduling identified in section 3.3 of the literature review, with the available data set regarding measurements of OR procedures extracted from the hospital's system, a set of variables was chosen to be analysed and calculated in order to assess the efficiency of the current scheduling method. More specifically, patient waiting times, throughput, makespan, utilization, anaesthesia preparation time, average surgery duration, were the chosen KPIs. These metrics were chosen because their calculation was feasible using the available data set, and literature KPI information. The equations used to calculate the KPIs are also shown.

Waiting Time: The time between a patient's arrival and the start of his/her operation.

Waiting Time = $\text{Surgery Start time} - \text{Patient Arrival time}$

Equation 1

Throughput: Number of surgeries performed on a day

Utilization: The percentage of available time of the operating rooms that is used on a given day.

Utilization = $100 * \frac{\text{Total Surgery Duration}}{Total\ OR\ Available\ Time}$

Equation 2

Makespan: Total amount of time to complete all surgeries on a given day.

Makespan = $\text{completion time of last surgery} - \text{start time of first surgery}$

Equation 3

Anaesthesia preparation time: total time between patient's arrival and anaesthesia completion.

Anaesthesia preparation time = $anesthesia\ release\ time - patient\ arrival\ time$

Equation 4

Surgery Duration Time: Amount of time needed to complete a surgery.

Surgery Duration Time = $suregry\ end\ time - surgery\ start\ time$

Equation 5

4.1.2 Data cleaning

Data preparation and cleaning

First and foremost, worksheets available were formatted in excel and every cell had the right format according to its value and meaning. The dataset extracted from Hospital X's operating room IT system, was originally in the German language. As a result, a translation of the headings of each worksheet in English was made for the proper analysis of the data provided. Moreover, the data extracted from the operating room system of the hospital, are extracted on hand and are currently not being used in any way by the OR management team. As a result, missing data and inconsistent values may be noticed throughout the file provided. In order to increase the reliability of the study and produce as accurate results as possible, the data were observed and cleaned, by deleting rows or columns in the worksheets that even though had a heading, were empty and had no values written. Moreover, during observation and cleaning, some misleading and inconsistent information was noticed in the dataset of Figure 4. For instance, in Figure 4 were detailed operational data are shown, missing or invalid datapoints of patient arrival, anaesthesia release and operation start as well as end times were noticed. There were rows including, equal operation starts and completion times, operation start times prior to the release time from anaesthesia of a patient or even operation start times that were before the patient's arrival. Overlapping measurements in operations were assumed as inconsistencies as the completion of a surgery for example is impossible to be before the patient arrived, was released from anaesthesia or started his surgery at the hospital.

There were also significant deviations in Figure 4, between the completion of an activity and the transition of a patient to the next operational activity. For instance, certain rows were a patient arrived at the hospital at 8 pm and didn't get released from anaesthesia before 12 am were observed. Cases were the patient operation started more than 7 hours after the patient's arrival or the surgery completion time was more than 7 hours after the start of the operation were also observed. Additionally, admission or release time of patients in activities during non-operating hours of the hospital, like 3 am were observed as well. Having that in mind, any data points from single operation activities that included extreme deviations (over 8 hours of OR available time daily) and/or missing data were assumed invalid. This entails, that if only one of the variables discussed is considered invalid based on the assumptions made, the valid data points from this operation, will still be used to calculate the rest of the metrics. In that way, while a single operation activity datapoint might be invalid, the rest of the operation's characteristics can still be used to produce reliable results and increase the sample size. For instance, even though the patient arrival and anaesthesia release time of an operation were found inconsistent, the surgery duration for that operation can still be calculated given valid operation start and completion time.

Surgery starts and end times are essential for calculating the OR start time lateness, which is a key metric to determine schedule efficiency, as described in section 3.5. Moreover, patient anaesthesia release time is also crucial for determining the anaesthesia delays that therefore cause OR start times delays and influence the whole schedule execution. All of the factors mentioned are important for the proper analysis and comparison of values calculated to benchmarks in the industry. The specific inconsistent or missing datapoints discussed in the second worksheet, would decrease the reliability of the measurement by including misleading values that would therefore affect the KPI calculations of the analysis. Moreover, missing data points may also prevent the calculation of some KPIs. For instance, as shown in Equation 5 surgery duration time KPI, requires both surgery start and end time to be calculated. As a result, missing data-points of start or finish time in an operation prevent the calculation of surgery duration time and therefore decrease the sample of the study. Taking into account the identified inconsistencies in the available dataset, the data filtering process were data decreasing the reliability of the KPIs chosen calculations will be excluded and valid data will be included in the sample of the analysis, is discussed in the following paragraph.

Data Filtering in Excel/Exclusion criteria

To filter the data provided and ensure reliable analysis for the metrics chosen, simple excel functions and formatting techniques were used to exclude the misleading data points identified. Variables that contribute to the overall flow of operating room schedule, as described in the literature review, if not taken into account when making the schedule, can increase uncertainty and result in negative effects for the operating room performance. Moreover, missing points that prevent the calculation of the chosen metrics for the analysis, were filtered out.

Any data points that prevent or influence the calculation of the KPIs chosen, were excluded from the analysis. For instance, using conditional formatting in excel, missing points in any of the variables monitored in Figure 4, where highlighted red. Furthermore, operational activities that were conducted after the completion time of the last surgery for a given day were also filtered out of the analysis. This was achieved by using the latest surgery completion time for a certain day in Figure 5 and comparing the measurements of patient arrival, anaesthesia release, operation start and completion times of that day in Figure 4. Using the count if function and conditional formatting in excel, measurements after the completion time of the last surgery of a given day were highlighted and filtered out of the analysis. Similarly, patient arrival, anaesthesia release and operation start times of the day-by-day breakdown worksheet in Figure 5, including daily breakdown of operations, that were monitored after the completion of last surgery for a given day were also highlighted and filtered out from the analysis.

Rows including operations with overlapping patient arrival, anaesthesia release, operation start, or completion time were also highlighted red and excluded from the analysis. Considering that an invalid operational activity datapoint might prevent the calculation of some metrics chosen for analysis, but the rest can still be calculated, as mentioned in the beginning of this section, an invalid variable did not make the whole operation invalid. This was achieved by using the equations of the KPI chosen for analysis and conditional formatting the rows were there was any overlapping of the variables used to calculate KPIs, in the detailed operational data worksheet in Figure 4. For example, when operation start time equalled the operation completion time, the surgery duration KPI (Equation 5) of that operation was not measured. However, the patient waiting time (Equation 1) and anaesthesia release time (Equation 4) for that operation were not filtered out, if the monitored variables used to calculate them were not found missing or invalid.

Finally, conditional formatting was also used to identify and highlight operations where the transition times from one activity to another were exceeding the 8 hours of OR time available daily. For example, in the detailed operational data worksheet, if the interval between the patient's arrival time and the patient's anaesthesia release time was exceeding 8 hours, these two activities for that operation was filtered out and the measurement of the KPI associated with those variables was not done. In that way, unreasonable patients' anaesthesia release times of 3 am in the worksheet were not used for the analysis and do not influence the KPI measurements and therefore the reliability of the study.

In conclusion, the highlighted data points, were deleted and the valid operations sample was determined for each worksheet and each KPI. Filtering data in excel, resulted into a different sample of valid operations for each worksheet and some KPIs. In the detailed operational data worksheet, the excel filtering resulted into 252 out of 762 valid operations. Moreover, day-by-day breakdown of operations worksheet, was determined to have 120 valid operations out of the 200 monitored. Overview of operations worksheet was not filtered as it included only general information regarding the number of patients arrived and treated during the 29 day period with no durations of activities included.

Sample Selection

The filtering process ensured the reliability of the data included in the study. As discussed, a big percentage of the datapoints was excluded from 2 of the worksheets. However, during the filtering process, an invalid operational activity datapoint did not make the entire row of operation activities invalid, so that the valid sample size of each KPI chosen was maximized. In worksheet 2 and 3, even though 252 and 120 valid operations were determined after filtering the data from 762 and 200 total operations respectively, the sample size used to calculate each variable was not the same regardless of the worksheet used to calculate it. Certain variables could manage a higher percentage of this sample as mentioned in this section. The sample size for each KPI including the worksheet calculated from is shown in the following table.

KPI	**Worksheet used for calculation**	**Sample size**
Waiting Time	Detailed operational data (2)	252 operations
Throughput	Overview of Operations (1)	29 days
Utilization	Detailed operational data (2)	252 operations
Makespan	Daily breakdown of operations (3)	29 days
Anaesthesia preparation time	Detailed operational data (2)	269 operations
Surgery Duration time	Detailed operational data (2)	533 operations

Table 2: KPI sample size

Waiting time as shown in Equation 1 is calculated by subtracting patient arrival time from surgery start time. Moreover, this information was found in the detailed operational data worksheet as described in section 4.1.1. Moreover, throughput is measured by the total number of operations completed in the operating rooms in the 29 days monitored in the data as shown in Operational data overview worksheet.

As defined in Equation 2Equation 3 utilization is determined by comparing the available time in operating rooms, with the duration of surgery periodically, to determine what percentage of the available time is actually used. Moreover, available time in operating rooms is known through chapter 2 and surgery durations were retrieved from the detailed operational data worksheet shown in Figure 4. Additionally, makespan is calculated using Equation 3. Moreover, information about the first surgery of the day start time as well as last surgery completion time are exclusively shown in day-by-day breakdown of operations worksheet in Figure 5. There, the earliest daily start time of operations for a period of 29 days was available and was subtracted from the latest completion time. As a result, the sample size is 29 for this KPI. Anaesthesia preparation duration is associated with anaesthesia release time and arrival time of a patients as shown in Equation 4. Moreover, this information is found in the detailed operational data worksheet and the sample used to calculate it was 269 operations, as 17 additional valid patient arrival and anaesthesia release time variables were found during filtering for that KPI. Finally, as show in Equation 5, surgery duration estimation is calculated by subtracting the surgery start time, from the surgery completion time of an operation. During the filtering process the 252 operations became 533 valid variable measurements found on the detailed operational data worksheet, used to calculate surgery duration time. 281 added valid measurements of surgery start

and completion times, were found and resulted into an increased sample size for the KPI surgery duration.

Benchmark Definition

Benchmarking in OR is difficult because of the wide range of medical institutions, patient demographics, and types of surgeries. As a discussed in section 3.7, establishing standardized efficient values for several key performance metrics is challenging (Salluh et al., 2018). Reliable benchmarking requires high-quality data, which is sometimes challenging to acquire regularly (Neumann et al., 2020). Moreover, despite these limitations, effective benchmarking is critical for hospitals to assess performance, identify inefficiencies and make improvements (Pedron et al., 2017). Considering the lack of established benchmarks of the KPIs chosen to analyze, benchmarks defined for this study are based on the literature review and align with Hospital X's specific objectives, constraints.

Utilization: According to section 3.7, efficient operating room utilization is in the range of 75-85%, where allocation of resources is balanced (Moshier, 2019). As a result, a utilization benchmark range of 75%-80% will be used on this study to provide a comparison standard.

Average Anaesthesia Preparation Time: Anaesthesia preparation times vary greatly depending on the complexity of the surgery. According to Brown et al. (2023), preparation times for complicated surgeries such as congenital cardiac procedures range from 38 to 66 minutes, whereas smaller operations like cataract removal typically take 10 to 15 minutes (Eurostat, 2024). Given the wide range of preparation durations found and the lack of recognized KPI benchmark, assumptions about the efficient anesthesia preparation time range, including upper and lower bounds, were made. Considering 50.000 patients are being treated annually on the hospital, a wide range of surgery types is being performed. As described in section 1.1, the most fundamental strength of Hospital X is the “conservative and surgical treatment of cardiac disorders”. However, with 20 operating rooms available at the hospital, the performed operations during the 8 hours of OR time available daily, consist of both short duration and long duration types. Taking into account all the previous, an efficient average preparation time of 15 to 40 minutes is assumed, accommodating both simple and difficult procedures.

Average Waiting Time (WT): Determining benchmark values for patient WT is challenging. Chen et al. (2010) reported an achievable average waiting time of 31.6 minutes after analyzing about 20.000 different operations. This benchmark was obtained using a booking system and flexible physician planning, which resulted in much lower waiting times. By taking into account the complexity and variety of operations, the value of 30 minutes benchmark will be used as a realistic and efficient comparison objective for this study.

Makespan: Efficient makespan occurs when the period between the first patient's admission and the last patient's discharge is minimized according to literature. For Hospital X, where operating rooms are accessible for 8 hours each day, an efficient makespan is defined as 8 hours daily. This benchmark guarantees that OR activities are finished within the available timeframe, avoiding overutilization.

Average Surgery Duration: The typical procedure duration varies greatly according to section 3.7. Shorter procedures, such as cataract surgery, last 10 to 20 minutes, whereas more complicated surgeries can take up to 120 minutes (Weiss & Paarz, 2020). A study was conducted to calculate the surgery duration estimations accuracy. During this study, for a period of 4 years, around 98000 operations were analysed to find duration accuracy (Aljaffary et al., 2023). From that it was found that the average operation duration was around 30 minutes. Similarly to anaesthesia preparation time, because of the lack of established benchmarks for this KPI and the wide range of operations performed daily in the 20 operating rooms available, the average surgery duration benchmark for this study will be assumed based on the duration of long and short operations found. Taking the previous into account, the benchmark range for this KPI is assumed to be between 30 and 70 minutes.

Throughput: Efficient hospitals were found to aim for high values of throughput daily. The average surgery duration benchmark value was determined by considering 8 hours of OR time available daily. From the twenty operating rooms available in the system, we can determine the efficient values of throughput that will act as benchmark measures for this study. For 8 hours available, 480 minutes of OR time can be used. Using the surgery duration benchmark range average value of 50 minutes per operation, nine operations a day can be completed. However, considering there will be at least one major operation that requires additional time daily, due to delays or implications, six operation per day are assumed optimal. This assumption makes the benchmark of efficient number of surgeries performed daily to be $6 * 20 = 120$ operations per day.

Assumptions and Simplifications

For the outcome of this study to be as reliable as possible, certain assumptions and simplifications, should be stated to make the analysis clear and reliable. Moreover, given that this study is interested in getting insights into the OR planning strategy efficiency of the hospitals, the demographics of patients as well as the operating room names are assumed to be irrelevant and will not be used or presented in the study for confidential reasons. Moreover, during the extraction of data from the hospitals OR system to excel, some percentage of the values extracted were either missing, inconsistent or illogical. The excel sheet provided including operation data for April 2024, with some data points found to be missing or have illogical values. Those were filtered using excel functions or tools as described, reducing the operation sample of the worksheets.

For the smoothness of this analysis, certain logical assumptions were made to clear unknown aspects of the planning strategy execution that would influence the study results. Moreover, the analysis was done taking into account an 8 hour OR time available daily and 20 operating rooms available. During the data observation process the following was assumed. Any significant time-related deviations of more than 8 hours between successive operations were assumed to be a result of data entry errors and have been removed during data cleaning. For operations that were not excluded because of inconsistencies or missing values, it is assumed that the recorded data is complete and accurate, with no more hidden errors or data errors in these valid entries. Furthermore, it is assumed that the hospital operates on a normal 8-hour OR day, and that any data points recorded after the completion time of the last surgery of the day are due to data entry errors rather than emergency situations, and therefore are excluded.

The data from the OR system of the hospital, include information on 20 different operating rooms. The accurate identification of inefficient or efficient rooms, requires the efficiency assessment of every operating room individually. However, the missing and invalid data points will reduce the sample of each room considerably and lead to unreliable conclusions. Calculating the metrics per OR, will result to a limited number of data points for each room's individual analysis. This fact could cause some small delays or waiting time deviations in operations, to be seen as a patterns or trends, influencing the final KPI measurements as well as the study results. For instance, if a sample of thirty operations for a given operating room, includes an extreme waiting time value, it would significantly influence the final outcome. Whereas in a sample size of 250 operations, such values can be better balanced and show more accurate results. To achieve an adequate sample size, the variables will be averaged over all operating rooms and reported as total average values. Although this strategy may lower the study's reliability, it will help in identifying patterns and pinpointing strengths and weaknesses of the planning strategy more accurately.
Following the previously made assumptions, the determined performance metric benchmarks, were based on benchmark values in the industry and the objectives of the hospital. Where no benchmark values were found, additional assumptions based on the hospitals restrictions and the other benchmarks found, were made to determine the efficient values that were be used to compare current performance and assess the planning strategy efficiency.

5. RESULTS

Throughout this chapter, the results of the study explained in chapter 4, will be described. This chapter will allow the efficiency of the planning method currently used by Hospital X to be assessed. After representing the performance metrics results of the study, conclusions about the OR performance and therefore efficiency of the strategy used will be made.

5.1 DATA ANALYSIS RESULTS

The results of the performance metrics analysed in this study, including standard deviations are shown in table Table 3 and compared to the defined respective benchmarks. Moreover, the deviations between the KPI measurements and the benchmarks defined are visualized and better understood looking at the cluster bar charts of measurements in Figure 6. Box plots of the measurements of the KPIs are shown in appendices B in, Figure 7, Figure 8, Figure 9, Figure 10, Figure 11.

KPI	Average Calculation	Standard Deviation	Benchmark
Total OR Utilization	65.62%	17.49	75-85%
Average Anaesthesia Preparation Time/patient	33.24 minutes	26.58	15-40 minutes
Average Patient WT/patient	92.05 minutes	55.9	30 minutes
Makespan/day	9.71 hours	63.03	8 hours
Surgery Duration Time/patient	47.4 minutes	36.3	30-70 minutes
Throughput/day	91.21 total operations	4.22 per OR	120 operations

Table 3: Data Analysis Results

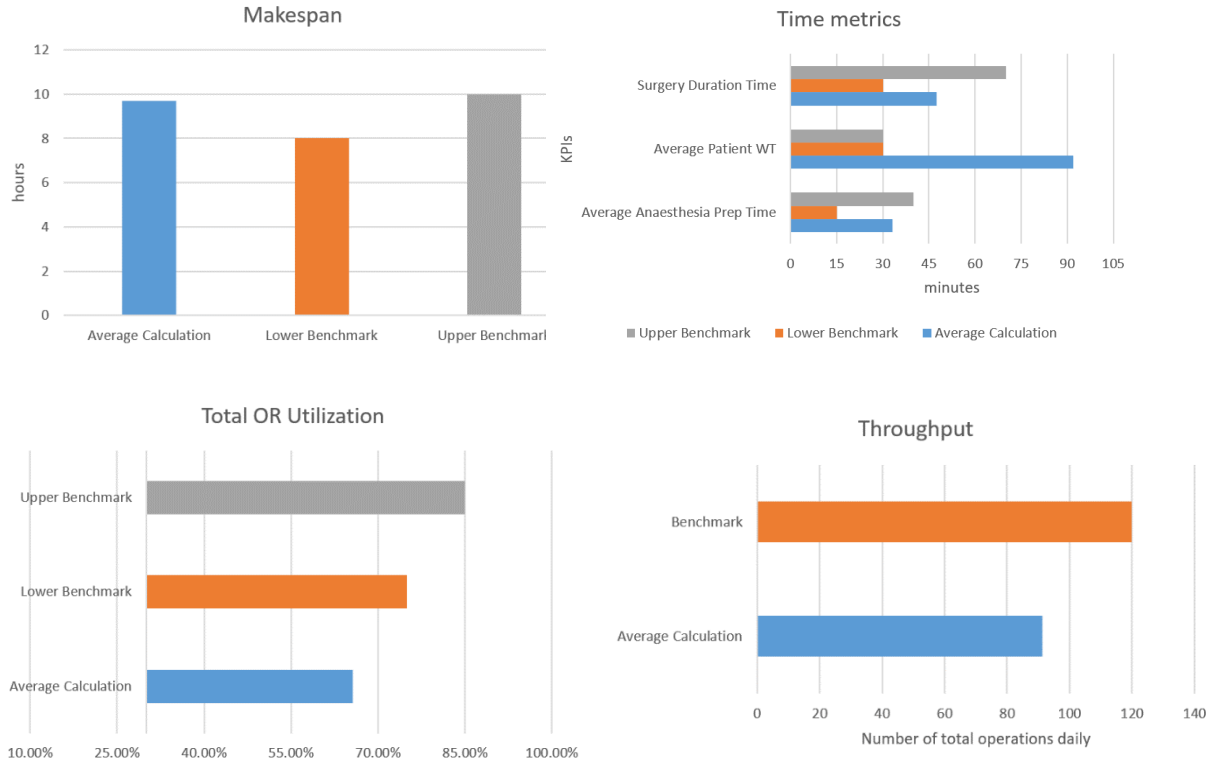

Figure 6: Analysis results Cluster bar chart.

5.2 COMPARISON OF KPI MEASUREMENTS VS BENCHMARKS

Looking at the results of the data analysis of this study, as well as the comparison of them with benchmark values of efficient hospitals found in the industry, shown in section 5.1, remarks and observations can be made about the current OR planning strategy performance of hospital X.

After the comparison of the values achieved during the study conducted, deviations between the benchmark values of the industry and the calculated values were noticed.

The analysis results showed that, despite the considerable throughput of 91 operations per day measured, the utilization of the hospital had a significantly lower than the industry benchmark value. For instance, 65.6% utilization achieved compared to the 75-85% range benchmark, shows that the resources available in the operating rooms of the hospital, are underutilized. The variation noticed, suggest inefficiencies in the distribution of resources, addressed in the substantially high patient waiting times measured. Average waiting time was calculated 92 minutes on average, where the industry benchmark was 30 minutes. High average waiting times, cause operational delays and extension of operating hours in the hospital. As a result, the overall efficiency of the operating room schedule is reduced. The value of 10 hours makespan calculated is reasonable considering the high waiting times of patients that leads to delays as well as cancelations and therefore cause extension of operating room hours needed to complete all surgeries.

On the contrary, operational efficiency, represented by the average surgery duration calculated, complies with the industry norms. The value of 47 minutes achieved is included in the lower bound of the range of 30-70 minutes benchmark per operation determined, indicates that surgeries are completed efficiently in the hospital. The throughput achieved, is also reasonable, given the significant surgery duration achieved and anaesthesia preparation time of 33 minutes, is within the benchmark range of 15-40 minutes. As a result, room for improvement can be identified in the patient flow aspect of the schedule.

In conclusion, the relatively low utilization rate was found to be caused by the long patient waiting time, opposed to operational inefficiencies. Variability in the measurements played a big role in limiting the overall utilization of the hospital's OR. As measurements tend to vary significantly over the 29 day period measured, schedule inconsistency and inaccuracy is evident. As a result, improved patient flow can be achieved by reducing waiting times and making the patient preparation process more consistent and predictable. Achieving the previously mentioned, the overall efficiency in planning strategy of the operating rooms of Hospital X can be improved. In that way, the performance of the operating room metrics analysed will accomplish values within the industry standards.

6. EFFICIENCY ASSESMENT OF THE HOSPITAL'S OR PLANNING STRATEGY

The results of the data analysis, comparison to benchmarks and the planning strategy description in chapter 2 allow this research to evaluate on the efficiency of the planning method used.

The comparison of the KPI analysis with the benchmarks, allowed the identification of factors limiting planning efficiency. Moreover, inefficiencies in the planning strategy used currently by the hospital to schedule operating rooms can be identified and the efficiency of it can be assessed. Moreover, using the context analysis in chapter 2 as well as the analysis results in chapter 5, certain aspects of the strategy that lead to deviations and variability in the metrics measured will be identified.

Hospital X's planning method, while organized and precise, reveals significant inefficiencies that lead to variations in the operating room performance metrics measurements. For instance, it was noticed that scheduling is based only on handwritten estimates of professionals. The head physicians of each department are in charge of submitting the estimated surgery durations of their specialty into the IT software system. The dependency only on human predictions, raises uncertainty and increases the risk of potential mistakes or miscalculations. As estimations do not always indicate the real needed time necessary for surgery, the strategy currently used by the hospital, increases operational delays and difficulties with scheduling execution.

Additional inefficiencies occur in the distribution of staff and nurses. Distributing the responsibilities for staff and resource allocation through different stakeholders, can lead to delays and inefficient communication. The anesthesia nurses as well as the OR coordinating management team for example, arrange and determine the number of staff and equipment needed separately. In that way, after determining the nurses needed for a given day, the OR coordinating team, should also check and approve the required staff set by the nurses. Any complications in these actions, can lead to delays, causing inefficiencies that influence the operating room schedule execution.

Furthermore, the fact that all operation schedules and estimates should be provided by 1:00 PM of the preceding day of the operation, is decreasing planning flexibility for the hospital. Even though, this restriction is set in order to allow enough time for cooperation by the OR coordinator, it implies that modifications or emergencies that occur after this time limit, cannot be easily integrated into the timetable. Therefore, inefficient and cost incurring use of resources may result, from last-minute changes that are challenging to be implemented in the system. This restriction can cause extended use of the OR hours used as well as low utilization, as shown in the performance metrics measured, were increased makespan of 10 hours and utilization of 65% was achieved, with 8 hours available OR time daily.

Moreover, the implemented strategy inefficiencies promote the need for a more adaptable and comprehensive method for operating room scheduling. The use of the current performance analysis, of operations performed daily in the hospital, can help with understanding the inefficiencies and increasing patient satisfaction. In that way, needed time estimations will not only be based on professional experience but also on historical operation data. Finally, improving communication as well as collaboration between departments and lowering the dependance on manual human estimations, can all help reduce inefficiencies and improve overall OR performance. This will allow Hospital X to match its operating room performance with industry benchmarks, while also improving its resource usage and patient flow.

7. KPI RECOMENDATION

On this chapter, after identifying factors limiting OR performance as well as inefficiencies in the current planning strategy implemented, KPIs will be identified for the efficiency improvement of the planning strategy used. Considering the available data, the identified performance limiting as well as strategy inefficiency factors, additional KPI'will be identified, that specialize into providing greater insights and increasing the efficiency of the hospital's implemented planning strategy. All this, based on the challenges found, will be identified using crucial OR performance indicating metrics, described section 3.3 of the literature review. Table 4 shows the additional KPI's suggested based on the planning strategy assessment in chapter 6.

KEY PERFORMANCE INDICATOR	**USAGE**
First Operation Start Time Accuracy	Measures the deviation of planned and actual first operation start time, showing its impact to the rest of the daily schedule
Overtime Hours	Measures the number of additional hours needed to complete operations, determining the extra or reduced hours that suggest over/under-utilization.
Cancelation rate	Measures the rate at which operations are being cancelled, showing the effects if waiting times on the schedule and reflecting planning challenges.
Average Turnover Time	Measures the time taken between the end of a certain operation and the start of the next, influencing utilization and throughput.

Table 4: KPI recommendations.

Four new performance indicators have been identified. More specifically, first operation starts time accuracy, cancellation rate, overtime hours as well as turnover time. These metrics, focus on the identified challenges of the OR planning strategy used by the hospital, and their main goal is to provide greater insights into where exactly the challenges of the strategy implemented are, in order to promote improvement. For instance, because of the high makespan measured in accordance with the 8 hours available of OR time daily, overtime hours KPI has been introduced to track down the extra OR hours needed every day to complete planned operations. This way, overtime hours can be explicitly measured, the cause of variability in makespan can be realized and the accuracy of the planned schedule can be assessed, to identify needed changes or adjustments.

Moreover, cancelation rate is another KPI suggested, in order to monitor the number of cancelled operations daily. This metric will not only help the hospital understand the impact of high waiting times achieved, by getting insights into the influence waiting time and the variability of values achieved has on cancelations, but also identify patient preparation challenges as well as scheduling accuracy. In addition, first operation start time accuracy, is also a KPI added to help understand the reason behind the high waiting times achieved. By acknowledging the delays in the first surgery conducted daily, the hospital coordinating team will be able to identify whether the high waiting time and makespan values are caused and influenced by that fact, thus affecting the whole day's schedule. As a result, the efficiency of the planning strategy can be assessed better, considering the first operation extra information retrieved from the new identified metrics.

The fourth KPI identified to help better assess the efficiency of the operating room planning strategy used, is turnover time. Turnover time monitors the time between the end of certain surgery and the

start of the next one. This information will be very useful for the hospital, as it indicates the time wasted between consecutive operations, providing additional insights into why such significant waiting time value and standard deviation is achieved. As mentioned in the literature review, low turnover times can increase throughput as well as utilization, making this performance metric ideal for the management department of the hospital to understand the challenges experienced using the planning strategy implemented and make adjustments.

The KPI's identified during this section, will be crucial for the hospital to understand where the root of these challenges is, and improve efficiency. However, the calculation of these metrics is nearly impossible, given the data quality and the available data of operational information. The data gathering methods and data quality of the extracted information, would have to improve, in order to provide more insightful, precise and reliable information that is currently not available. According to Ubiali et al. (2021) as the number of performance indicators that monitor the efficiency of the planning strategy used by the hospital increase, the available data and actions required to help professionals generate reasonable and more accurate assessment also increases.

8. CONCLUSIONS

This chapter will conclude the research findings, answer the main research question, and provide organizational recommendations to help the hospital's management team, implement targeted improvements and achieve greater OR planning efficiency. Recommendations for an operating room assessment framework will also be given.

8.1 SUMMARY

This research's focus was to assess the efficiency of the operating room planning strategy of hospital X. This was achieved, by comparing the performance metrics of the planning method used to benchmarks. The analysis and understanding of the six metrics measured in the study, utilization, throughput, makespan, average waiting time, average anaesthesia preparation time and average surgery duration, provided better insights regarding the OR planning strategy efficiency of the hospital and identified aspects in need for improvement. Throughout the literature review, the importance of OR assessment, as well as the need for continuous improvement of OR processes, the most commonly used key performance indicators in the industry and some implications that complicate OR procedures, were identified and discussed. Throughout chapter 6 results of the analysis were shown, and performance inefficiencies were identified by comparing the measurements to benchmarks. Identified strategy inefficiencies that are represented in the values calculated were discussed during the final planning strategy assessment in chapter 6. This assessment, allowed this research to make conclusions about the planning efficiency of hospital X.

Through the data analysis performed during the assessment of the planning strategy, inefficient aspects of the schedule were revealed. For example, even though the surgery duration and throughput measured, were within or close to benchmarks range identified, the significant deviation in waiting time and utilization values achieved pinpointed inefficiencies in the resource allocation and patient flow aspects of the planning. Following these measurements, the operational aspect of the hospital was determined efficient, ranging within or slightly deviating from the benchmarks used. Consequently, while operations are being performed efficiently, the patient preparation procedures in OR show inefficiencies, which result in long waiting times as well as underutilized operating rooms.

In order to address the inefficiencies discovered, additional key performance indicators were identified to help with identifying the specific source that causes such a performance and underutilization. The KPI's identified were, cancellation rate, first operation starts time accuracy, overtime hours and turnover time. Using this metrics, the hospital can comprehend the cause of the problems experienced and address them by making specific improvements for greater planning efficiency.

The research also highlights the need for, and importance of, establishing reliable data gathering methods in order to increase data quality and future assessment accuracy. Reliable and accurate available data is critical for tracking performance indicators and making targeted improvements. Moreover, the existing reliance on handwritten estimations, combined with the restricted flexibility in scheduling operations and the data quality, address the need for improved data handling techniques. Improving data gathering methods will increase the accuracy of the performance metrics measured, therefore OR assessment efficiency, allowing the implementation of an improved planning strategy.

To summarize, although Hospital X revealed operational efficiency in certain areas of the planning, significant adjustments in patient flow and resource allocation aspects are essential to achieve benchmark performance. Hospital X can improve its current OR planning strategy by addressing identified inefficiencies and integrating the recommended KPI's. Doing so will result in greater overall performance, reduced operating costs, and greater patient satisfaction. Finally, improved data quality

and gathering methods are needed for performance measurements of greater accuracy and reliability, ensuring the assessment of the schedule is more precise and OR efficiency continuously increases.

8.2 ASSESSMENT FRAMEWORK RECOMMENDATIONS

From the analysis, findings and conclusion of this research, it can be summarized that a comprehensive framework assessment for operating room planning, is essential to improve scheduling efficiency. The structured framework recommendations made in this section are suggested to the operating room coordinating team to help implement targeted improvements and increase planning efficiency. The suggested actions will allow the hospital to create a planning assessment framework that not only focuses on identifying inefficiencies of the schedule, but also in continuously improving its processes.

Use reliable and established automated data collection methods:

The use of established data collection methods will increase the accuracy and reliability of the available data and therefore performance metrics to be analysed. Implementing automated data gathering methods will allow the hospital to prevent the reliance on on-hand estimations and increase the data quality used to measure performance. This way the data gathering methods implemented, will match the reliable software IT system used to implement and finalize the schedule and therefore data quality will increase. Consequently, the operations performed daily in hospital X, can be reliably monitored, and used to measure performance more accurately.

Implement Suggested Key Performance Indicators:

The identified KPI's in chapter 7, will help the hospital identify specific weakness points throughout the identified areas in need for improvement. Adding cancellation rate, overtime hours, first operation start time accuracy and turnover time, will provide essential insights for inefficient aspects found that will allow the coordinating team of the operating rooms to make targeted improvements and overcome such problems.

Implement prediction using historical data analysis during estimations:

Using historical data to predict the duration of a certain activity involved in the operating rooms, will increase the accuracy of all estimations. The integration of professional estimations based on experience with reliable historical data monitoring information, following the suggested data gathering methods, will increase the efficiency of the schedule. Using the analysis of historical operational data, OR resource allocation of the hospital will become more accurate, reducing delays and waiting times, identifying trends and patterns in the data, all of which can be used to decrease uncertainty and variability in surgery duration estimations.

Improve collaboration between departments:

Improving the collaboration and communication between the different departments operating in the rooms of the hospital, will reduce uncertainty and help the accurate execution of the schedule as discussed in sections 3.1, 3.2. More specifically the collaboration between the coordinating management team, the surgeon, anaesthesia, and nursing department, is essential to ensure similar objectives around all departments. For instance, being responsible for the staff allocation and activity duration estimations, the departments should meet frequently to ensure common objectives and resolve any miscommunication or implications coming up. To this extent, unexpected cancellations can be dealt with more efficiently, following the better collaboration and communication of the responsible departments.

Monitor OR performance regularly:

Implementing typical monitoring deadlines periodically, will allow the performance of the operating room planning strategy used, to be evaluated and continuously improved. Performance monitoring routines allow the identification of challenges present in the planning method as mentioned in literature.

8.3 RESEARCH REFLECTION

This research project has helped significantly in my personal and professional development. After the completion of this research, I am able to conduct research starting from scratch, according to the final objective intended. More specifically, it has helped me improve my skills in data analysis, critical thinking, and problem solving. The experience of working with complicated datasets and producing vital conclusions has enhanced my analytical skills. Furthermore, the challenges encountered and solutions discovered have strengthened my adaptability as a researcher and will help in possible future research projects.

One of the main challenges I experienced during my work, was dealing with the quality and completeness of the data extracted from the hospitals IT software system. Missing data, inconsistent values and illogical data points observed, required complicated screening and validation actions. The variability throughout the data, as well as the employment of different sample sizes for specific KPIs, required careful organization to ensure the analysis's reliability. Moreover, evaluating the analysis results in a way that provided valuable insights while considering the limitations of the data proved to be quite challenging. Balancing the aim of a comprehensive analysis with clear findings needed significant thought before execution.

For instance, in order to identify data limitations and the study's scope, a comprehensive approach was necessary for interpreting the research findings into practical institutional recommendations. An approach were the operational realities, objectives and restrictions of the hospital as well as the literature review generated was taken into account.

Through this process, I realized the significance of accurate and consistent data gathering approaches in research settings. Furthermore, through my work I understood the significance of a systematic approach in data analysis, which includes the use of proper analysis techniques, the need to account for data variability and definition of standardized values for making accurate comparisons as well as conclusions. The difficulty experienced in the interpretation of results of the analysis of my research, emphasized the importance of context analysis for comprehending outcomes. For instance, understanding the hospital's specific operational environment, objectives, restrictions and the complexity of the data was critical for the production of reliable conclusions for my research. It also emphasized the importance of clearly communicating findings to stakeholders who may lack technical expertise. By realizing that an average reader may not be familiar with technical words or knowledge of the specific topic the research is associated with, interpreting the information all over my research to be comprehensible by individuals who may lack a technical expertise helped me better realize the scope and limitations of this thesis. The practical implications experienced during the conduction of my research highlighted that effective research involves more than just theoretical analysis. It also includes practical, real-world solutions that can be established and sustained.

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APPENDICES

A: SCHEDULING TECHNIQUES

The consequences of an inefficient OR schedule discussed, can be resolved using different techniques, depending on the main issue identified by the hospital causing these implications. Furthermore, in order to overcome such issues, solutions need to be developed, optimizing the operating room scheduling process as well as execution.

A strategy that addresses, psychological issues that are directly connected with surgical delays, such as stress before surgery, can be solved using preoperative clinics. Those clinics have been proved efficient by supporting the patient psychologically as well as physically before and after the surgery and could still be used (Meyers et al., 2024, p. 120). Additionally, distributing operating rooms efficiently, implies that all surgical as well as other deadlines have been met. Using surgical deadlines as the main scheduling factor, can improve efficiency in operating rooms (Posnick, 2022, pp. 420-421). By considering the impact deadlines have psychologically on patients, Posnick (2022) believes that surgeons can overcome the stress of conducting an operation and use it as motivation in order to appropriately prepare and improve the clinical outcomes, promoting proactive planning.

To address the realization of how important deadlines and proactive planning are to efficiently schedule operating rooms utilization, an application was developed by Gaon et al. (2023, p. 14) to allocate and schedule OR. This application has implemented models and algorithms to automatically allocate every patient to a ward while ensuring privacy and meeting constraints. The main goal of this application is the optimization of OR utilization as well as minimization of delays in the schedule. This is achieved by identifying the relationships between different departments and meeting all requirements, while leaving room for continuous improvements and changes in OR scheduling (Gaon et al., 2023, pp. 8-15). By promoting the balance between "exploration and solution stability," this application was developed to ensure effective allocation of resources (Gaon et al., 2023, p. 14).

Another strategy suggested for achieving OR scheduling efficiency, is an integrated model considering emergency as well as elective patient planning (Eshghali et al, 2023). It is believed that machine learning approaches can help with accurately estimating arrival time, operations duration as well as the emergency patients in the system. This approach is focused on tackling the uncertainty of emergency and elective patients, by optimizing OR allocation, using a predictive model. The integrated model suggests rescheduling mathematical models on a daily or weekly basis in order to adapt and improve the OR schedule based on the situation experienced. This model's main goal is limiting unpredictability and ensuring the highest possible utilization for the lowest possible cost as well as issues caused. Using machine learning to predict arrival time and operational durations, it ensures the emergency patients retrieval to OR on the specified time. Therefore, operation cancelations that influence patient's anxiety and satisfaction will be prevented.

Last but not least, there was a simulation study done by Schoenfelder et al. (2021, p. 3-10) during an evaluation of operating room management policies, in order to assess the effectiveness of various ones suggested by the OR management. For example, the policy of extended operating hours was evaluated, where the hospital implemented new opening hours until 8 pm for every OR, using them as additional facilities to operate elective surgeries until that time instead

of rescheduling for the following day. The evaluation of this strategy showed an increased amount of semi-urgent patients treated on arrival date, which might cause longer waiting times during the afternoon, but will prevent deferred surgeries for the next day. The second strategy evaluated was, Parallel Induction of Anaesthesia, where the operating room is only occupied for the expected amount of time needed for surgery and patients are given anaesthetics elsewhere. The evaluation of this study showed higher utilization of OR, however a trade-off between higher utilization and reduced planning stability was identified, since the strategy is based on expected durations and uncertainty is normal to exist. Moreover, the third strategy evaluated by Schoenfelder et al., included a variation of the sequencing policies, First in First Out (FIFO), Shortest First (SF) as well as Longer First (LF), where FIFO was found to be the most efficient of the three. Even though SF showed improvements in some performance measures, decreased performance metrics outnumbered them, as a result FIFO is proved to be the most efficient sequencing policy. The last strategy evaluated through this simulation study, was closing the dedicated emergency room, which turned out to not be a beneficial OR scheduling policy, as OR's performance was decreased and the emergency patient waiting time was increased, causing critical conditions to not be taken care of.

In conclusion, numerous possible implications that are connected with mismatches of a hospitals OR schedule were identified. Possible strategies with different focus and various techniques used to resolve such issues as well as their trade-offs, were discussed, allowing the management department of hospitals to implement a respective strategy depending on their current situation and performance measurement focus.

B: KPI BOX PLOTS

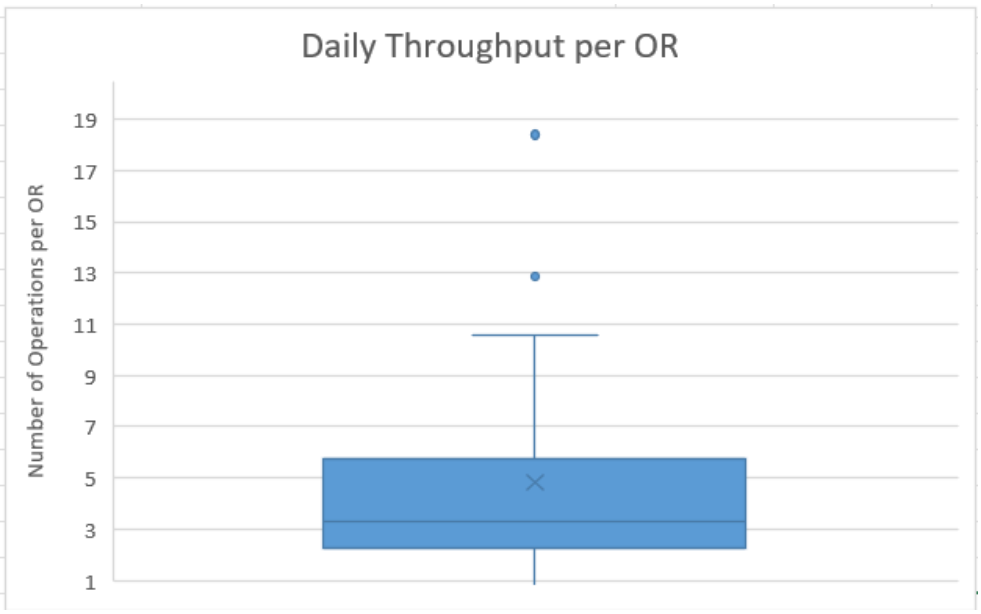

Figure 7: Throughput Box plot.

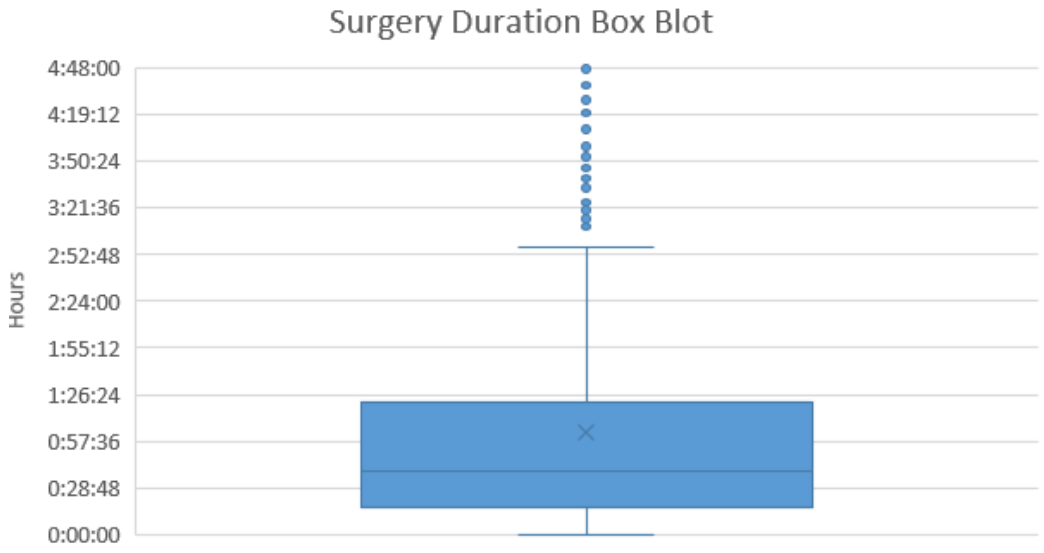

Figure 8: Surgery Duration Box plot.

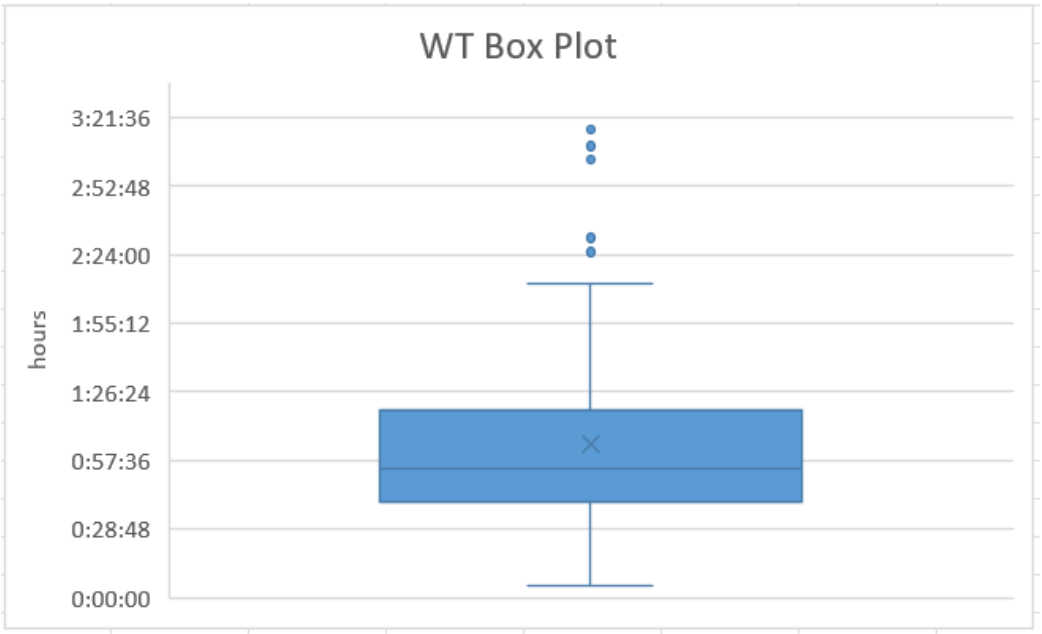

Figure 9: WT Box plot.

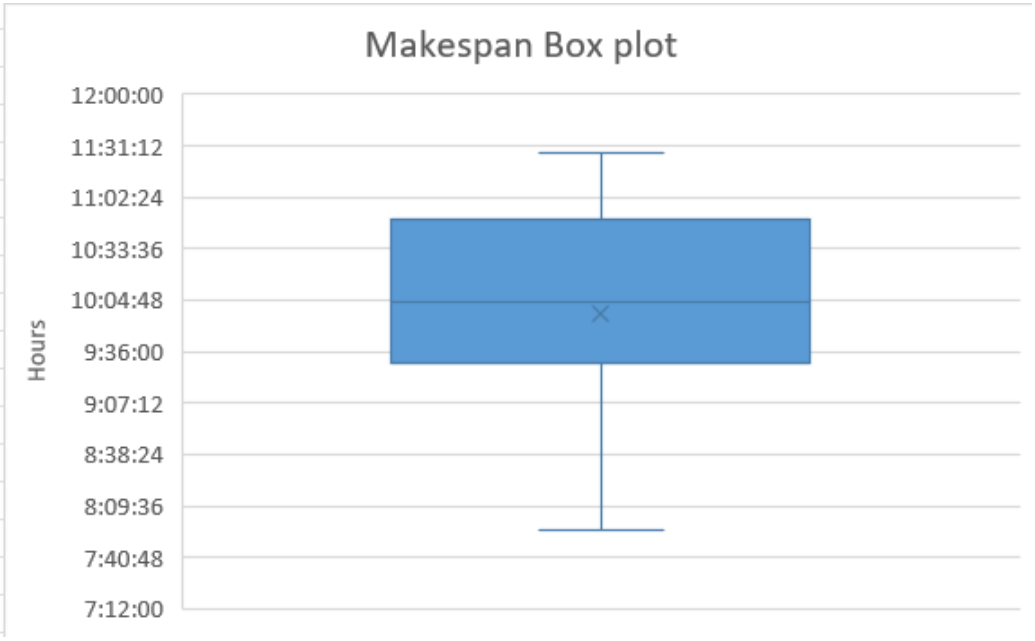

Figure 10: Makespan Box plot.

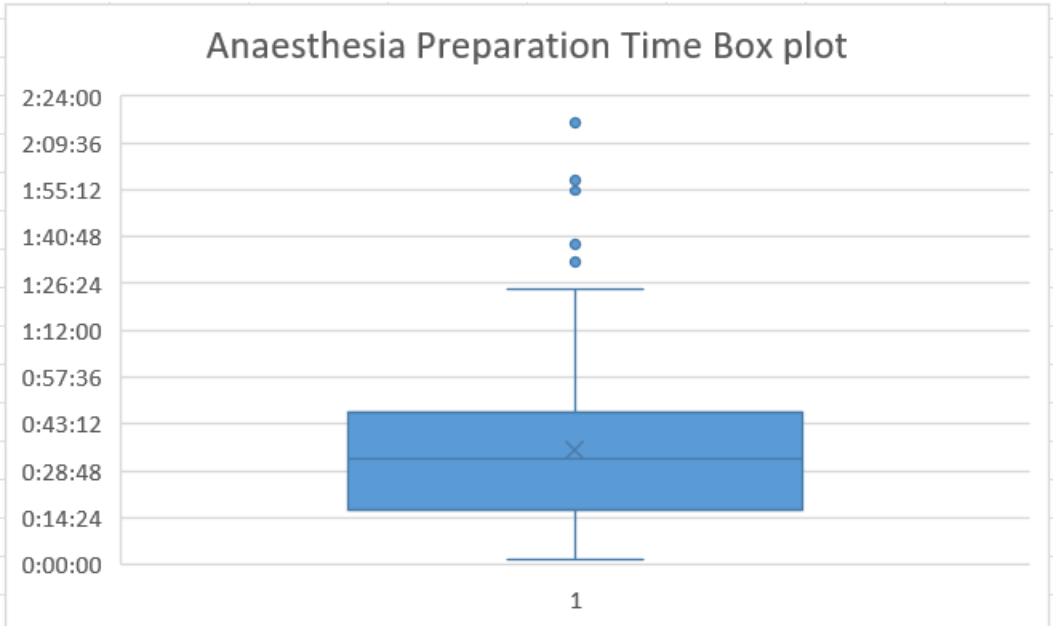

Figure 11: Anaesthesia Preparation Time Box plot.

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